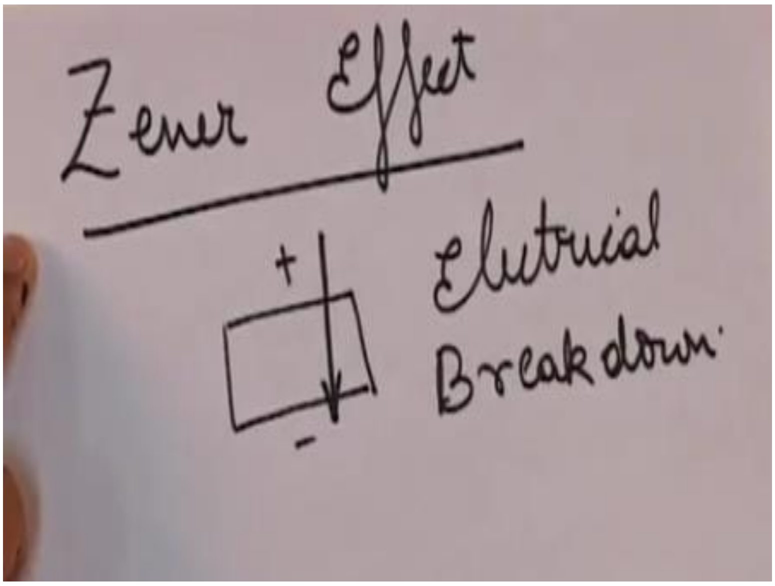
Analog Circuits
Prof. Jayanta Mukherjee
Department of Electrical Engineering
Indian Institute of Technology - Bombay

Week - 08
Module - 01
Zener Effect, Rectifiers

Hello welcome to this course analog circuits, now we are in the week 8 of this course, so in the past week, we had been discussing about multi vibrators that is the astable, bi-stable and the mono stable multi vibrator, now we are going to start another topic on this general topic of non-linear circuits non-linear analog circuits that is so in this module we will be discussing about the Zener effect.

Now the Zener effect is very is a very popular technique used for voltage regulation so voltage regulation means you know you are given of input voltage and you do not want the output voltage to exceed certain value in those applications the Zener effect or the Zener diode as the device that is used that is known that comes in handy.

(Refer Slide Time: 01:18)

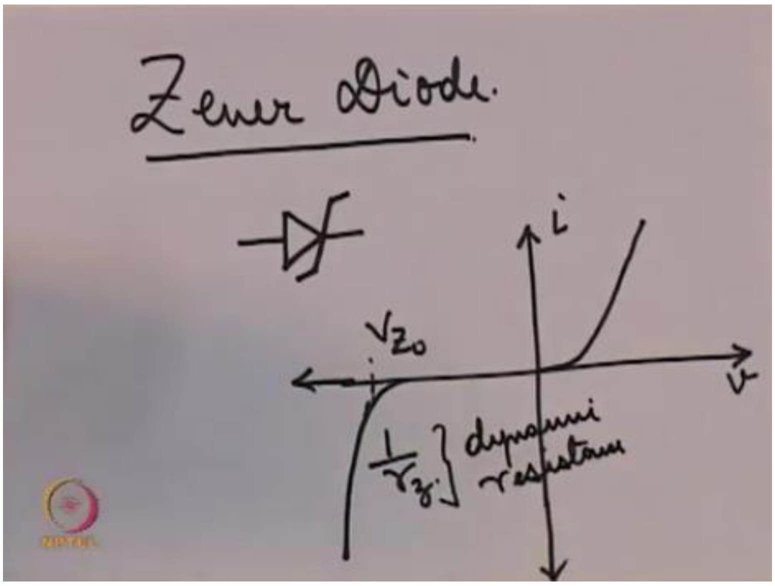


So let us discuss about this Zener effect, first of all we have to understand that the Zener effect is what is known as a quantum effect usually when a material an material is subjected to high voltage at a certain high voltage this will break down means the electrons suppose this was an insulator initially under the influence of the very high voltage the electrons will be pulled out and this material will go from conducting from a non conducting to a conducting now usually when this happens the material cannot go back to its previous state so if it breaks down what we call an electrical break down.

