Basic Electronics
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Module -5
Power Circuits and System
Lecture - 6
Four Layered Diode

Today we will discuss about a four layered diode. Earlier we have seen two layer diodes. In transistors also we have seen there are two junctions and we had p-n-p, three layers. But today we will discuss about a device having four layers of semiconductor materials which is silicon material. The name of this four layer diode is p-n-p-n diode because here in these type of diodes p and n type materials on silicon are connected in alternate way. That is p of the semi conductor material is connected to n of the silicon material and again p and again n; so, we have four layers. Now the family of p-n-p-n devices is consisting of many useful devices like silicon controlled rectifier which is known as SCR.

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SCS - this is called silicon controlled switch, then GTO that is gate turn off switch, LASCR - light activated SCR and UJT is uni junction transistor. These different types of p-n-p-n devices are used. In many useful applications, we find that these devices which are nothing but family of p-n-p-n devices are used extensively and in power control, mainly we will find applications of p-n-p-n devices like SCR which is also known as thyristor. We are going to discuss a p-n-p-n diode and what are their characteristics?

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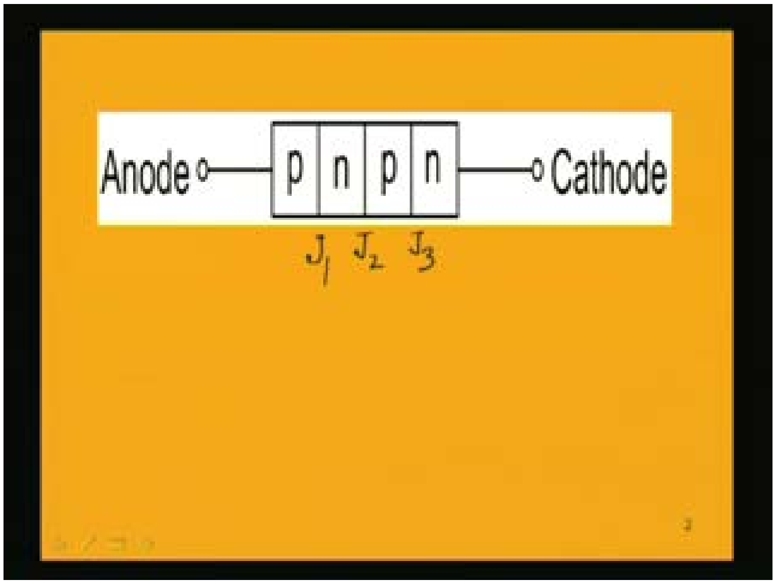

Let us consider a p-n-p-n diode having p and n layers alternatively as shown here. We are having four layers and to the two ends we are having two terminals which are known as anode and cathode. This anode terminal is to the outer most p-type and the cathode terminal is connected to the outer most n-type. In this four layer diode we will have three junctions because in between this p and n there will be one junction say J_1, then between n and p there will be another junction J_2 and between this p and n another junction will be there which is J_3. The total number of junctions will be three in this four layer diode and the two terminals are anode and cathode. As the name suggests they are connected to positive and negative of a supply.

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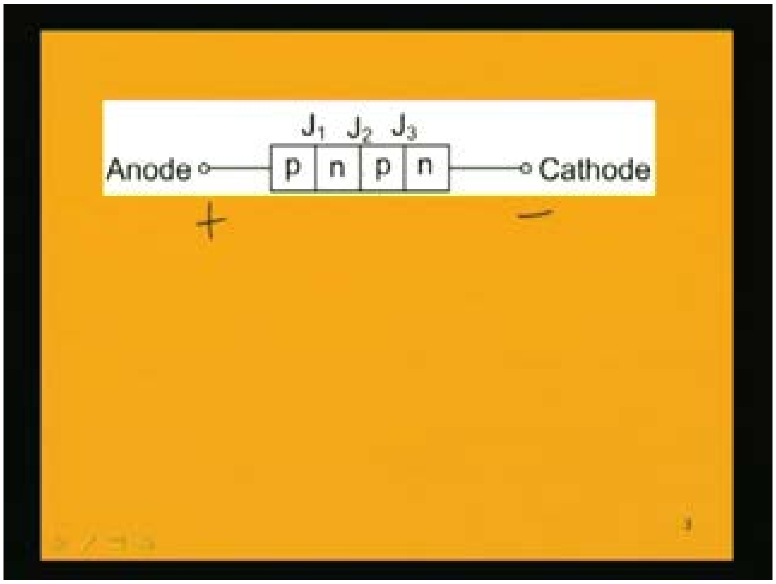

We now have three junctions J_1, J_2 and J_3. The anode and cathode are connected to positive and negative of a supply. What will happen to the junctions? In order to understand that we have to note that the junction J_1 between p and n is forward biased because the anode will have a positive of the supply and the cathode will have the negative of the supply. The anode and cathode are always kept in this fashion that the anode is at a positive potential with respect to the cathode. The junction J_1 between this p and n will be forward biased. Similarly the junction J_3 which is between this n and p, this will be also forward biased because this n is connected to negative. But if we consider the middle junction J_2, this middle junction J_2 will be reverse biased.

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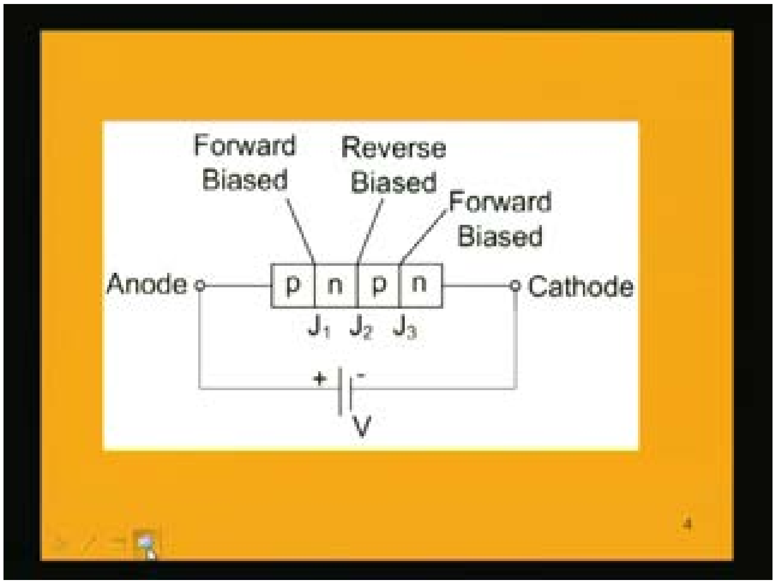

Three junctions are there in this four layered diode. Out of these three junctions the extreme two junctions are forward biased and in between junction which is the junction in the middle that will be reverse biased. Here we are applying the potential V whose positive is connected to an anode and negative is connected to cathode. This is the way we will have to connect this diode. Now what will happen is because the reverse biased junction is there is there, so even though we are applying a supply voltage V, there will not be conduction of current since the externally applied bias is reverse biasing this middle junction. If we only apply a very high potential or a high voltage V, when this reverse biased junction J_2 will have break down due to the avalanche breakdown, then only there will be a sharp rise of current and the device will be ON. Otherwise in this four layer diode with this type of configuration having only a supply voltage to anode we will not have conduction of this device until and unless the reverse breakdown happens in the middle junction J_2.

