Basic Electronics
(Module – 1 Semiconductor Diodes)
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Lecture - 4
Diode Rectifier Circuits

In the last classes we have seen the equivalent circuit of the diode. Today we will be discussing about the rectifier circuit which is an important application of semiconductor diode. Basically what is a rectifier? The rectifier circuit is a circuit which rectifies AC voltage into DC voltage. In most electronic applications we will be requiring DC voltage that it constant voltage supply. In order to get constant DC voltage from the supplied AC voltage because in our homes we get AC supply that is we get alternating current and so in order to get DC voltage level from AC we will have to use rectifier circuit where diode is used. The DC power supply has different stages. Starting from an AC supply it will be using a transformer to bring it to the desired level of AC voltage and then rectifier circuit to rectify the AC into unipolar voltage and then there will be filtering circuit to smoothen out the pulsating DC voltage which we get after rectification and then another regulator circuit will be there to finally keep it at a constant voltage level.

Starting with an AC voltage a steady DC voltage is obtained by rectifying first then filtering to DC level and finally regulating to obtain a desired fixed DC voltage.

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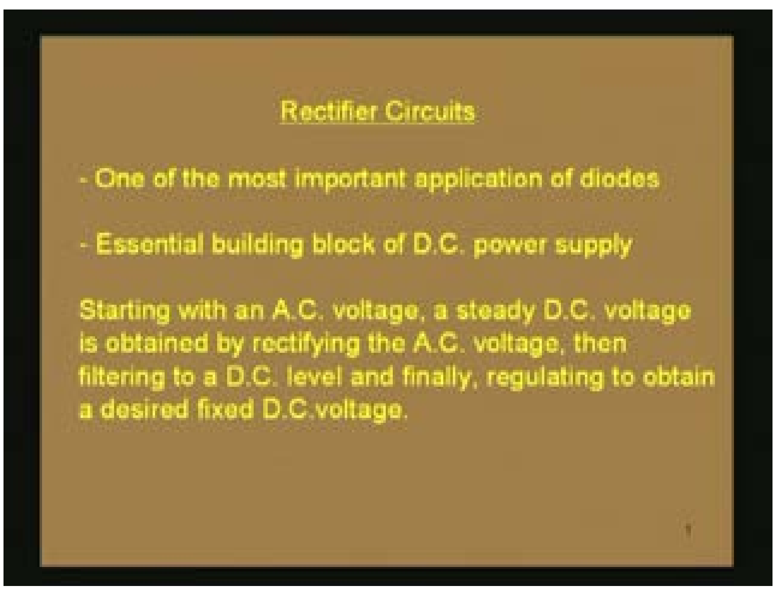

In block diagram form here first stage is transformer. This transformer will be getting the AC supply which will be given from the power supply at the rated frequency and in our household devices we have AC supply at 50 hertz.

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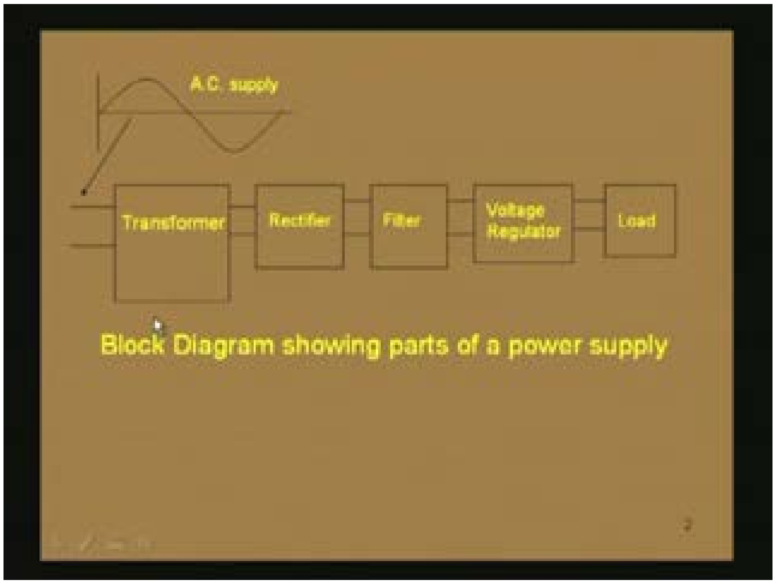

This transformer is there to bring the level of this AC input to the desired level by transforming it. Voltage transformation is done; we can step up or step down the voltage by adjusting the turns ratio in the transformer. This rectifier circuit will have the diode which will be rectifying the AC voltage to a unipolar DC voltage and then this filtering circuit will be there. This is an extra circuit which will be required for smoothening out the pulsating DC and then finally a voltage regulator circuit will be there which regulates the voltage level even if the load varies. Finally this load that is the output circuit where we want to apply this DC voltage, we will get the DC voltage and these DC voltage as desired it should be constant level voltage. For this rectifier circuit we use the semiconductor diode which we have discussed earlier.

First of all let us discuss a half-wave rectifier. This half-wave rectifier circuit will be converting the AC voltage to a unipolar DC voltage. But only one half of the input AC voltage will be available and in the other half we will get zero voltage. If we now consider a half-wave rectifier circuit, the circuit will be having a single diode as shown in this diagram. We have this input voltage which is AC and let us consider a sinusoidal voltage which is practically what you get in the power supply and there will be this resistance. The voltage available across this resistance is named as V_0. This output voltage V_0 will be used for a load. In this circuit we consider this diode and this input voltage. We will first of all convert this diode to its equivalent model. As we discussed earlier piecewise linear model will be a constant voltage drop V_{D0} and the forward resistance average resistance r_D will be in series with the ideal diode. This ideal diode is to show the direction of conduction of the current and this is the resistance across which we will be having the output voltage V_0.

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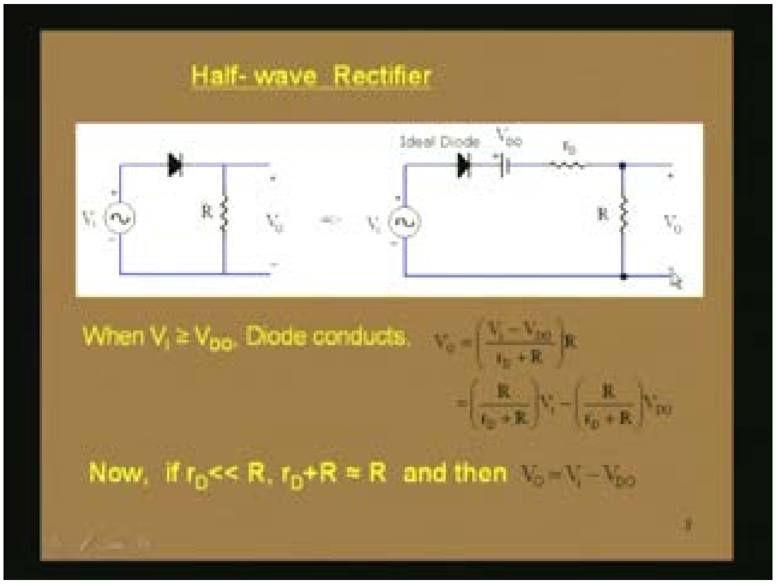

This is an AC supply. In a complete time period T, it will have one positive half cycle and a negative half cycle. Whenever you have this V_i greater than equal to this V_{D0} that is the threshold voltage then the diode will conduct. That means in the positive half cycle of the input AC voltage whenever we have input voltage greater than V_{D0} this diode will be conducting and then the current will be flowing in this circuit. If we now find out the output voltage V_0 this output voltage is equal to the current flowing through this resistance R multiplied by the resistance R. What will be this current flowing in the circuit? We can find it out. This is V_i minus this drop V_{D0} divided by the total resistance in this circuit rD plus R into this resistance R. This will be the voltage across this resistance. Separating these two terms which are combined by this negative that will be equal to R by r_D plus R into V_i minus R by r_D plus R into V_{D0}.

In such type of circuits what we get is that the resistance is comparatively very, very high in comparison with this average resistance of that diode where as resistance of the diode use in the order of a few ohms only and we can very well ignore this resistance in comparison with this resistance R; R is far bigger than r_D. If that is the case that is r_D, average resistance of the diode is very, very small as compared to R. The denominator in these two terms r_D plus R can be approximately written as equal to capital R because this whole term will be almost equal to capital R since r_D is very small and then this output voltage will have this expression as simply V_i-V_{D0} naught because if we replace this r_D plus capital R by capital R only then these two cancel out in both of the terms. We get V_0 equal to V_i-V_{D0} and this is nothing but the approximate equivalent circuit of this diode which we have discussed earlier that V_{D0} will be now here and this will be ignored, r_D will be ignored. As r_D is ignored it is nothing but the constant voltage drop model. We can now assume that we are replacing this practical diode by its constant voltage drop model.