If there is an electrical breakdown then the material cannot come back to its initial state however this Zener effect what happens is that due to the special construction of the diode now we will not go into the details of the construction of the diode just know that there are some special techniques used for construction the Zener diode such that when a high voltage is applied there is a log of charge carriers which are formed but then once the high voltage is reduced or we go back to the initial state the material also comes back to its initial state.

So that is the Zener effect that is different from the normal electrical breakdown phenomena that we know so I Zener diode this Zener effect is usually exhibited by a device called the Zener diode.

(Refer Slide Time: 03:29)

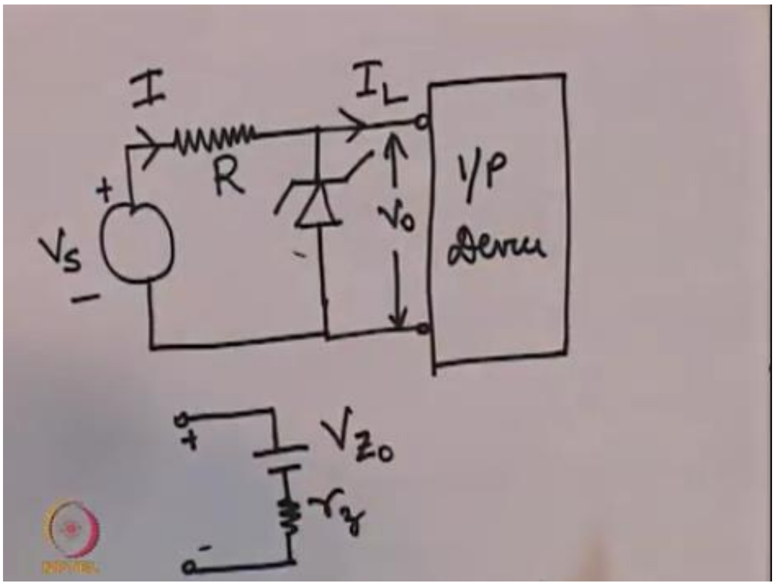


The symbol for a Zener diode is like this okay and the I versus V characteristics of a Zener diode is something like this that is the current and voltage relationship is something like this so just like the threshold voltage or the forward bias threshold voltage of a diode.

We now have a reverse threshold voltage if the voltage across the Zener diode is made more negative than this VZ0 then there will be a sudden spike in the current flowing through the diode or the resistance offered by the diode in the reverse bias region will suddenly fall and in face we can will fall and go to a value say rz.

So usually we know that in the reverse biased state a diode cannot conduct any current but for this Zener diode when the voltage is when the voltage is more negative than VZ0 there will be a sudden spike in current and the resistance goes from a infinite value some finite value rz this rz by the way is a dynamic resistance, dynamic resistance means that it is a AC resistance that it response only when there is an AC input, now the circuit that is that as I mentioned the Zener diode the most popular application of a Zener diode is for voltage regulation.

(Refer Slide Time: 05:55)



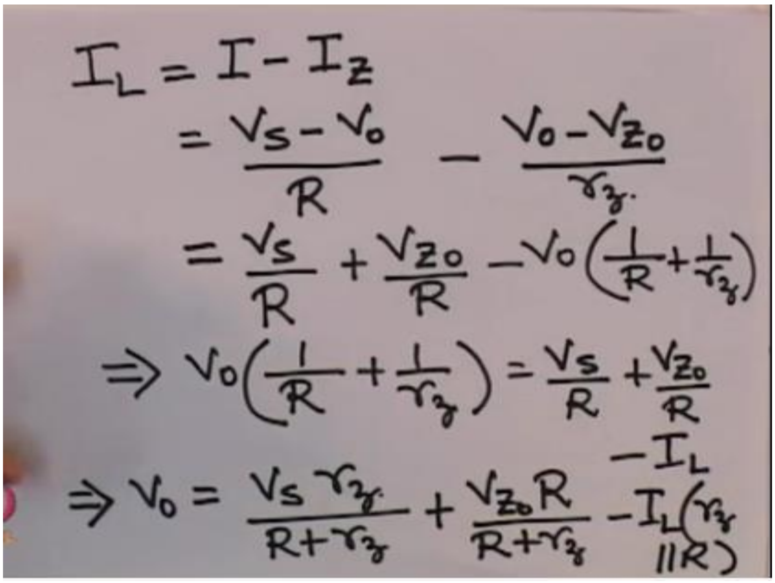
So let us draw the circuit for that voltage regulation, so the circuit is very simple actually you have a source VS with an internal resistance R this is our Zener diode and this output voltage that is produced by this Zener diode is fed to some device, now the equivalent model of this Zener diode based on the characteristics that I just showed can be represented like this, so there is an internal resistance AC resistance rz and there is a voltage source VZ0 representing the threshold voltage.

