Switched Mode Power Conversion
Prof. Ramanarayanan
Department of Electrical Engineering
Indian Institute of Science, Bangalore

Lecture - 2
Diode

In today's lecture we will look at one of the components in the switched mode power converters. We had seen in the earlier lectures that the power converters, in order to efficiently process power consist of components which do not dissipate energy.

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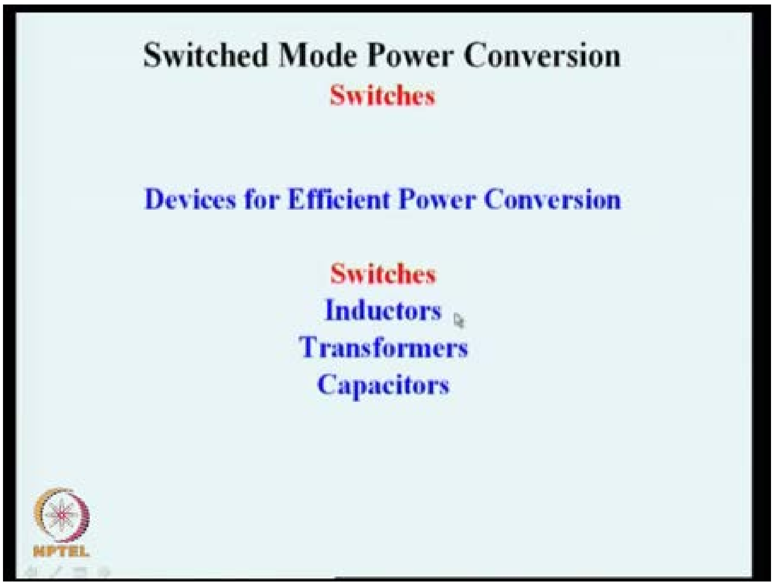

These electrical circuit components or switches, inductors, transformers, and capacitors; switches do not dissipate energy, because when they are on the voltage across them is zero in when they are off the current through the switches is 0. Inductors store energy and when they are discharge they will give back that energy, transformers transform power do not dissipate power.

Capacitors just like inductors, store electrical energy, which can be latter on recouped, so all the components that are used in power converters or lost less components on account of that the process of power conversion is efficient. The devices that are used for efficient power conversion are the switches, inductors, transformers and capacitors. So, in this session we will try to learn the features of switches, what are ideal switches? What are their properties? What are these characteristics? How the switches are realized with electronic components and how they are driven how they are protected? How they function? How they help in functioning the process of power conversion.

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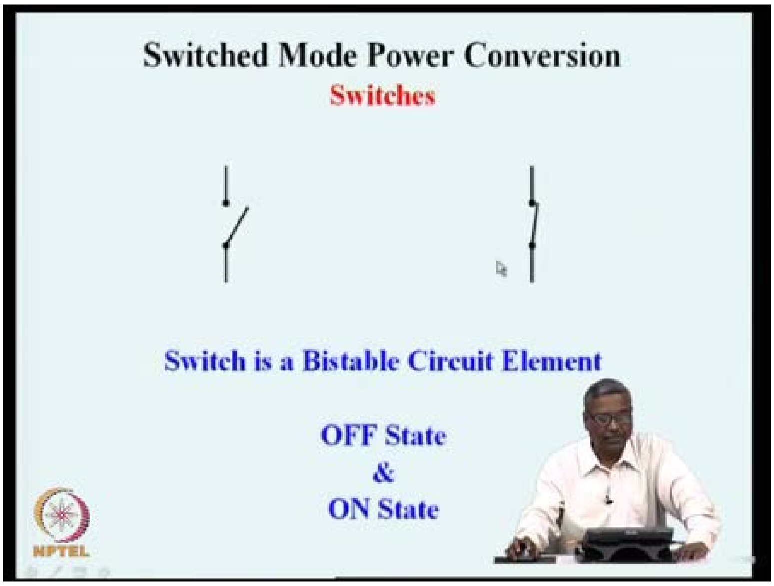

A switch is a circuit element this circuit element has two stable states just like other circuit elements resistor or inductor or capacitor. A switch also has two terminals, it is a two terminal device, but unlike resistors or inductors or capacitors, a switch has two stable state; one state is called the off state and the other state is called the on state. So, we might say that switch is a by stable circuit element, which has two terminals and it has two possible states. In any one of these possible states, it can operate stably. These two states are called the off states and the on state.