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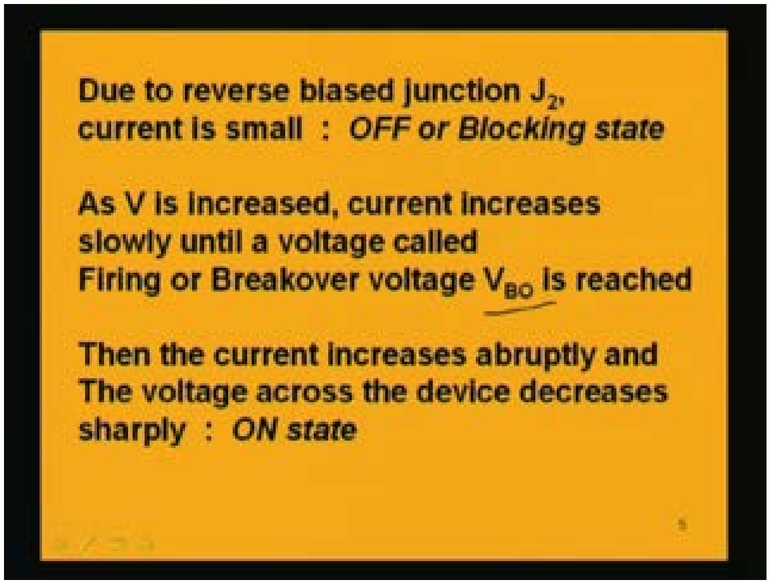

The device will be OFF or in the blocking state. It is called blocking state which is nothing but when the device is OFF due to the reverse biased junction J_2, because in that condition we know that the current is very, very microscopic and it is very small; only the reverse saturation current flows. It is almost similar to assuming that zero current flows. In this state which is the blocking state or OFF state we are getting that the device is non conducting and then if we go on increasing the voltage V, then current slowly increases. Initially the increment of the current, when we go on increasing the voltage, will be very slow until or till the applied voltage reaches a value which is known as break over voltage or firing voltage and it is known as V_{BO}, the break over voltage and that is the voltage at which the reverse biased junction is having breakdown.

If we consider a normal diode in the reverse biasing condition, the saturation current which will normally flow will be very small and if we go on increasing the reverse biasing voltage then at a point the avalanche breakdown will take place. This is the condition when because of the very high kinetic energy being supplied by the high reverse biasing voltage, the charged carriers which are electrons they will be knocked out from the covalent bonds and become free. These free carriers will again knock out other electrons from the covalent bond and this process will be a cumulative process. There will be an avalanche of electrons which will be accumulated and because of which there is a sharp rise of current and this fundamental we have earlier studied while we were discussing a normal pn diode. As far as this four layered diode is concerned, the junction which is reverse biased will undergo the similar process when we go on increasing the reverse biasing voltage and that voltage where this breakdown which is nothing but the avalanche breakdown is taking place in the reverse biased junction that voltage is known as break over voltage.

At this break over voltage or firing voltage the device starts conducting and that means the rise of current will be very enormous at this point. That is why the conduction is taking place and then the device is stated to be in ON condition. We have a blocking state and an ON state for the device. Blocking state means the OFF state and then we will have the ON state when the current in the device rises sharply and the voltage across the device falls very sharply. Because when it is ON, it is saturation condition and during saturation we know that the voltage across the device will be very, very small and it is like you are short circuiting. When it is OFF, it is like open circuiting. So, the resistance is very high. Similar analogy can be applied here for this four layered diode also. It is having two states OFF and ON which is like open circuiting and short circuiting condition.

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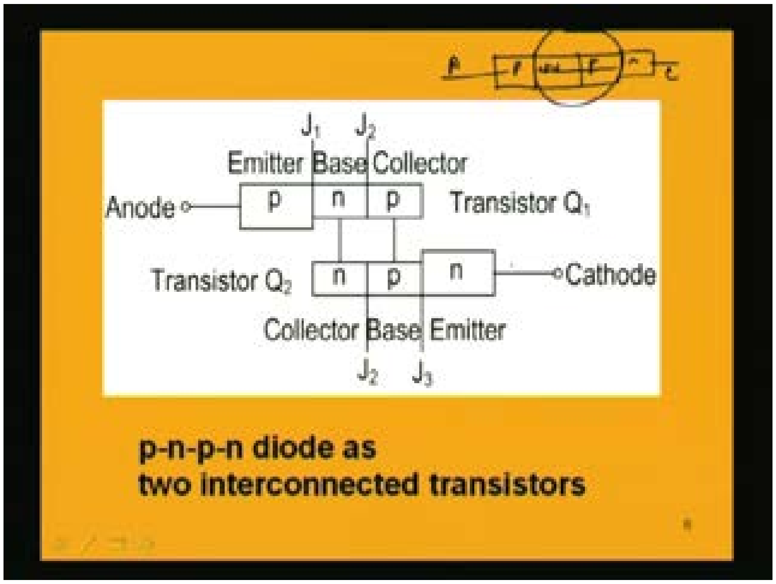

Now, if we try to analyze the four layer diode a little deeper, we can very conveniently detach the two layers which are between the two extremes. We know that the anode and cathode are the terminals at the two extreme layers of p and n and in between we have n and p layers. If we now separate them, detach them mechanically just to show the configuration in a more clearer way then we can assume that we are having the pnp in one block and the other block will have npn. But this n and this n, is the same n layer; what we are doing here is that we are just drawing it differently in two individual blocks.

Similarly the p layer is also detached mechanically and these two are drawn separately just to show that finally what we are having is nothing but two configurations of transistor. One is the pnp transistor and the other is the npn transistor. What we were having was we were having this p-n-p-n diode. This is anode, this is cathode and what we are doing? In between these two extremes which are connected to anode and cathode, in between these two layers n and p we are just making two blocks and showing an attachment in between them basically to show that these two are nothing but the same block; but we are just spreading out in order to bring in the transistor configuration.