Assuming the constant voltage drop model we are getting a simplified circuit which will be having only the constant voltage drop V_{D0} of the diode. In the positive half cycle of the signal at any point instantaneous voltage V_i whenever it is greater than in a positive half cycle, whenever it is greater than V_{D0} the diode will start conducting.

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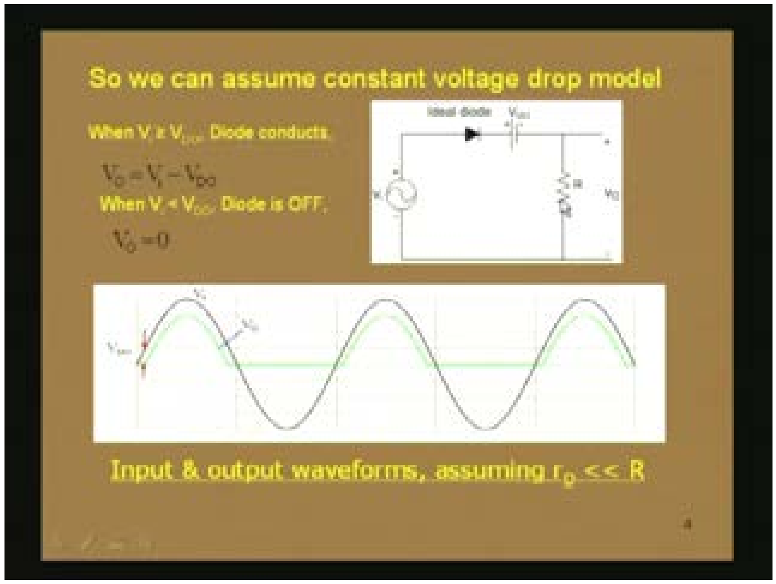

The voltage output V_0 will be V_i-V_{D0} and in the negative half cycle we get that it is less than zero. That means in the negative half cycle input voltage is negative and in the negative half cycle there will be no conduction in the diode. So we will be getting zero current and that is why the voltage V_0 across R is also zero. In the negative half cycle we will be getting a zero voltage and in the positive half cycle only we will be getting the output voltage V_0 which is V_i-V_{D0}. Consider the input voltage and the output voltage V_0, and if we superimpose each other then we get this type of voltage waveforms where you can see here that the output voltage is different from the input voltage by V_{D0}. V_{D0} drop will be there across this diode and at each point the output voltage is having a difference from the input voltage by the diode drop V_{D0}. These are the input and output waveforms assuming constant voltage drop model of the diode.

This output voltage as we see here is completely zero in the negative half cycle and a little portion inside also it is zero. That is because whenever it is less than 0.7 for silicon that is less than V_{D0} then output voltage will be zero. From this point you see that the voltage becomes zero. Here one complete time period of the input waveform if we consider that is capital T then for even less than T by 2, half of the time period we have conduction of the diode. But this small region where the output current is zero that is very small. We can say that for half of the input waveform the output voltage will be zero. If we want to find out what will be the average voltage V_0 then we have to integrate these output voltage waveforms within this time period. That we will be doing to get the average output voltage V_0. For that purpose we will be again assuming the diode to be ideal because if I exactly want to find out what is the output DC voltage then I cannot integrate between zero and capital T by 2. It is not exactly that because for a small portion we see that the current is not there. That means zero current. Output voltage is zero but then for all practical purposes like in a rectifier circuit we can consider the diode to be ideal because we are mostly interested in knowing the rectification and do the analysis from that point of view. Even though we are not exact at this point for integrating between zero and T by 2 which is not exactly correct but that we can do so.

We will consider ideal diode. That means we are further simplifying the model by ignoring V_{D0} as well as ignoring average resistance of the diode r_D.

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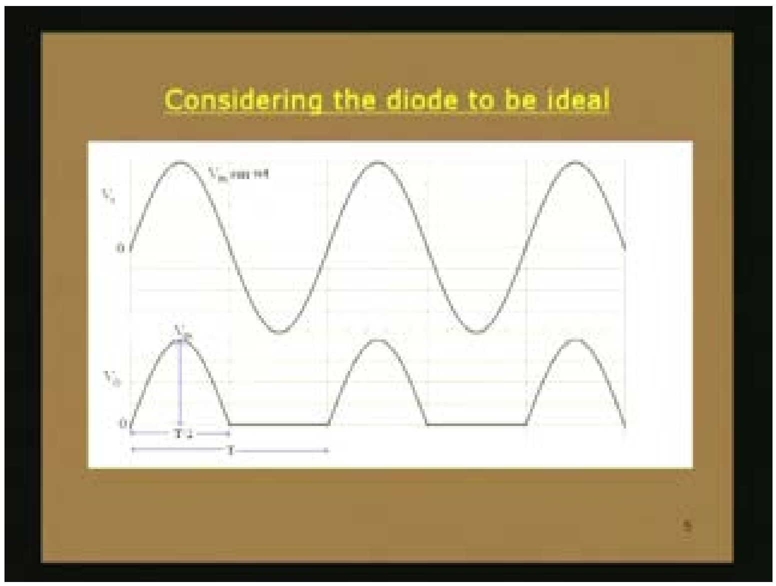

Let us find out first from that approximate model what will be the output voltage V_0 assuming the diode to be ideal. That we will do now and for that let us first consider again the input and output waveforms. Considering the diode to be ideal that will be as shown here. It is the input waveform which is an AC waveform. V_m sin omega T will be the expression for that AC waveform. This is the well known expression for sinusoidal waveform of voltage which is V_m sin omega T. Omega is the angular frequency which is equal to 2 pi F. F is in cycle per second of Hertz and our power supply which we get domestically that is having 50 Hertz of the supply frequency means F will be 50 cycle per second or Hertz. This waveform is input waveform V_m sin omega T and output waveform, considering the diode to be ideal, is like this. We will be carrying out the analysis with this output waveform. Exactly one half cycle the diode will be conducting and the other half the diode will be off. We will be getting zero voltage. That means we are getting a pulsating DC. This is called pulsating DC with one half cycle off.

Let us do that analysis for finding out the output voltage or average DC voltage. By V_{DC} I mean that output voltage which is the average DC voltage. For finding that out we have to integrate between this whole time interval zero to capital T. In order to find out the average DC voltage 1 by whole time period T integration zero to T V_m sin omega Tdt because this input and output waveform have exactly the similar shape that is the sin wave. We can easily integrate it by this ideal assumption.

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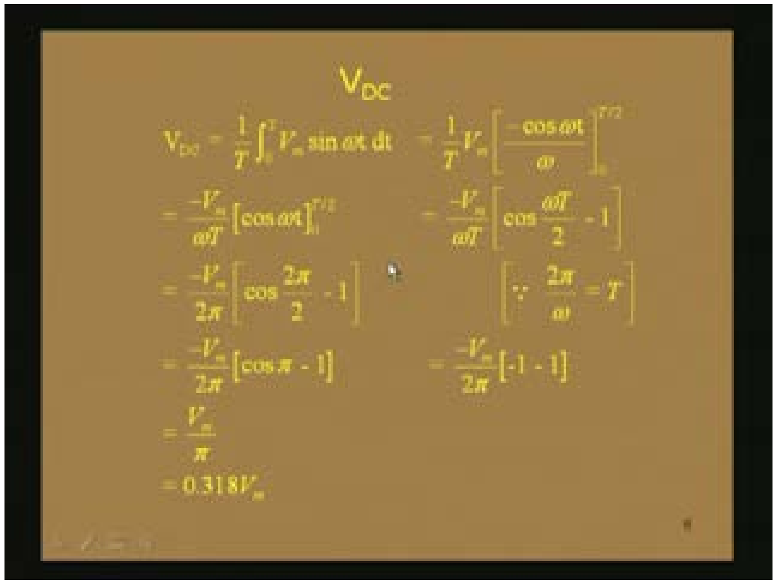

This is a simple integration. If you carry on that integration it will be equal to 1 by capital T V_m. Within that integration if we do the sin omega T integration it will be -cos omega T by omega between this lower and upper limit zero and capital T by 2. Here you have to note that because one half cycle is having zero voltage we have to integrate it between zero and capital T by 2 because the other half is totally zero. We are further simplifying it by integrating it between zero to capital T by 2. This expression of -V_m by omega into capital T can be taken out. Then cos omega T which is in between the limits zero and capital T by 2. Putting the limits it will be cos omega capital T by 2 minus 1. Here we can substitute omega capital T equal to 2 pi because 2 pi F equal to omega. From that 2 pi F equal to omega, f is equal to 1 by T. From that we find out that capital T into omega is equal to 2 pi. Substituting that here, it will be further boiling down to -V_m by 2 pi within bracket cos omega T you substitute 2 pi by 2-1. We get cos of pi - 1 in the bracket that is equal to cos pi minus 1. Minus of minus 1 is minus 2. Finally we get that is equal to V_m by pi. In a half-wave rectifier we have the output average DC voltage equal to V_m by pi. If you find out the value 1 by pi it is 0.318; 0.318 V_m will be the average DC value of the half-wave rectifier.