So when the voltage becomes more negative than VZ0 there is a sudden spike in current flowing ok by more negative I mean between these 2 this terminal and this terminal, so it is please do not confuse it with the forward biased threshold voltage of a normal diode.

When I say more negative than VZ0 because for example if I give this circuit diagram then it almost appears as if it has to be more positive than VZ0 no note that a Zener diode always works in the reverse bias condition and here I have connected this Zener diode in a way that when the source voltage increases it becomes it is it goes into the reverse bias region and the higher the source voltage is the more deeper it will go into the reverse bias region.

So how to analyze this now first of see that because this Zener diode has an internal resistance rz and also the characteristics of a Zener diode are like this, so it is not a perfect cut off circuit that is if the voltage becomes more negative than VZ0 it is not that it will be immediately cut off the output or there will be a huge surge in current that will make that will short out but no it is not like that because of this finite resistance rz a Zener diode is just like any other device not an ideal cut off device and we have to analyze it properly, so to analyze it how do we do that let us look at this current IL so this current IL if I keep it here by.

(Refer Slide Time: 09:59)

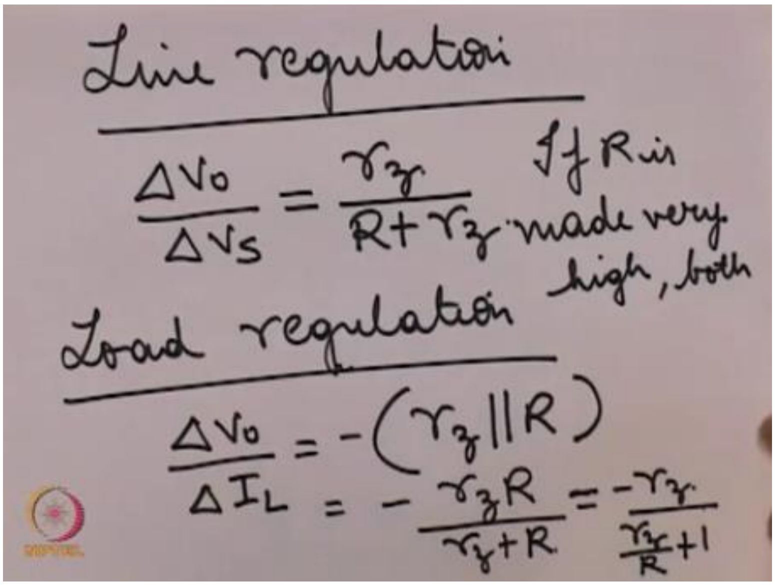


IL is given by this current that is the current from the source and suppose the current through the Zener diode is IZ then IL will be = the difference of I and IZ right now what is this current I can I write this as = VS - V0 ok upon R and what is this current IZ can I write it as V0 - VZ0 upon small rz ok, so then simplifying I get this as = VX upon R okay + VZ0 upon R - V0 into 1 upon R + 1 upon rz okay.

So further solving this I will get V0 1 upon R + 1 upon rz okay is = VS upon R + VZ0 upon R - IL and from this I can write the formula for V0 as = VS rz upon R + rz + VZ0 R upon R + rz - IL rz in parallel with R.