The upper one is nothing but a pnp transistor which we are naming as Q_1 and the lower one is a transistor named as Q_2; its configuration is npn. That means we are having two transistors. One is the pnp transistor and the other one is the npn transistor but they are interconnected. In the upper transistor if we look into the emitter, base and collector, the emitter is having the anode terminal drawn out from it. The lower one will be an npn transistor and this n at the extreme will be connected to the cathode. The emitter which is here that is connected to the cathode and in between is the base and the other layer is the collector. If we look carefully then we find that the base of the upper transistor Q_1 is the collector of the lower transistor Q_2 and the collector of the upper transistor is the base of the lower transistor.

So, two interconnected transistors are now there which are shown here which is the p-n-p-n diode being analyzed as two transistors which are interconnected. What will happen if we are having an anode connected to the positive of a supply and the cathode connected to the negative of a supply that can be very well understood if we now take this two transistor analogy for this p-n-p-n diode? Just to understand clearly how the current conduction takes place in the four layer p-n-p-n diode, the transistors having pnp and npn configurations and interconnected are shown here and we will proceed to analyze the current conduction by looking into the state of these two transistors.

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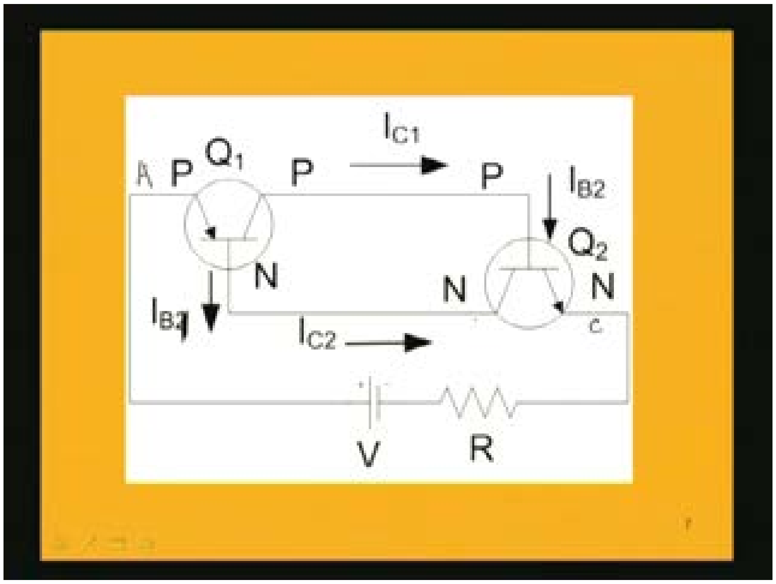

Here we are having the two transistors and the supply voltage through a resistance is given to the p-n-p-n diode having basically the two transistors interconnected. Q_1 is pnp transistor and Q_2 is npn transistor as just now we have found and the anode is connected to the positive of this supply voltage V. This is basically the anode terminal which is nothing but the emitter terminal of the pnp transistor Q_1 and the negative is connected to the cathode of the other transistor Q_2 which is the emitter of the transistor Q_2. The base of the transistor Q_1 is the collector of this transistor Q_2. Similarly the base of this transistor Q_2 is the collector of this transistor Q_1. What will happen now is the supply voltage as it is acting on the two transistors, the emitter of the first transistor Q_1, which is P is connected to positive and so there will be a current flow in the base and this is shown as the I_{B1}; this is I_{B1} and this I_{B1} is the I_{C2} for the second transistor.

Due to the positive supply, there is a very small collector current which is due to only the reverse saturation current, as we have earlier said. Because of the in between collector base junction between the two transistors the collector base junction is reverse biased. That is why the four layer diode will not be turned ON. Now in order to turn ON this four layer diode, what we will have to do is we will have to increase this supply voltage to a very high value so that the collector base junction will have enough high voltage to cause breakdown. What happens if we go on increasing and increasing the voltage that we will now see. We will try to find out the p-n-p-n characteristics by taking into consideration both the positive and negative half of the supply voltage.

As we were finding earlier, when we were considering normal diodes in order to find out the V-I characteristic, what we did was we increased the V and we found out the corresponding I both in the positive direction as well as the negative direction. We go on increasing the supply voltage in this forward region that we will see and also we will study what will happen in the reverse condition if V is increased?

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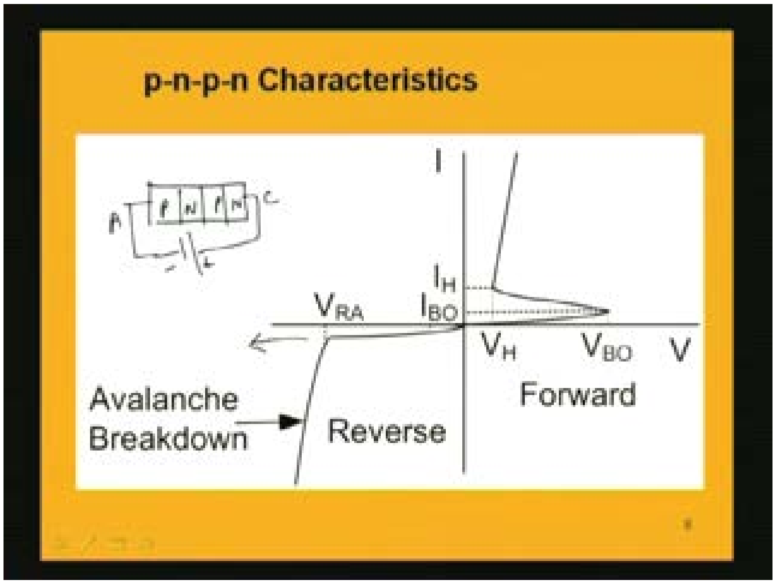

If we look into the p-n-p-n diode, here we are having this two transistor configuration (Refer Slide Time: 25:16). But we consider the p-n-p-n layers and imagine we apply a negative voltage. That means anode is connected to negative and cathode is connected to positive. Just the device is being reverse biased. The device is reverse biased means as far as the two extreme diodes are concerned they are now reverse biased in this negative region of the supply voltage. So, what will happen is as is the case with normal diode when we go on increasing the reverse basing voltage, then what will happen is just similar to the normal pn diodes.