Here in the half wave rectifier we have one disadvantage or one draw back of half-wave rectifier is that in one half of the input waveform the output voltage is totally zero. That means what? We are not getting this output wave or output voltage for one half cycle of the input waveform.

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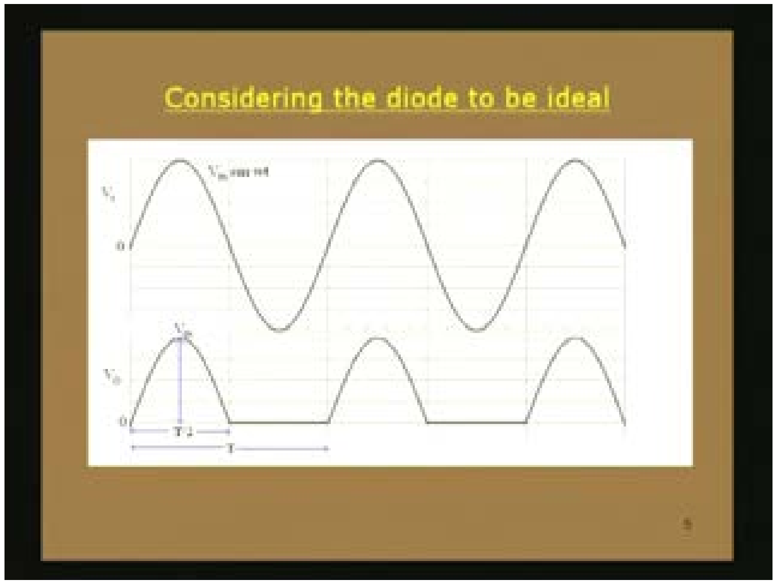

This is not exactly what we want. We want the output voltage to be a constant DC level. We will be going to another advanced rectifier which is known as full wave rectifier. It will be rectifying the whole input waveform. That is the full wave will be rectified. That means in both the half cycles we should get rectification. That is full wave rectifier which has advantage over half-wave rectifier that we are going to discuss now. But before that we would like to now what will happen if we consider the practical consideration of diode drop of 0.7 volt. If we consider silicon, silicon has diode drop of 0.7 volt. Output voltage will be V_i minus that drop. The output voltage V_0 if we find out, in this analysis whatever we have done using ideal diode here instead of V_m we will have to put V_m-0.7 for silicon or if germanium it is 0.3. That drop will come within the bracket V_m-V_{D0}. Finally our expression for V_{DC} or average voltage drop at the output, the DC voltage will be equal to 0.318 V_m minus V_T.

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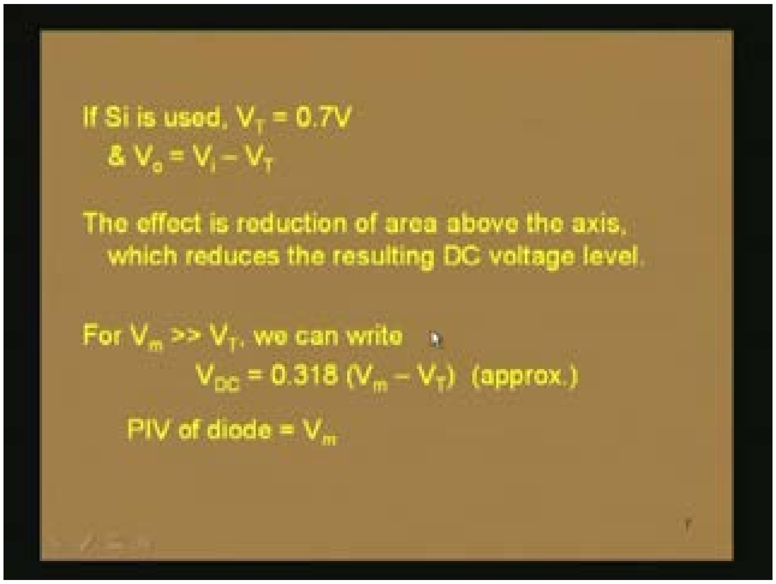

V_T means the threshold voltage or the diode drop or V_{D0} as we have named it. Approximately we can write that output voltage, DC voltage 0.318 or 1 by pi into V_m minus V_T. There is another important term to know. That is the peak inverse voltage of the diode. Peak inverse voltage as we have mentioned or discussed earlier is the maximum or peak voltage that the diode can withstand when it is not conducting. That has an important analysis because in order to not enter into a break down we must always remember what the peak inverse voltage of a diode is because in the reverse bias condition when the reverse voltage is greater than a breakdown voltage it will enter into the breakdown and it will be suddenly rising. But in all practicalities we do not have or we should not overcome that peak inverse voltage. In this case if we consider this circuit again, when the diode is not conducting in the negative half cycle of the input waveform then what will be the voltage across it? That is the peak inverse voltage and you can very well see here it is nothing but the peak voltage of the input wave that is V_m. V_m is the PIV of this half-wave rectifier circuit.

Now we will be considering a full wave rectifier which will be a better rectifier than a half-wave rectifier. Full wave rectifiers have a different configuration of circuits and let us consider first a bridge network that is bridge full wave rectifier having a bridge of or a network of diodes. There will be 4 diodes as arranged in this configuration as we can see here. There will be D_1, D_2, D_3 and D_4; 4 diodes. The input V_i is an AC waveform. Let us consider sinusoidal. If we consider a positive half cycle of the input waveform then the conduction of which diodes will be taking place? The diodes which will be forward biased those diodes will conduct. We will be applying this input voltage having V_m sin omega T.

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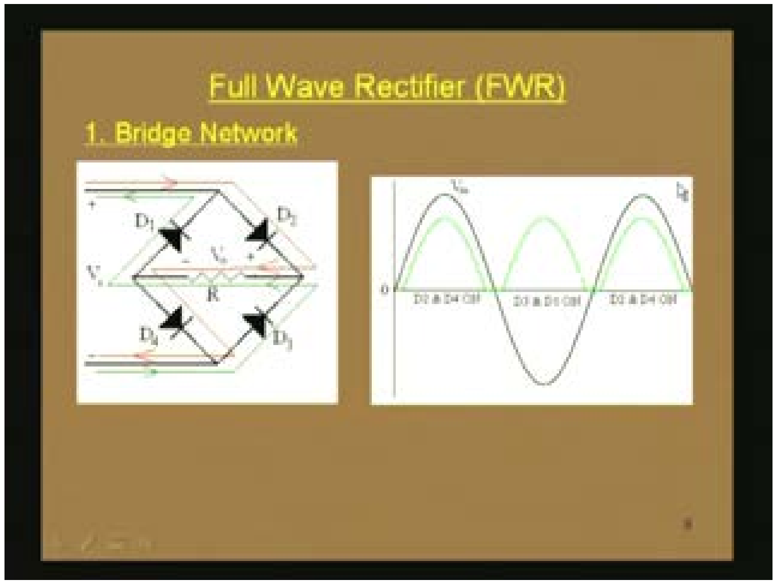

Output voltage that will be obtained across this resistance R which is V_0 and it is denoted by this polarity. This side is positive, this side is negative. When it is positive in the positive half cycle of the input voltage waveform the red colored straight line will be showing the conduction of the diodes. The diodes D_2 and D_4 as you can see here will be forward biased. This is positive connected to P; this diode is also forward biased. That is why the current part will be shown by this red line. The current will be flowing through D_2 and D_4. Across this resistance R, this current will produce a voltage drop V_0. As it is a resisted drop it will be following the input voltage waveform in shape. There will be a time lag in order to start the current because of the threshold voltage of the diode. This will be the waveform and in the negative half cycle, when this lower point is positive upper point is negative of the input voltage waveform then the green line will be showing the conduction of current because the diodes D_3 and D_1 will be now forward biased in the negative half cycle of the input voltage. The current will be flowing in this direction. That is through D_3, through all and then through D_1. The output voltage for the negative half cycle is this one. For both the positive and negative half cycles of the input voltage, we get output voltage across this resistance. So it is better than the half-wave rectifier. For both the half cycles we are getting an output waveform.

In this case if we want to find out what will be the output voltage or DC voltage again we have to do the integration. But here while doing the integration as we have output waveform for both the half cycles 1 by T by 2 integration will be from zero to T by 2. That means we can take one half of the input waveform and we can integrate it. It will be similar for the other half also. Finally we do this integration, put down the limits and we find out that omega capital T is equal to 2 pi. Again substituting we get finally the output voltage average value is equal to 2 by pi into V_m. This value is exactly twice than the output voltage which we got in half-wave rectifier.