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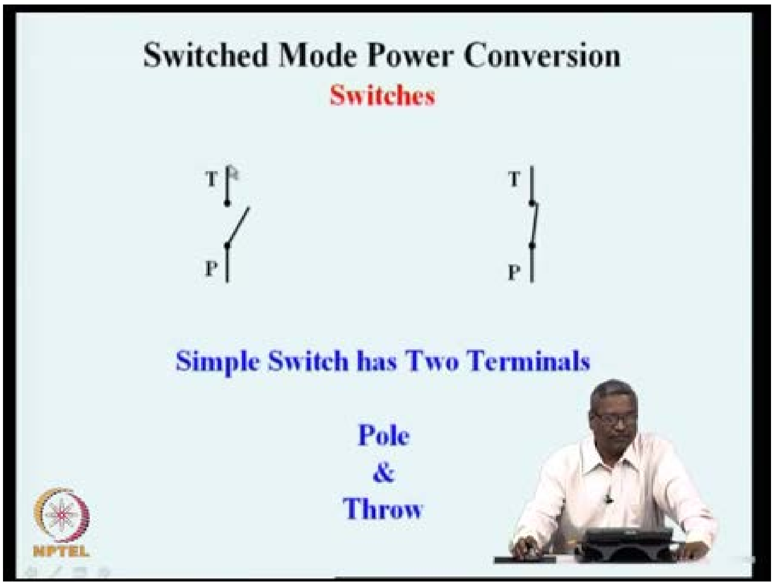

The terminals of the switches are designated as throw and pole. Here I have shown the schematic of a switch in its off state and the switch in its on state. In the off state the throw T and the pole P are not connected to each other, they are isolated from each other. In the on state the throw T and the pole P, they are connected to each other electrically, the simple switch that we see here has two terminals and two stable states, the stable state are the off state here. The on state here and the terminals are designated as a pole and a throw, so this particular switch has one pole and one throw. So, this is a single pole single throw switch.

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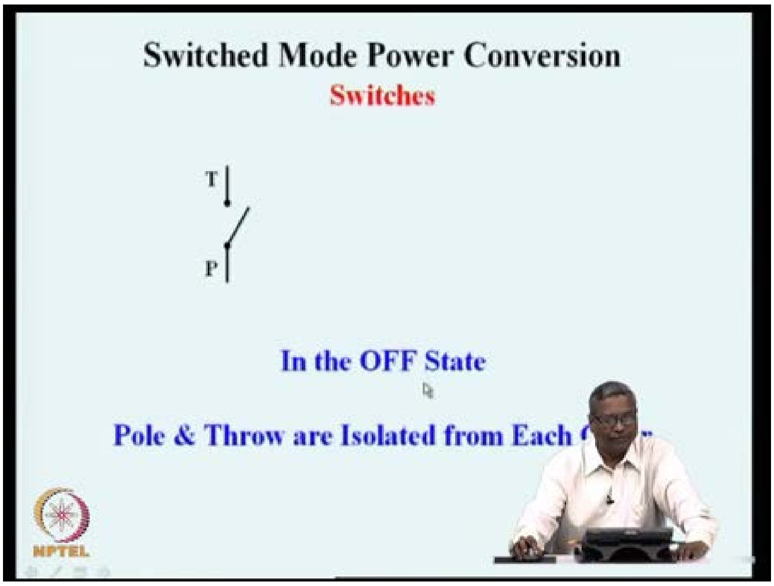

In the off state the pole and throw are isolated from each other. You see the throw here and the pole here are not electrically connected and that is the off state of the switch.

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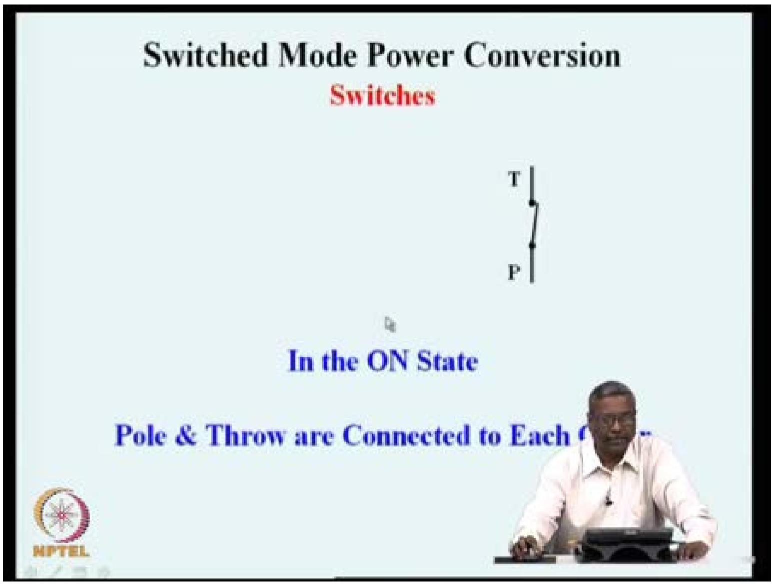