So, what this equation basically means is that if V0 is a function of VS and as VS varies V0 will also vary of course it will depend on the other parameters of the circuits like this capital R and small rz but it is not that if VS becomes very high then V0 will you know stay constant or it is not a perfect cut off like that the 2 terms that are frequently used in the as a performance criteria of a Zener diode are one is known as line regulation.

(Refer Slide Time: 14:03)



Which is defined as the change in V0 due to change in the source voltage Vs and the other parameter that is also performance parameter of a Zener diode is what is known as load regulation which is the change in V0 due to change in the load current.

Now this ratio is similar to a derivative and if we go back to this equation for V0 then change of V0 with respect to change of VS is simply = rz upon capital R + rz because the other terms once we differentiate both sides with respect to VS this term and this term will be 0 only this terms which is a function of VS will remain and so this delta V0 upon delta VS can be written as rz upon R + rz.

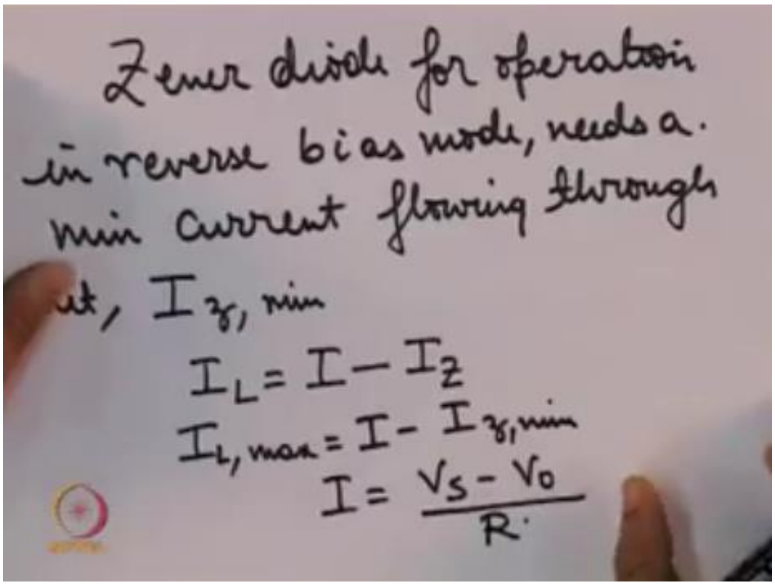
Similarly if we want to find out this delta V0 upon Delta IL then we go back to the equation for V0 differentiate both sides with respect to IL then this terms and this term will cancel or not exist after differentiation only this term will exist and the value of delta V0 upon delta IL will be = - rz parallel to R, now what do we see from these equations whether way why are these so important line regulation says that how much will V0 change due to change is VS, because we ultimately want an ideal voltage regulator right.

So ideally what we want is that the change in V0 should be 0 for any change in the supply voltage VS similarly we also want that the output voltage should be immune to any change in the load if we change the load value then out load current will also change and this parameter is a measure of how stable our output voltages with changes in load, so measures how stable our output is with respect to changes in the supply side and this measures how stable on output voltages with respect to changes in the load side.

Now from both these equations we see that if R is made very high both line regulation and load regulation become very low isn't it if so this I can write as = - rz R upon rz + R and this is in turn = - rz upon rz upon R + 1 usually this rz value is a small value, so if my R is very high then this will reduce to - rz and rz become being a very small value our load regulation value will also be the magnitude of the load regulation will be small, similarly the line regulation also if R is made very high then delta V0 upon delta VS becomes negligible.

So that is the way to do it if R if my R is mad high then we can ensure that our line regulation and load regulation is very good so then is that the way to do it that is if we just make the value of R very high can be ensured that you know that our all our problems are solved not quite ideally, we could have made this R = infinity but then there is also the problem that we have to maintain a minimum current flowing through the Zener diode.