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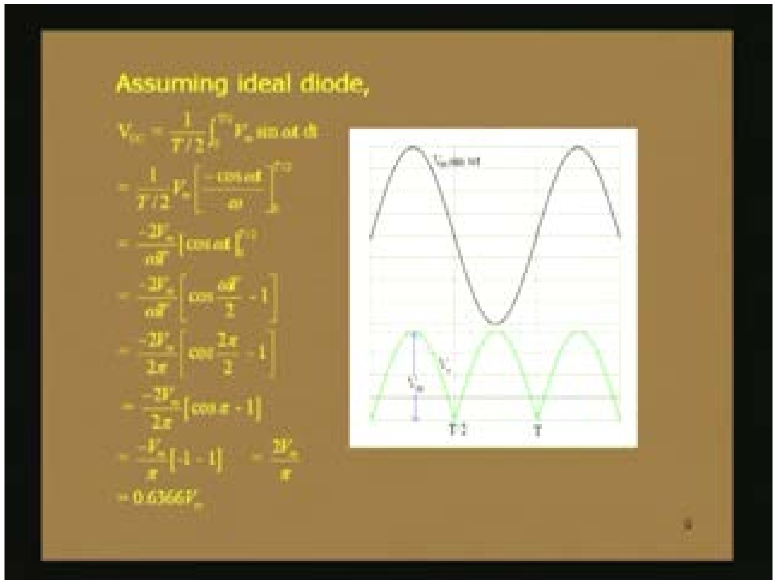

The average output voltage in a full wave rectifier is twice the average output voltage in a half-wave rectifier. That is 0.6366 times V_m, V_m being the peak voltage of the input. Here also for doing this analysis we have assumed ideal diode approximation. If we consider a practical diode having cut in voltage of V_D, then we have the average value 0.6366 V_m minus $2V_D$.

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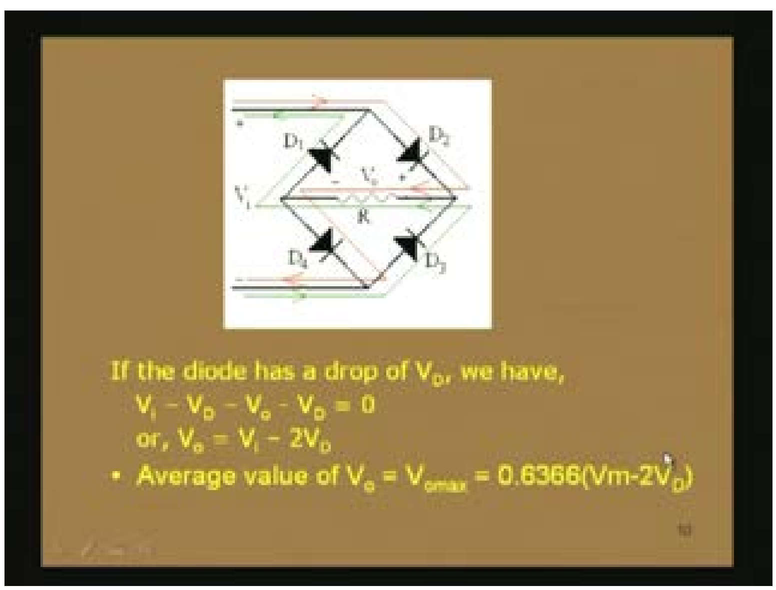

It is $2V_D$ because in the positive half cycle the current will be flowing through D_2, then R and then D_4. There is drop here. There is drop here also. So two voltage drops will be coming into the picture. The diode drop V_D will have to be multiplied by 2. That means

V_D plus V_D. This $2V_D$ will have to be subtracted from the peak value of the input waveform to get output voltage wave and that will have to multiplied by this 0.6366. For a practical diode we have this as the average value.

We find out the PIV of this full wave rectifier. Peak inverse voltage of each diode you can find out when the diode is non-conducting. When one diode is non-conducting what will be the maximum voltage that is across it? That is the peak inverse voltage. If I consider say positive half cycle then this D_2 D_4 are conducting and D_1 D_3 are non-conducting. What will be the voltage that will be applied across this D_1? Because D_1 is non-conducting that can be found out if you consider the two ends of this D_1 diode. What will be this voltage? Applying Kirchoff's voltage law through this mesh then this voltage drop is nothing but V_i minus this drop because this is one end and this is the other end. So this drop is equal to V_i minus this drop. That is V_i-V_{D0}. For other diodes also when they are non-conducting the same PIV we will be getting which is equal to V_m-V_{D0}.

Here also we are not nearer to a constant DC voltage even now because what we are getting is a pulsating DC voltage like this. This is what we get. But then we want get a constant voltage. This is not obtained till now. We have to now modify the circuit or we have to add something extra to get exactly a DC voltage.

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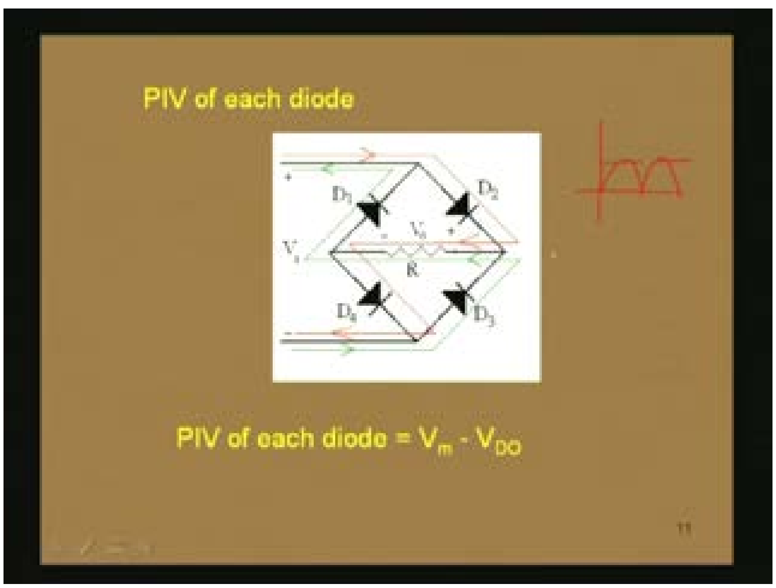

For that we will be going for another circuit that includes the filter circuit. But before that I will be discussing another type of full wave rectifier that is using center tapped transformer. Transformer is a device which can transform or which can convert the voltage level; the input voltage level can be stepped down to a lower voltage or it can be stepped up depending upon the turns ratio of the primary and secondary winding of transformers. A center tapped transformer has the secondary side tapping at the center. That means this portion of this or the upper portion of this secondary winding will have equal voltage to the lower portion. If this is V_s this will be also V_s and this is center which will be grounded.

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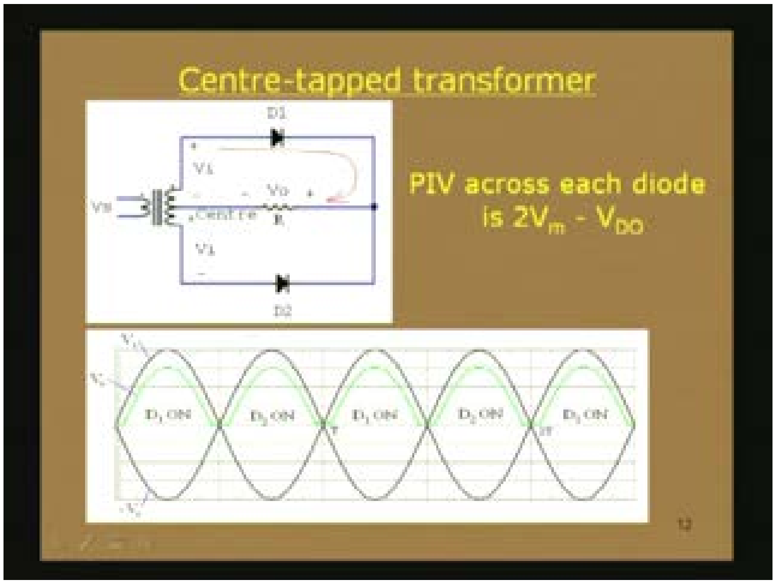

I mean exactly equal voltages we get at the secondary. That is in the centre tapped transformer, tapping is at the center of the secondary. In this full wave rectifier this transformer which is center tapped is used to bring the input voltage to its desired value. Here there are two diodes D_1 and D_2. Circuit is like this. We are getting the output voltage across this resistance which is V_0. The conduction will be taking place when this is positive, upper point is positive with respective to the center. Upper one diode will conduct and when the center is positive with respect to this that means this lower one if we consider if this is higher at a higher potential than this, then this way the diode will conduct. But the resistance through which the current will conduct in both the cases it will be in the same direction so that the polarity of the voltage which you get across this resistance will be in the same way. Input voltage is V_i and output voltage which is obtained across this resistance will be pulsating DC as we are getting here.

For each half cycle we will be getting the voltage across this resistance and what will be this peak inverse voltage across each diode in this case? If we consider this secondary side voltage V_S then V_S is having a peak value say V_m. When this diode is non-conducting that is in the case when this upper diode D_1 is conducting then the voltage across these two ends of this diode will be how much; the total voltage across secondary minus this drop. If one half is V_S and peak value above one half is V_m then total voltage, peak value will be 2 times V_m. 2 times V_m minus V_{D0} that will be the peak inverse voltage in this centre tapped transformer which is a full wave rectifier. But here we are employing 2 diodes instead of 4 diodes in the bridge rectifier.