Initially when the reverse voltage is small, the current in the four layer diode will be very, very small and as we know if we go on increasing and increasing the reverse voltage, at a point avalanche breakdown will take place and then the reverse current will flow very sharply. This is the phenomenon that happens even in the normal diode. As far as this reverse voltage region is concerned, there is no difference between the normal and the four layer diode.

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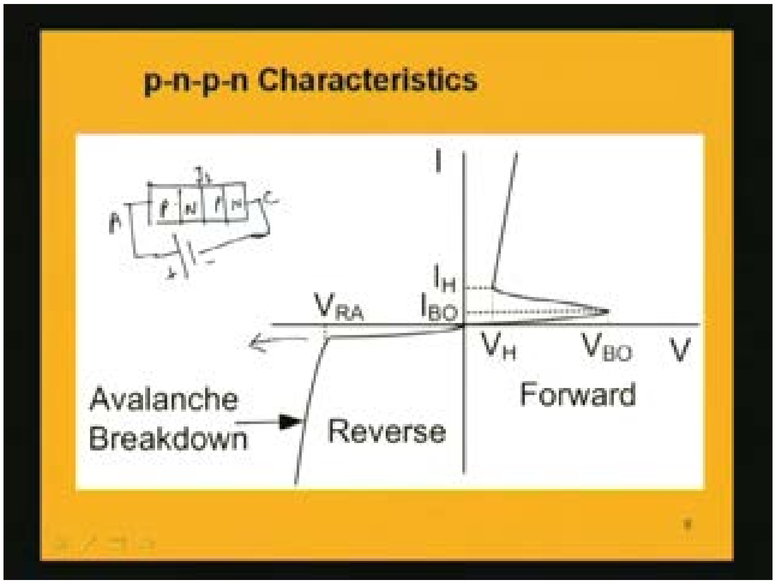

In the forward region, when the supply voltage is such that the positive of the supply is connected to anode and the negative of the supply is connected to cathode then what will happen? As I indicated earlier, because of the reverse biasing of the middle junction J_2, the device will be turned OFF because the current cannot rise because this in between junction is reverse biased. As you can see, initially even though we go on increasing the voltage, the current will not rise. But as you go on increasing and increasing the supply voltage more and more what is seen is that there will be a sharp rise of current. When the current rises very sharply the voltage across the device starts to fall and this is because when the device is turned ON because of the saturation the voltage will be very small and the current rises very sharply.

In this plot we are showing that. You go on increasing the forward voltage or the supply voltage in the forward direction till a point when this firing voltage is reached or break over voltage is reached which is denoted by V_{BO}. This is the break over point. At that point, the junction J_2 is undergoing reverse breakdown or avalanche breakdown. So, the current will immediately start to rise very sharply and the voltage across the device will fall. It will come down to a value where it is called V_H or the holding voltage and the corresponding current is the holding current. This holding current is significant because you can turn OFF the device only if the current in the device is brought below this holding current. This region is blocking or the OFF region. From this point to this point the device is OFF. After this point the device is turned ON but again if the current through the device is made to fall below this holding current, then the device will be turned OFF. In order to turn OFF the device, the current through this device should be made to fall below this holding current.

This typical curve shows that two significant terms are there which are V_{BO}, the break over voltage after which the current starts to rise sharply and the holding current. That is the current we must let flow in the device or the minimum value of that current which must flow in the device to continue the device in ON condition. If we make it below this holding current then it will be OFF. The device will be again turned OFF and when the current is I_H the corresponding voltage in the device is V_H; that is the holding voltage. This characteristic is the V-I characteristic of p-n-p-n diode.

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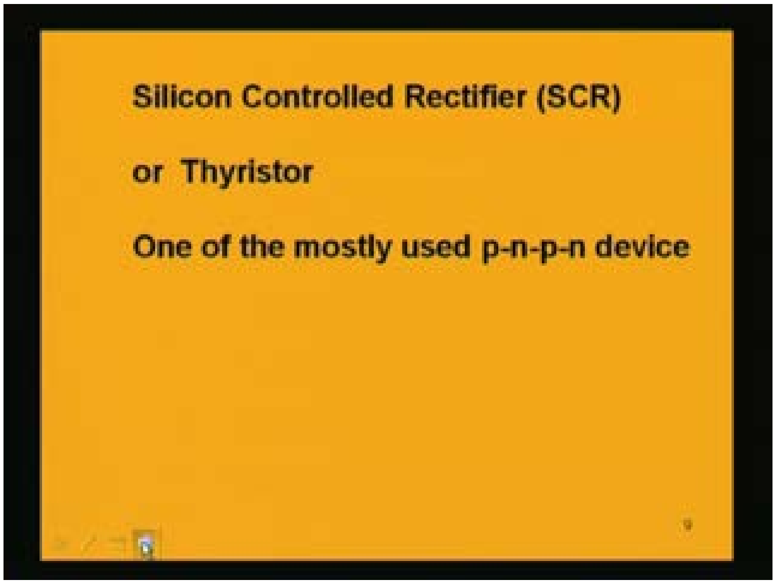

The important applications as I have indicated for this p-n-p-n diode are many. But one of the most import applications of this p-n-p-n diode is SCR. It is called silicon controlled rectifier. It is also known as thyristor. This thyristor or silicon controlled rectifier is very important and its application is in motor control or in regulated power supply or in inverters, choppers etc. We can find extensive use of SCRs in power control circuits.

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Some typical examples where we use this SCR or thyristor are relay controls, motor controls, regulated power supplies, static switches, inverters, cycloconverters, battery chargers, phase controls, etc. Typically we will find in control applications, motor control using thyristor, we can control various other devices. We will find that these thyristors are used in power control or motor control or relay control, etc.