(Refer Slide Time: 19:29)



So Zener diode for operation in reverse bias mode needs a minimum current flowing through it and let us say I call this minimum current as Iz min now coming back to the circuit once suppose the current flowing through the Iz is equal to or the current IZ flowing through the Zener diode is equal to the minimum value IZ min then what is the current flowing through the load this IM, now you know we know that IL is equal to current from the source - the current through the Zener diode.

Now if this I is fixed then the maximum load current that can be supplied is given by I - IZ min right, so my load supply current is constant if my supply current is constant then and suppose the minimum current is flowing through the Zener diode in the maximum current that I can supply to the load will be IL max and that will be given like this, now I is given by what that supply current is given by the source voltage - the output voltage upon the internal resistance of the supply source.

(Refer Slide Time: 22:09)

$$I = \frac{V_S - V_0}{R}$$

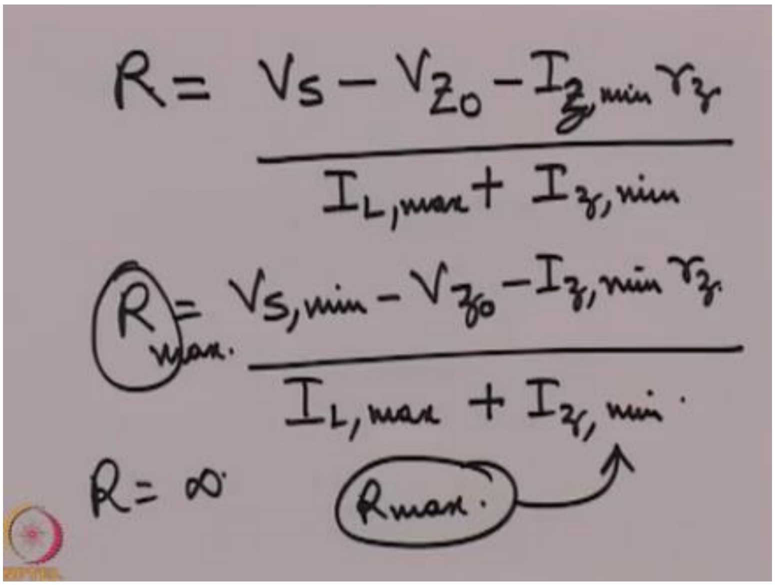
$$= \frac{V_S - V_{Z0} - I_{z,min} r_z}{R}$$

$$I_{L,max} = \frac{V_S - V_{Z0} - I_{z,min} r_z}{R} - I_{z,min}$$

So this in turn can be written as, so I have I = VS - V0 upon R which in turn is = VS - VZ0 - IZ min into RZ, so where did I get this relationship if I go back to my circuit the voltage output voltage V0 can be written as the total voltage from here to here and that is = the diode drop VZ0 + the voltage drop across this resistance rz.

So that is and since the current flowing through the diode now is IZ min so we write instead of IZ I am writing IZ min this whole expression upon R and therefore IL max can be written as VS - VZ0 ok - IZ min RZ upon R - IZ min this follows from this equation which I had written earlier this equation ok.

(Refer Slide Time: 24:40)



So here I have just substituted in place of I this equation so from here the value of R that we get is = VS - VZ0 - IZ min RZ whole upon IL max + IZ min, now suppose there is a minimum value to the supply voltage also so then the value of R will be = VS min - VZ0 - Izmin RZ upon IL max + Iz min.

So if my now this value of R that I get is for the worst case by worst case I mean when the supply voltage is at a very at its minimum value when the minimum current is flowing through the Zener diode the what should be the maximum value of R if R goes above this value that we just derived then there is a possibility that the current flowing through the Zener diode this current going through the Zener diode its minimum value required for the operation for this diode and so that is why R should not be higher than this value.

So ideally we wanted R to be equal to infinity but Rmax there is a certain maximum value of R given by this expression above which we cannot go if we go then either then there is a possibility that the Zener diode will stop operation because of the current flowing through it being lesser than its minimum value. So I hope I was able to I was able to convey this concept of Zener diode to you properly it is as I said used mostly for voltage regulation, in the next module we will be covering the topic of rectifiers, so thank you.