In order to smoothen out the output voltage we will be employing a capacitor. That is a capacitor filter will be applied to smoothen out the DC voltage which we are getting without capacitor.

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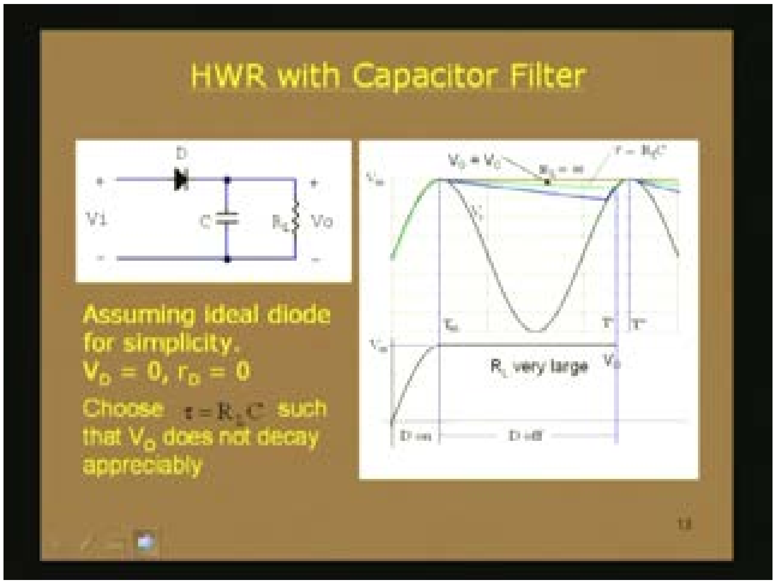

That means we will have to get a constant DC level without any ripple. But till now whatever we have got in half-wave rectifier and full wave rectifier is unipolar voltage, no doubt. But it is not purely DC. To get an ideal DC voltage we will be employing a filter circuit using a capacitor. What will be achieved using a capacitor that we will have to see in the circuit. Let us first consider half-wave rectifier. Half-wave rectifier with capacitor filter will be this circuit where a capacitor is included across this resistance R_L, load resistance. Here we will consider ideal diode for simplicity because we are concerned about the analysis. Let us consider an ideal diode where the cut in voltage is zero as well as the average resistance is also zero. In the positive half cycle when this upper point is positive with respect to the lower point for the input voltage V_i, the diode will conduct as it is forward biased and it will be charging these capacitors. The capacitance will be charged and this diode is having zero resistance. The time required for charging the capacitance is almost zero. Because instantly the capacitor will be charged there will be no time lag. The capacitor will be charging to the peak value of the input voltage instantly and V_C will be the output voltage. This voltage across R_L is nothing but the voltage across this capacitance. If the input voltage is V_i output voltage if we draw for a particular resistance R_L we are considering, then it will be first of all charging. The capacitor will be charging to the peak value of the input voltage.

When you notice the input voltage it is sinusoidal. It is varying with time. From the peak value it is falling off. If we consider the capacitance, the capacitance has already charged to the peak value V_m but after this peak point, input voltage V_i is going down but then if we consider the diode this cathode and anode, at the cathode the capacitor voltage is being applied and the anode is the input voltage. The capacitor voltage is V_m peak value but the P side anode is having V_i which is less than the capacitor voltage after this peak point. If we consider this point for example here the capacitor voltage is V_0 which is equal to V_m. But at this point the input voltage is falling down. This diode will be reverse biased and it will not be conducting. So this circuit is off. Now what will happen? The capacitor voltage will be discharging through this resistance R_L. This discharging which is taking place is shown by this green line. This capacitor is discharging through this resistance R_L. This discharging rate will be dependent upon the time constant which is R_L into C. If we have a bigger time constant it will take more and more time to discharge. If we have low resistance, R_L is a small value then the time constant will be small. It will be falling of very soon. That means rate of discharging will be very fast.

Here the capacitor is discharging and discharging but you see that input voltage is now at this point increasing here and after this point input voltage becomes higher than the capacitor voltage. Input voltage is higher means the diode will be again forward biased. From this point it will be again forward biasing the diode since V_i is greater than V_C and the conduction of the diode will be taking place and therefore the capacitor will be charged. Charging will be taking place. Again after this point input voltage is lower than the capacitor voltage. So discharging will be taking place. Charging and discharging will be going on, finally giving a voltage which is having a ripple. It is a not constant voltage but it will be having a ripple. So we will get this type of voltage.

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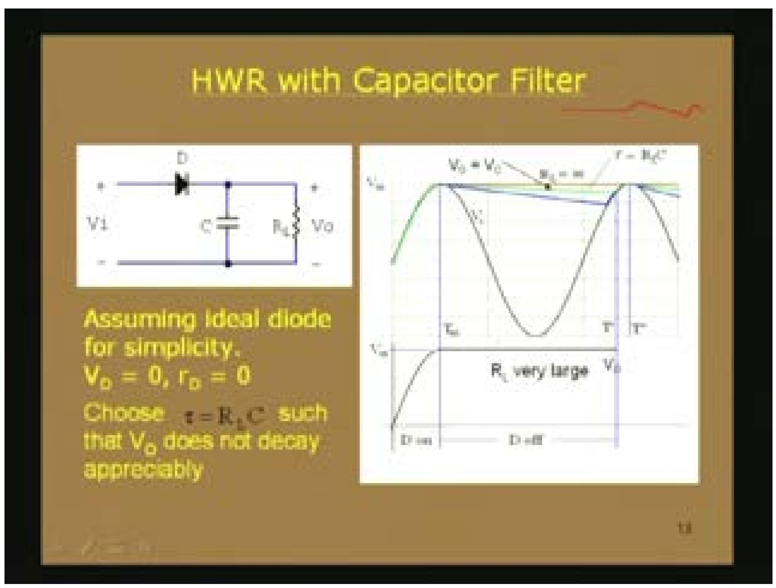

If we go on increasing the resistance R_L ideally so that it is almost equal to infinity then there will be no discharging at all and we will be getting a constant voltage which is not practical. It is not true. We cannot get an infinitely high voltage but we will be getting more and more towards DC if you go on increasing the R_L resistance, load resistance. Capacitor is not changing; capacitor we are fixing.

How much value we should choose for the time constant? That is time constant should be such that it should not decay appreciably when you consider the time period of the input voltage. If the input voltage has time period capital T then this time tau which is the time constant for the discharging circuit should be sufficiently large compared with this time period of the input voltage. Then only we do not see much falling of the output voltage and output will be almost constant like a DC. So you have to choose this resistance R_L value sufficiently larger to have a larger time constant. If we consider the diode conduction how much time the diode will be conducting? The diode is conducting for a very small time, only for this portion. The diode current is such that it will flow for a very small time and then it will become zero. It is called a surge current. If we consider this half-wave rectifier and see the conduction of the diode, the diode current will be like a surge. Suddenly it is increasing and then within a very short time it will be falling off also to zero.

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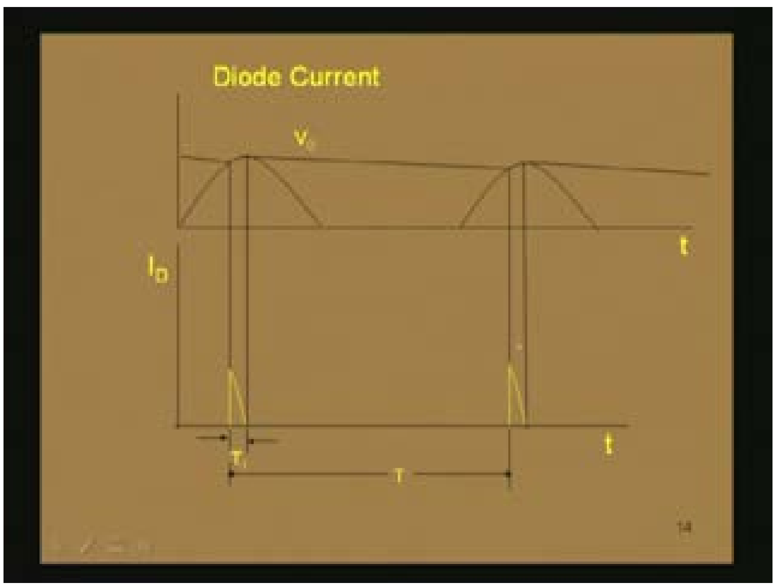

This diode conducts for a very, very small time. That is why it is called the surge current. For example if we consider the whole time period, only for a small portion T_1 it is conducting. If we consider our power supply which has 50 Hertz frequency supply, the time period will be 1by F, 1 by 50 Hertz which gives you 20 millisecond.