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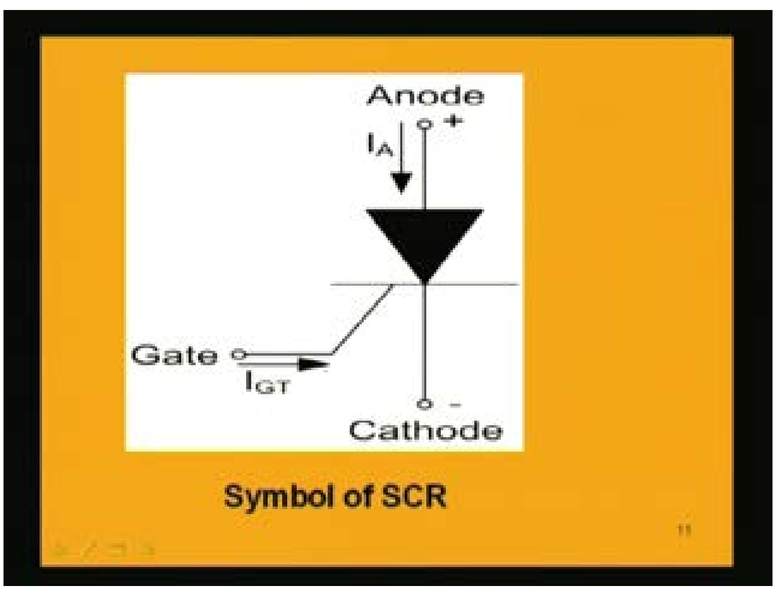

What is a thyristor or an SCR? It is a device belonging to the family of p-n-p-n diode, no doubt; but there is one important terminal which is known as gate. The symbolic representation of an SCR is as shown here. There is an anode, there is a cathode and there is a third terminal which is known as gate. Basically why it is used we are going to discuss that. This gate is the controlling terminal. That means by means of this gate voltage which is applied at the gate terminal we can control the SCR. We can control the conduction in the SCR by applying voltage at the gate terminal. In earlier example, when we were discussing the p-n-p-n diode, we saw that in the V-I characteristic we have to give a very high supply voltage; between the anode and cathode, we had to apply a very high voltage in order to conduct the p-n-p-n diode.

Now we will see how the conduction can be controlled and even the SCR can fire at a voltage below the break over voltage by applying another voltage at the gate terminal. Here this symbolic representation of the SCR is having this anode and cathode and this third terminal. The current I_A is the anode current and there will be another current which is the gate current, I_{GT} gate turning ON current.

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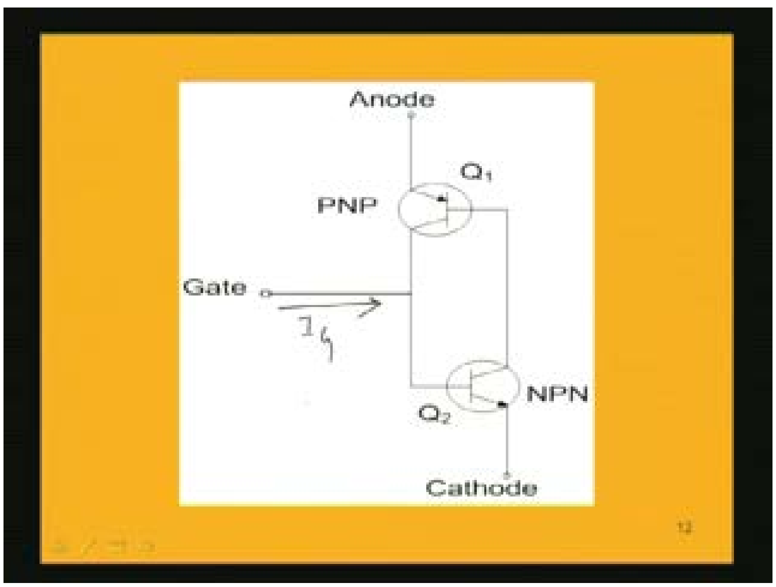

Again we are going back to the analogy of two transistors. Where this gate terminal is connected? Basically it is drawn out from the interior of the p-n-p-n diode. The external terminals anode and cathode which are also there in the p-n-p-n device that we were discussing, but another terminal is drawn out from the region near this P of the lower transistors or from near the collector base junction of the transistor. The two transistors Q_1 and Q_2 as earlier also we were discussing these are the same transistors here also shown. But another third terminal which is the gate terminal it is in between the collector of the first transistor and the base of the second transistor.

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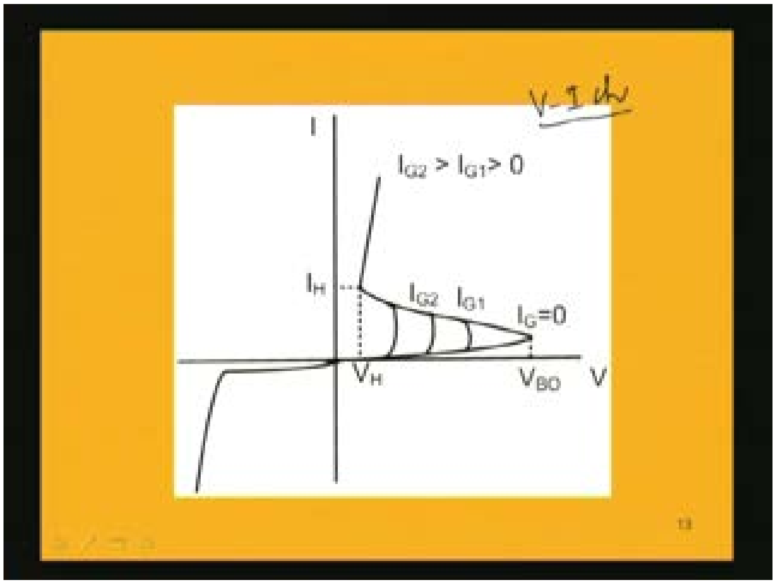

If we again consider the V-I characteristic for the SCR, V-I characteristic if we consider now, the V which is going on increasing and corresponding I that we are going to plot. Let us consider a situation where we are not applying any gate current by application of a gate voltage. What will happen is that it is similar to the earlier p-n-p-n device that we considered. We have to give a very high voltage which is the break over voltage at which the current will start rising. That means conduction will take place and the voltage across the device will drop because it is like saturation or short circuiting condition.

Suppose we are applying a gate voltage because of which there is a gate current (Refer Slide Time: 38:35). This current which is flowing in this gate terminal is say I_G. When we apply this I_G the change in the V-I characteristic will be that now, the device will turn ON even at a lower voltage than the earlier break over voltage. That means as we can see here we apply a gate current. Then V_{BO} is just here. That means the point where the device starts conducting that is at a smaller value than the value when there was no gate current. If we go on now giving a higher gate current, even then the V_{BO} will further go down. That means if I_{G2} that we are applying is greater than the earlier I_{G1}, then we can find that the V_{BO} will even go lower.

As we go on increasing the gate current, we will see firing of the SCR taking place at a smaller and smaller supply voltage. You do not have to spend a high supply voltage for conduction of the device, if we apply the control through the gate terminal by giving a supply voltage, another voltage at the gate side. If the current flowing through the gate terminal we go on increasing, then we can get the conduction of the device taking place at a smaller and smaller supply voltage. That is what is happening. That is shown in this V-I characteristic curve. In the reverse voltage it is similar to the earlier one. So, we are not very much even bothered about the reverse side because we are concerned or we are interested in this forward voltage side when you give a supply voltage which is having anode connected to positive of the supply and cathode connected to negative of the supply. So, in this region we are interested.