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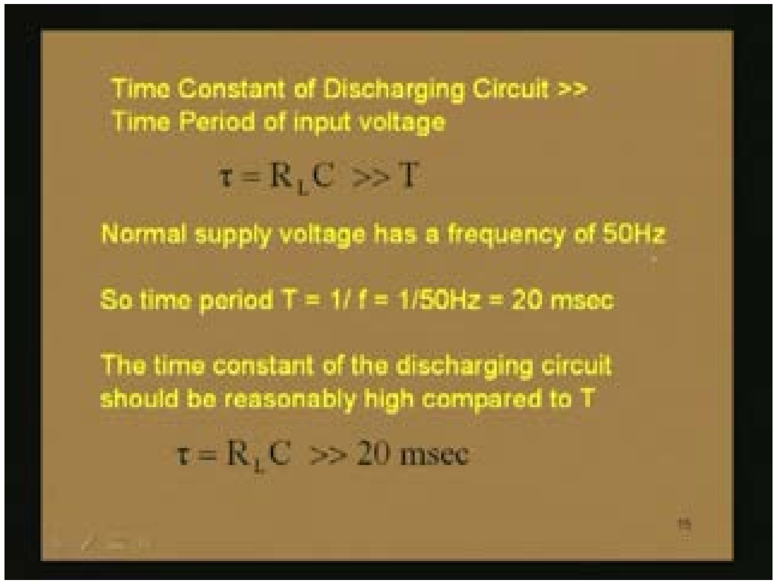

The time constant of the discharging circuit in the rectifier should be reasonably high compared to T means we should chose value of tau very, very great as compared to 20 millisecond. It should be sufficiently high so that we get overall almost constant DC voltage. It should not fall of drastically. Similarly if we consider full wave rectifier with capacitor filter there will be capacitance which will be connected in parallel with the load resistance.

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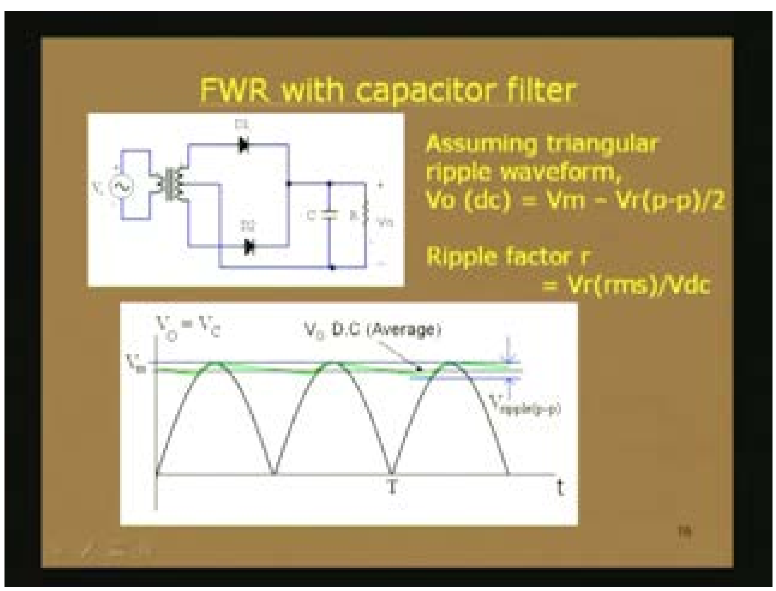

Here better approximation to DC will be obtained because if you consider the input voltage which is rectifier in full wave rectifier in the both half cycles again we are getting a discharging and charging phenomenon here. Overall if we consider the output voltage what we get across this resistance which is V_0 it will be like this waveform. It is like a ripple. This ripple voltage is because of this charging and discharging phenomenon. This voltage is called ripple voltage which is between one lower point, this is the lowest point, and this peak point. In between these two points this voltage is known as V ripple peak to peak. This V ripple peak to peak is a measure of how effective your rectifier is. The better and better rectifier will be having lower and lower ripple. The measure for this ripple factor is given by factor r, small r which is the ripple voltage in rms divided by average DC value. That is called the ripple factor. You should get low ripple factor if you are interested in making better rectifier.

What will be the output DC voltage finally we will be getting after this capacitor filter being included. To know that an approximation is done, by considering the ripple voltage to be a triangular voltage. If we consider a ripple voltage and assume it to be triangular it will be like this type of voltage. This triangular voltage if we consider and find out the DC value of the output V_0 DC will be peak V_m minus this drop that is this Vr peak to peak divided by 2. V ripple peak to peak divided by 2 is done to get the average DC value which is shown here by this black line. The average DC value is this peak value minus V ripple divided by 2 assuming triangular ripple so that the output DC level will be flowing towards the middle of this triangular voltage. It will be triangular voltage and the average DC level is through middle.

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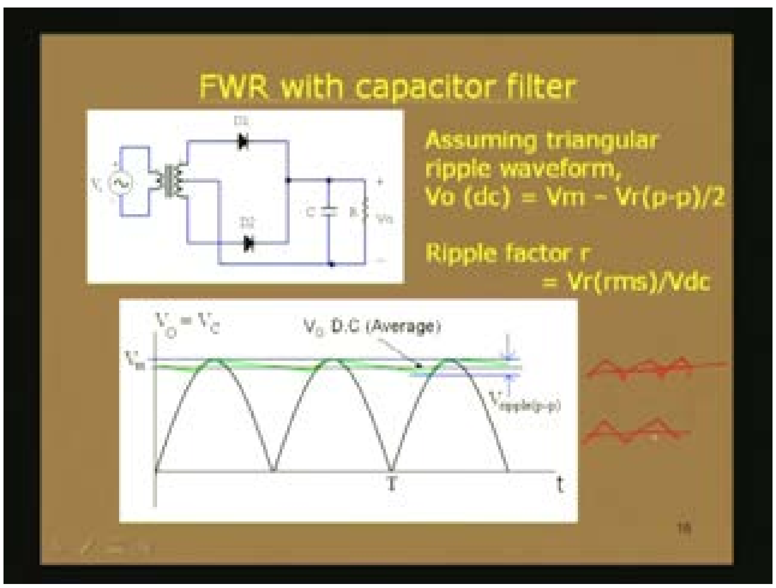

That is why V_m minus Vr peak to peak by 2 gives you that DC voltage for this full wave rectifier with capacitor filter. If we consider the whole conduction and non-conduction of the diode, the diode is conducting only for a very small portion. That is for a very small time T_1 and it is non- conducting and it is only because of the discharging of this capacitor that we are getting the output voltage. It is for capital T_2.

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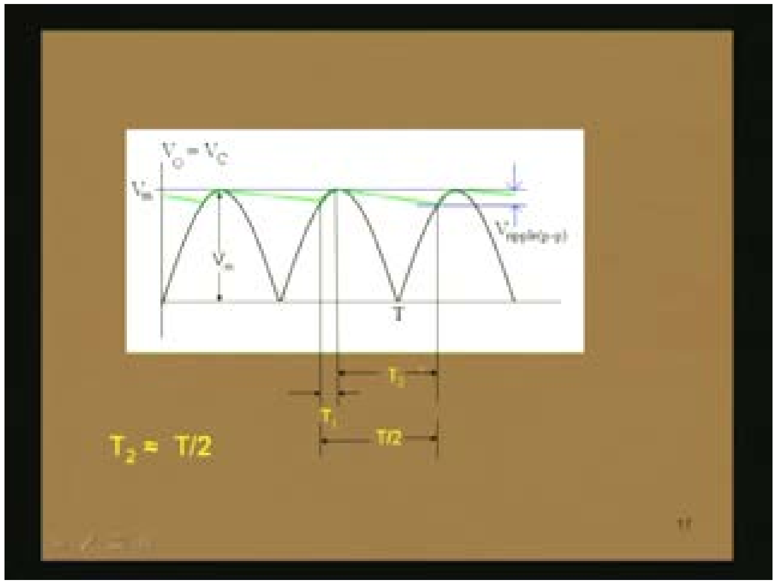

T_2 is the non-conduction time, T_1 is conduction time and the whole time for this half-wave rectifier is T by 2. That means half of the input voltage time period. Without much violation we can assume that T by 2 is almost equal to T_2. Because this T_1 is very small we can approximately say that T by 2 the whole time from this point to this point half of the time period of the input voltage that is equal to the non-conduction time T_2. If we assume that we can now find out an important relation because during discharging what will be this output voltage waveform? We know from capacitor discharging formula that the output voltage for a discharging capacitor will be given by the peak value into e to the power minus T by capital R capital C.