In the reverse voltage case when you give a reverse voltage, it will follow the normal curve of the reverse bias junction. The holding current and the holding voltage, these two are as shown by these dotted lines. Here we get a family of curves for different values of the gate current. If we go on increasing the gate current, we will get a lower and lower value of break over voltage. That is practically done while firing an SCR. When we want to fire a thyristor or a silicon controlled rectifier, both are same; I mean the name thyristor is used for SCR only. You can fire this SCR precisely where you want to fire. Suppose we want to fire the thyristor at some precise time or at some precise instant, then we can do that by giving the voltage at the gate side according to our requirement.

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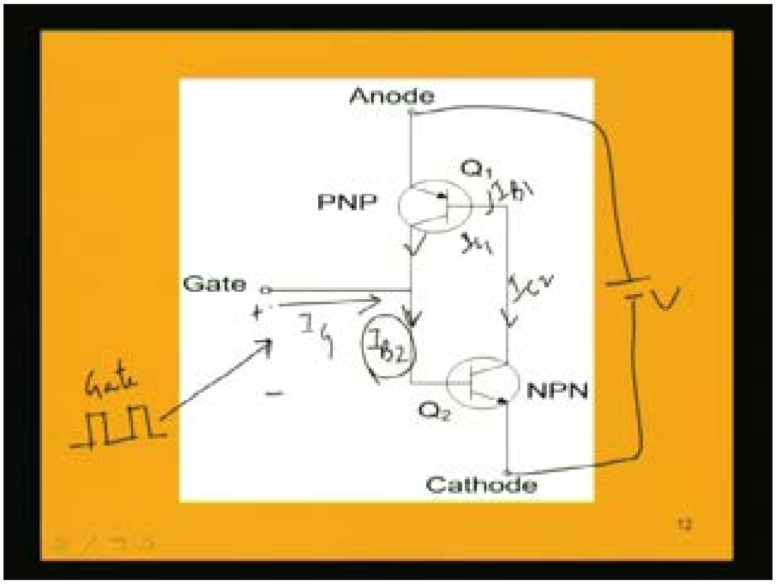

Now for example suppose we are giving a pulse voltage here. What will happen is that the pulse as we know, it is for a very short duration of time; it will be high for a very short duration of time. So, at that point or at that instant of time when the pulse becomes higher, the pulse has a value greater than zero. Suppose we are giving a pulse like this in the gate. If the gate is having a kind of pulse given by this then, this anode and cathode are already having this supply voltage. But apart from this supply voltage we are applying the voltage at the gate which is a pulse.

What will happen when we have this pulse being given to this p-n-p-n device? Then this transistor Q_2 will have this base current I_{B2}. If we look into the lower transistor, it will have this forward biasing between its base emitter junction. These two transistors as these are interconnected, what will happen is that when we have a gate pulse given or gate voltage given to it then the pnp transistor which is here and this Q_1 which is having this anode positive with respect to this cathode that transistor will be fired because now we are applying the gate current here. Because of this supply voltage being given at the gate terminal we are having a conduction taking place in the transistor and because of that base current, collector current will flow in the transistor. If we consider the upper one transistor then the collector current for this transistor is again the base current of this transistor.

This is IB_2 and here it is I_{C1}. I_{C1} is this current and this I_{B2} is this current. These two are the same. When there is conduction in the transistor Q_1, there will be flow of collector current. So, there will be flow of the base current and because of this I_{B2} there will be flow of collector current in the second transistor Q_2. When there is this collector current here in this transistor, then again the base current for this first transistor is the collector current for the second transistor. This is going on in a regenerative way because the first moment when we have the conduction taking place in one of the transistors which sets a collector current that collector current is again base current to the second transistor. So, that transistor will fire and there will be flow of collector current in that transistor which is again base current for the other transistor. As this is a regenerative process, it is going on cumulatively and finally we will get a very high current in the device and that is why the device is conducting.

This is possible because we are having a voltage at the gate terminal. Earlier when this gate voltage was zero there was no voltage given at the gate terminal. We had to give a very high voltage and when the break over voltage was reached then only the reverse break down was taking place in the reverse bias junction and the current was increasing. But now because this control is being given by this gate voltage, so whenever this voltage is applied at the gate terminal because this is a positive pulse being given. So, we are having the base current which is flowing in the second transistor and because of this base current in the second transistor, collector current will flow. This collector current is again base current to the first transistor and so on. So, the starting point or the start of the conduction is now easy because we are controlling with this gate current. The third terminal which is the gate terminal is the controlling terminal. This is the phenomenon that is happening which is leading to the ON state of the device or the SCR. Depending upon this I_G or the gate current (Refer Slide Time: 50:25) we can exactly trigger the firing of the SCR at that particular instant or angle of conduction where we want.

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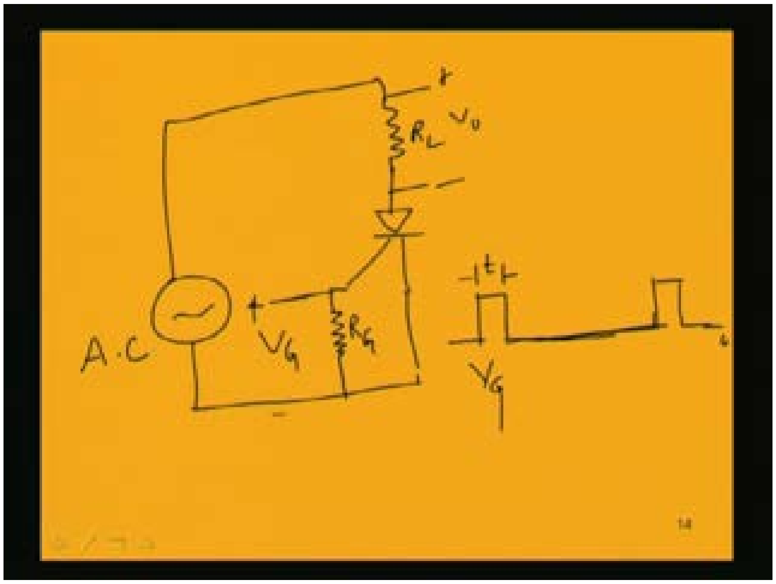

For example suppose we are having a circuit having an SCR. This is the symbolic representation of the SCR and we are using it in a circuit having a resistance say R_L, load resistance and this circuit is having an AC supply. This is an AC supply given to this circuit. At this third terminal, which is the gate terminal we are having a resistance R_G and we are applying a gate voltage V_G; V_G is being applied here. This V_G which is being applied at the gate is a pulse. It is a pulse like this. This ON and OFF time of the pulse are not same. It is OFF for a considerable amount of time and the pulse is high for a smaller amount of time. This time for which it is high is say t. This is the V_G. What will happen if now we are applying this kind of a pulse to this circuit?