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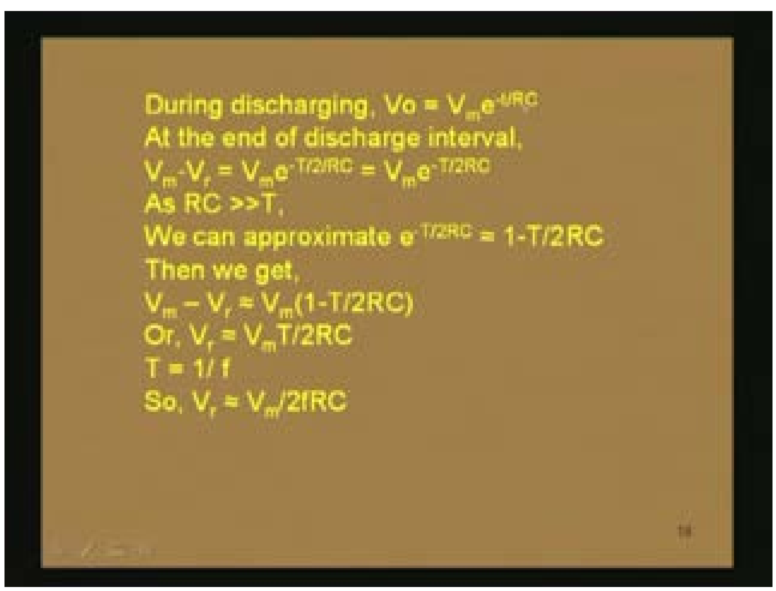

This is the time constant; RC is the time constant. At the end of discharging when it is completely discharged, when it completely ends its discharging period it comes to this value. From this value it falls down to this value. This voltage is nothing but the ripple voltage peak to peak. We can write here that at the end of discharge interval V_m minus V_r is the output voltage. If you see here the voltage which finally we will be getting after discharging is this voltage. What is this voltage? V_m minus V ripple; V_m minus V ripple is equal to the voltage after this discharging period. That is equal to V_m into e to the power minus T by 2 divided by RC.

Here I am using that approximation again because RC is very, very greater than T. Then we can write down this expression e to the power minus T by 2 RC equal to 1 minus T by 2RC. This power series, exponential series e to the power minus x equal to 1 minus x plus x square by factorial 2 etc, here if x is very small like this in this case this T is very, very less as compared to RC that we have assumed, only then it will be practically a good rectifier. In that case only keeping up to the first order that means up to 1 minus x we can write and others because square of the smaller term will be more and more smaller, we can ignore these terms. It will be approximately possible to write this e to the power minus T by 2 RC equal to 1 minus T by 2 RC. Putting down this value here we get V_m minus V_r equal to V_m into 1 minus T by 2RC. We have approximated for this exponential term.

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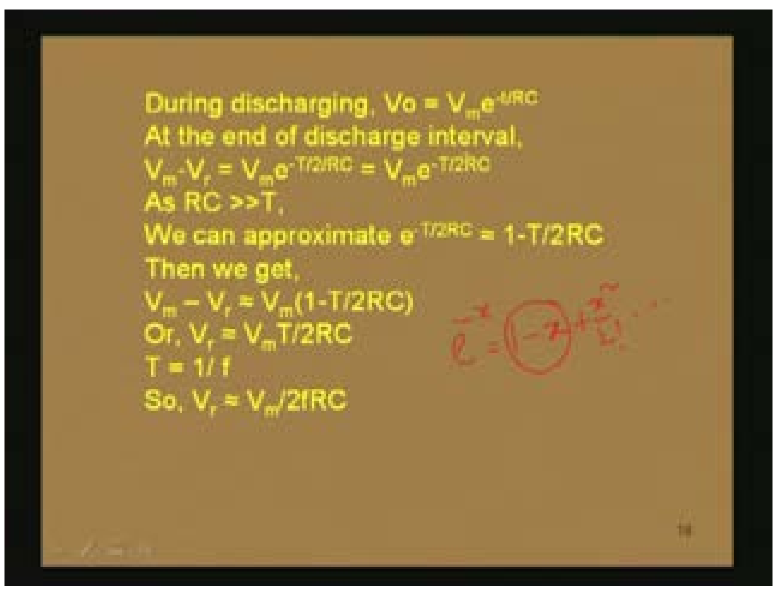

Then we get V_r equal to V_m T by 2 RC; V_m, V_m cancels. This term will be remaining and we know the time T is equal to 1 by frequency. We can write V_r that is the ripple voltage is equal to V_m by 2 f RC replacing T by 1 by f.

What is this expression? This expression actually gives the relation between the ripple voltage and the peak input voltage, its frequency and the time constant. From this analysis we can again find out the average DC value also because if we look into the capacitor it is discharging at a constant rate of current of I_{DC}. Then when discharging it will be loosing the charge equal to current into time. That is I_{DC} into T. That will be the charge loss by the capacitor while discharging. The change in the capacitor voltage because of this discharging is I_{DC} into T_2 by C. That is charge by capacitance. That will be the change in the voltage.

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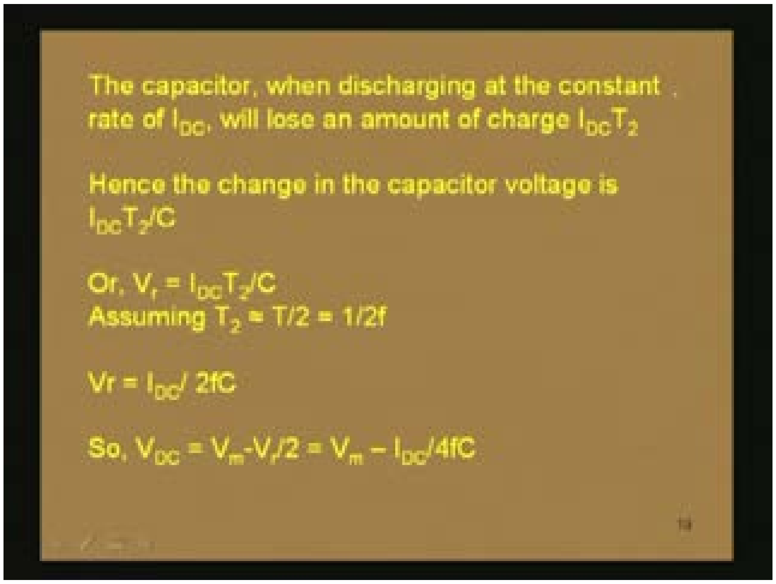

A change in the voltage is what? Change in the voltage is nothing but the ripple voltage V_r. So V_r is equal to I_{DC} into T_2 by capital C. Again assuming the same thing that is T_2 almost equal to capital T by 2 or 1 by 2f then we can write down the ripple voltage equal to be I_{DC} divided by 2fC replacing T_2 by capital T by 2 which is equal to 1 by 2f. This becomes the default voltage expression and so we can write about the V_{DC}, DC voltage or output average voltage equal to V_m minus V_r by 2 that we have just now derived and now substituting for V_r by this expression we get output DC voltage equal to V_m minus I_{DC} by 4fC. This 2 we will be making it 4fC. This relation gives you the expression for output DC voltage to the I_{DC} value, peak value of the input voltage, frequency of the input voltage and capacitance.

From this analysis we have seen different type of rectifiers. Half-wave rectifier, then full wave rectifier then half-wave rectifier with capacitor filter as well as full wave rectifier with capacitor filter. When you do not use capacitor we were getting the output voltage as unipolar DC but it had ripples like it was not perfectly DC. It was unipolar. It can be said to be pulsating DC. It is like a pulsating DC. But then this is not a good rectifier. We had to use a capacitor filter to smoothen out the pulsating DC to make it more and more nearer to a perfect DC voltage. For that after introducing the capacitance in both half-wave rectifier and full wave rectifier because of the charging and discharging phenomenon taking place in the capacitor we were getting a ripple which will be making it more like a DC voltage. We had a DC like voltage not exactly DC. Till now also it is not perfectly right to say that is DC but it is more DC like voltage with ripple on it. This ripple will be actually determining how much rectification we are able to get. If we get more and more, higher and higher ripple voltage that means it will not be a good rectifier. If this ripple voltage can be made lesser and lesser so that we get flatter and flatter output voltage which will be more towards a DC level ideally then we will be getting a better and better rectifier. In order to do that we should choose the time constant of the discharging circuit R into C judiciously. For that we have to see what is the input voltage frequency and that will give you a measure of how you will be choosing the capacitance value. That is input voltage frequency will give the time period. Compared to that time period we must have the RC value or time constant considerably larger so that the overall affect is not seen in the output voltage. Overall effect of this discharging is not clear or it is not very much drastic. That we can achieve by choosing a higher time constant.

We can do one example. This example is a centre tapped full-wave rectifier. This circuit is a center tapped transformer having two diodes. This is the full-wave rectifier.