We are interested in finding out what will be the voltage across the load? If we find out the voltage across this load V_o, what will be the shape of this V_o? We have to notice here that we are applying a pulse. The supply which is given to the circuit as a whole it is not DC; it is an AC voltage.

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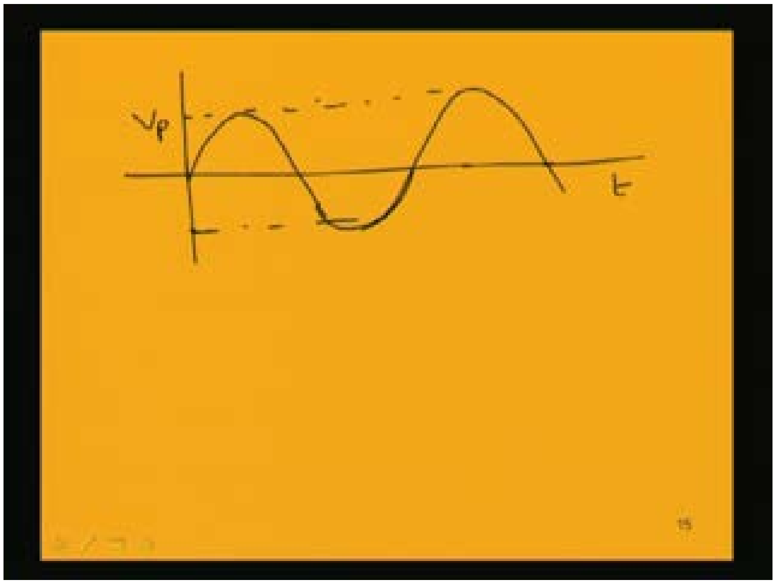

The voltage which is applied to the circuit is like this. It is an AC voltage having a peak value; some peak value it is having say V peak and this is a symmetrical waveform. So both the peak should be same. What will happen without this gate voltage? Suppose we imagine what will happen to this SCR without this gate voltage?

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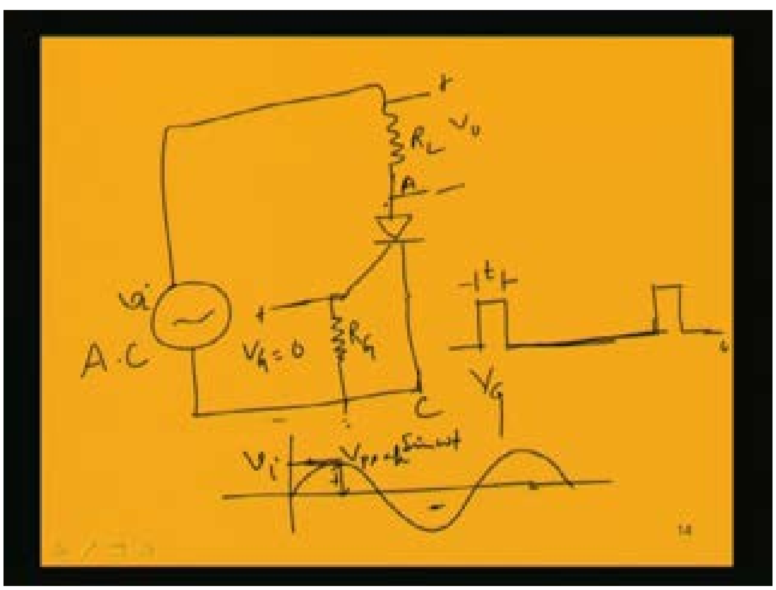

Suppose I am initially making this gate voltage zero. We are not applying any gate voltage. Here gate voltage V or V_G is equal to zero we make. This is a silicon controlled rectifier. It is having only this voltage between its anode and cathode. This is the cathode, this is anode. This point is connected here, this point is connected here and it is a sinusoidally varying voltage. As it is a sinusoidally varying voltage, what will happen is that it is positive for one half and negative for the other half. This is V_i. This is positive half, this is negative half.

If V_G is equal to zero, then it will be out of question for considering the negative half. Because when anode is negative with respect to cathode, in the negative half what will happen is this point is negative. Then this condition is not at all considered because we are always keeping the anode higher at a positive voltage with respect to cathode. In this application of this AC voltage what are we giving? What is the magnitude or peak value of this voltage which is given as input? This is an AC voltage. What is this peak value? If V peak is the peak value, suppose it is V peak sign omega t, then what is this peak value? It all depends upon the peak value of the voltage, in order to know whether the SCR is going to fire or not, in the positive half cycle. Because in the negative half cycle anode is negative, so it will be totally OFF.

This conduction will not at all happen in the negative half. But even though in the positive half cycle we have to know how much peak value is required for conduction to take place in the SCR. This sinusoidal voltage which is being applied is not sufficient to drive this SCR into break over, because if we look into the characteristic the break over voltage is the crucial point or the significant value of the voltage at which the conduction of the SCR takes place. The applied voltage has a peak value which is less than the break over voltage specified for that SCR because, every SCR I mean whatever device you are using, there is a specification data sheet for each device and those data which are specified in the data sheet will tell us what is the break over voltage for the SCR.

If this supply voltage is less than break over voltage then there is no chance of this SCR being fired or turned ON. It is the case when we are not having any gate voltage or V_G is equal to simply zero. Now we are applying the pulse at the gate.