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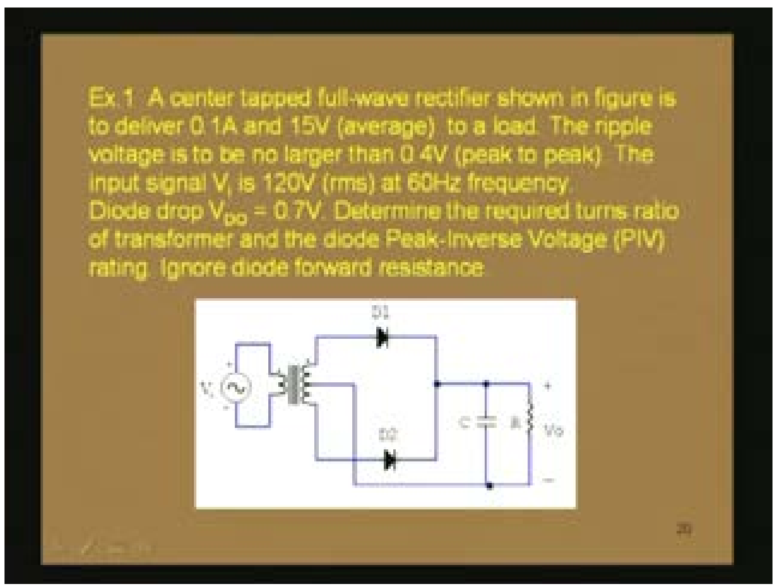

In this circuit you have been told that it should deliver 0.1 ampere and 15 volt average to a load. This V_0 should be 15 volt average and the DC current which will be delivering to the output load is 1.1 ampere. The ripple voltage is to be no larger than 0.4 volt peak to peak. That restriction is given. Input signal is 120 volt; rms value, root mean square value is given of the input voltage at 60 Hertz frequency and diode drop is 0.7 volt and you have to determine the required turns ratio of transformer and the diode peak inverse voltage rating and ignore diode forward resistance.

In this circuit a center tapped full wave rectifier is shown which is to deliver 0.1 ampere and 15 volt average to a load. The ripple voltage is to be no larger than 0.4 volt peak to peak. It is given to you that it should not be greater than 0.4 volt peak to peak. The input signal V_i is 120 volt rms at 60 Hertz frequency. Diode drop is given as 0.7 volt. You have to determine the turns ratio of the transformer and the diode PIV. You have to ignore diode forward resistance. To solve this problem let us draw the circuit again. It will be having a transformer in the input circuit. It is a centre tapped transformer having voltages V_S and V_S in the secondary. This point is positive with respective this point ground, this point is positive respective to this point and you have two diodes D_1 and D_2 and this is the capacitance across R. This voltage is V_0. This average DC voltage is given as 15 volt. What is this average voltage; we know. V_s max this voltage minus V_{D0} minus V ripple we have got this expression for full wave rectifier along with capacitor filter; this is peak to peak. Assuming triangular ripple we have analyzed it. So V_S max can be found out. V_S max is V_0 average plus V_{D0} plus V ripple peak to peak by 2. Put down these values whatever is given. This is 15 volt, this is given as 0.7 volt and V ripple is not to be larger than 0.4 volts. So we take this maximum value. This gives 15.9 volt as the V_S max. You have to find out the transformer ratio. This transformer ration is N_1 is to N_2; number of turns in primary to number of turns in secondary, the whole secondary. This N_1 is to N_2 is called turns ratio. You have to find turns ratio.

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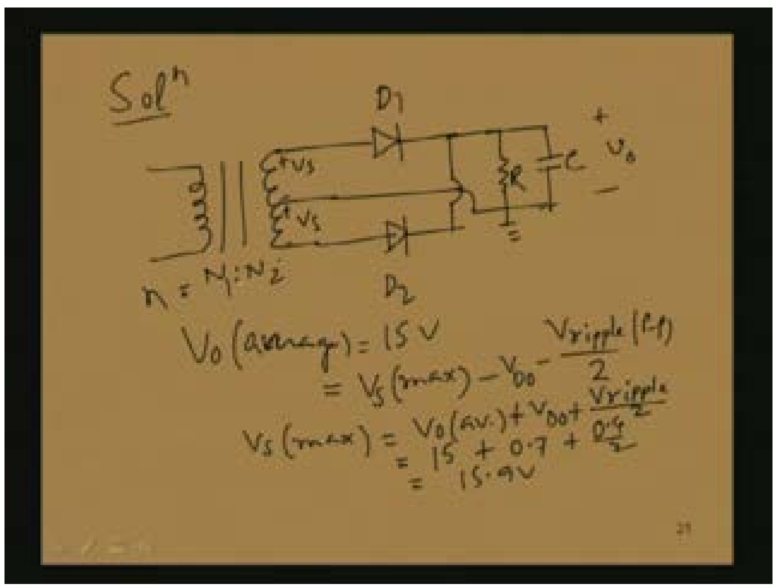

For that we must know what is the rms value? RMS value and peak value are generally two ratings that are being defined or denoted. If you want to find out the transformer ratio N_1 is to N_2. N_1 is to N_2 is nothing but Vinput by V in the secondary. The whole secondary is having $2V_S$ but both must be either rms or peaks. Let us take the rms value. These two must be in conformity. If you take rms both of them must be rms. This V_S max we know. What will be V_S rms? V_S max by peak value by root 2 is rms value. V_S max we have found out 15.9 by root 2 that is 11.24 volt. So turns ratio can be found out. N_1 is to N_2 is V_i rms by 2 Vs rms. The whole secondary if we look into, the whole is $2V_S$. This will be primary voltage by secondary voltage. Primary voltage is given as input voltage which is 120 volt rms. 2 into 11.24 V_S rms that gives you 5.34 as the turns ratio.

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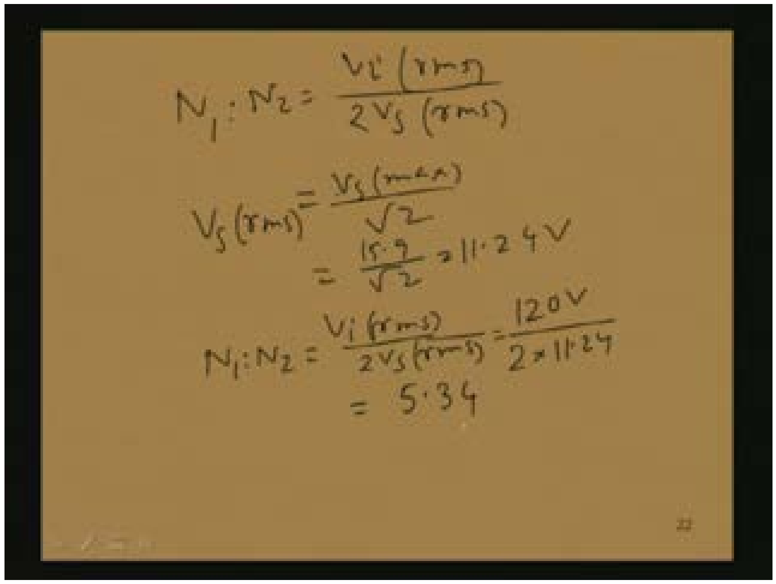

PIV of the diode can be found out. If we look into the circuit what will be PIV? $2V_S$ peak value minus this drop V_{D0} will be the peak inverse voltage of the non-conducting diode. So PIV is $2V_S$ max minus V_{D0}. So 2 into 15.9; V_S max is 15.9 minus 0.7 whole drop is given to you; 31.1 volt. This is the PIV and the turns ratio we have found.

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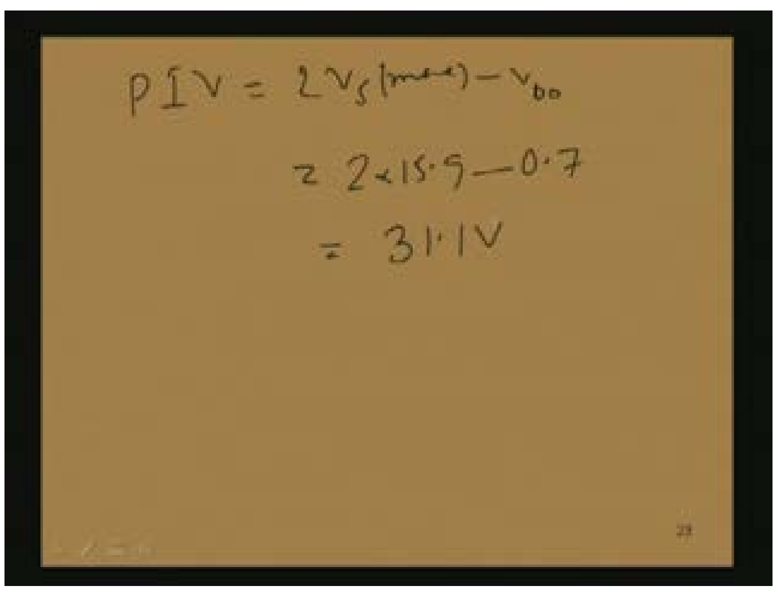

In this way we can solve this problem and whatever you do, you must assume either the constant voltage drop model or ideal diode. In this example it is given that it is constraint voltage drop; so we can proceed like that.

In today's class we have discussed about rectification which is an important application of diode which you will be finding useful in all electronic circuits because electronic circuits require a DC voltage mostly to be applied and that can be obtained by a power supply after rectifying an AC voltage source.