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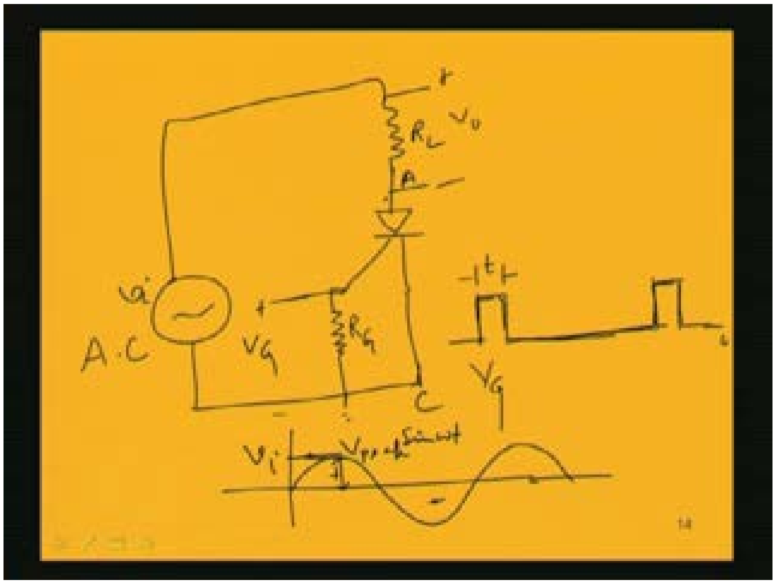

We are having now a voltage V_G, which is the pulse waveform as is shown here. So, this V_G is now applied. Only for a small duration this is high.

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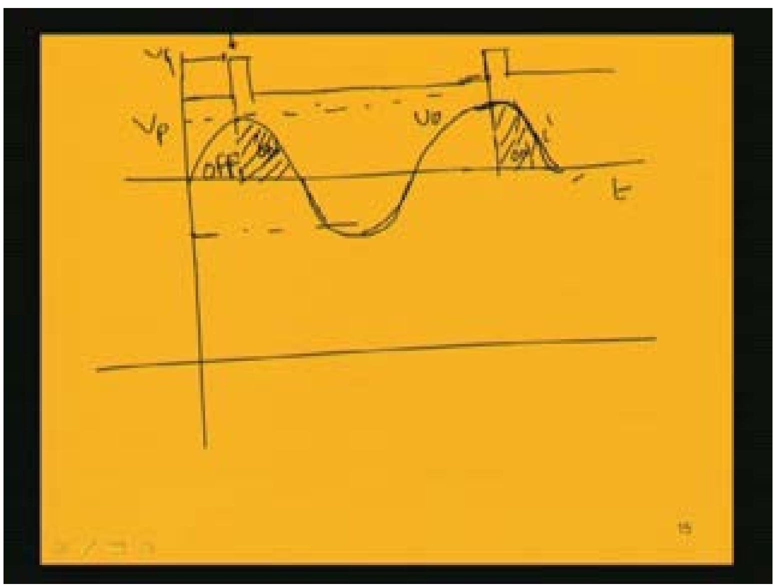

Whenever this pulse is being given, suppose we are having a pulse which is having this shape. We are giving this pulse voltage here and the period of this pulse is important because if we have a pulse having a value of zero for a long duration and a value high for a small duration t; this kind of a pulse suppose we are giving. What will happen is at this point of the input supply, this is the voltage which we are giving at input that is between anode and cathode and having a peak value V_P and this is the pulse which we are giving at the gate. This is V_G.

Precisely at this instant the pulse is being given. Whenever the pulse is high at this point, the device will be turned ON. The device will be having the gate current and because of this gate current being given as input, there will be base current flowing in the transistor which is collector current for the other transistor. Again that will make collector current flow and that will be base current for the other transistor and it will go on and regenerative process will happen and finally we will get a high current and that is where load current starts flowing in the circuit from this point.

The output voltage waveform if we look into which is nothing but this current into this R_L resistance, the current which will flow that will produce this voltage waveform and so the output voltage waveform will have positive value for this portion because this SCR is turned ON. SCR current will flow which will produce the voltage across R_L. Up to this point it was OFF. From this point onwards, the thyristor is ON. This is the ON and it will be ON for this portion only. When you have supply going to negative half cycle, we will have the thyristor OFF because the anode is now negative with respect to cathode. There cannot be any conduction. This portion will be OFF. Again from this point onwards, it will be ON. When the gate pulse again triggers, this will be ON. If we consider the output voltage waveform versus input voltage waveform, the output voltage will have a kind of waveform like this. This is your V_o.

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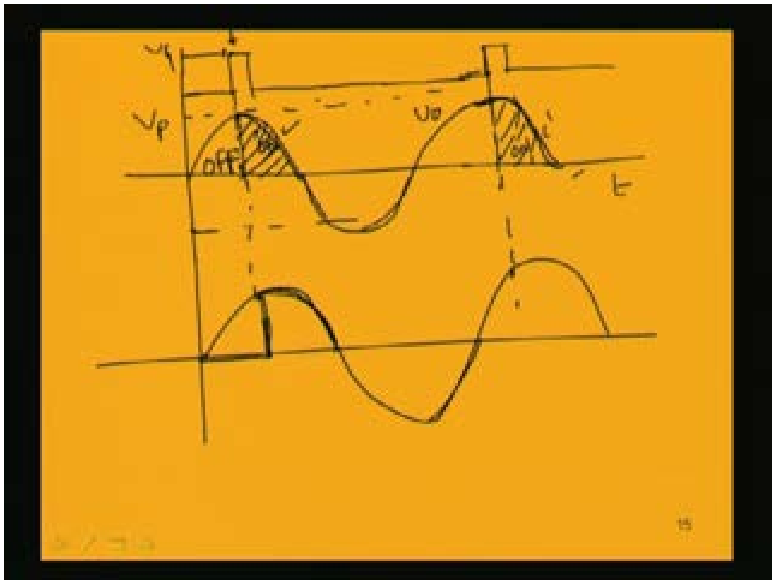

So, what we are having basically is if this was the input voltage waveform and from the input voltage waveform we have got, this is the output voltage waveform. This thyristor starts to fire from this point when the gate voltage is high. So, the conduction angle now can be adjusted by the triggering pulse. That means if you consider this angle of conduction at a point where it starts to conduct that can be actually controlled by the gate current which is flowing.

Here we are showing an example of a pulse. Depending upon this instant when the pulse is high, the conduction takes place in the SCR. We can vary this conduction angle. This is the portion of the waveform for which it is ON. This can be varied. You can control it; the firing can be controlled, the conduction angle can be controlled by this gate current or the supply voltage at the gate. Actually that is the idea how the SCR is used for controlling, in various circuits. Using SCR, we can control a relay, we can control a motor. In inverters, cycloconverters, choppers, etc., we will find this application of SCR. The most important point is the conduction angle or firing that can be controlled by using the SCR.

Today we have seen a very important application of four layered diode or pin pin diode. It is called pin pin diode because it is pn and pn and one important example of this p-n-p-n diode is thyristor which finds extensive use in power control circuits. We have seen the V-I characteristic of this thyristor, how by applying a gate voltage we can control the conduction angle for the SCR.