In the on state the throw of the switch and the pole of the switch are electrically connected to each other. This is the second state of the switch the on state.

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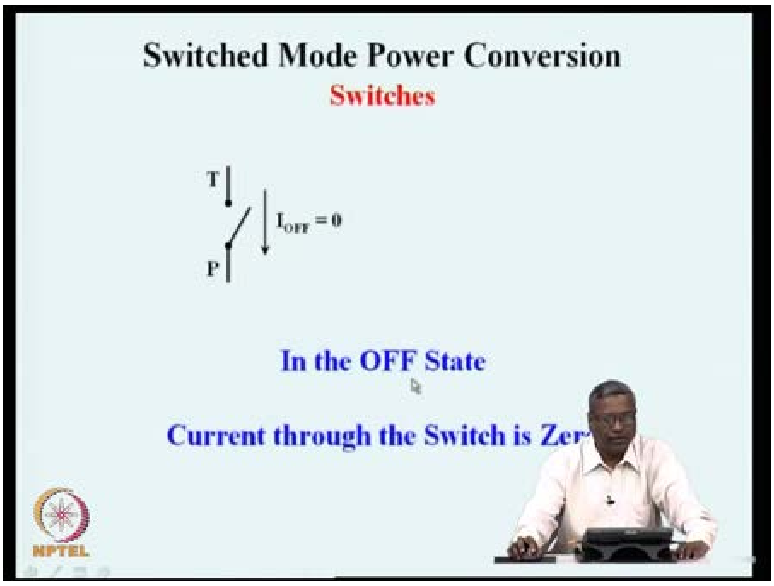

In the off state the important characters characteristics of switch are that the current through the switch is 0. This is the fundamental property of the off state the current through the switch is 0. You would say that the i of the off state current in the off state of the switch is 0, there is no current flowing from the throw to the pole or from the pole to the throw. This is the off state and the most important feature of the off state is that the off state current is 0.

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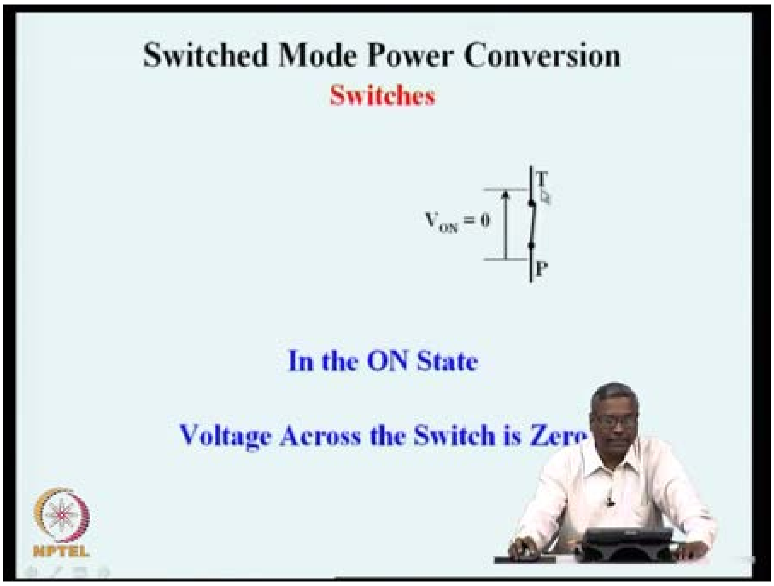

In the on state the throw of the switch and the pole of the switch are electrically connected to each other and the voltage across the switch is 0, the potential at the pole and the potential at the throw electrical potentials. They are both equal and so the potential difference between the throw and the pole of the switch in the on state is 0. So, we say that in the on state the voltage across the switch is 0, the throw and the pole are both at the same potential.

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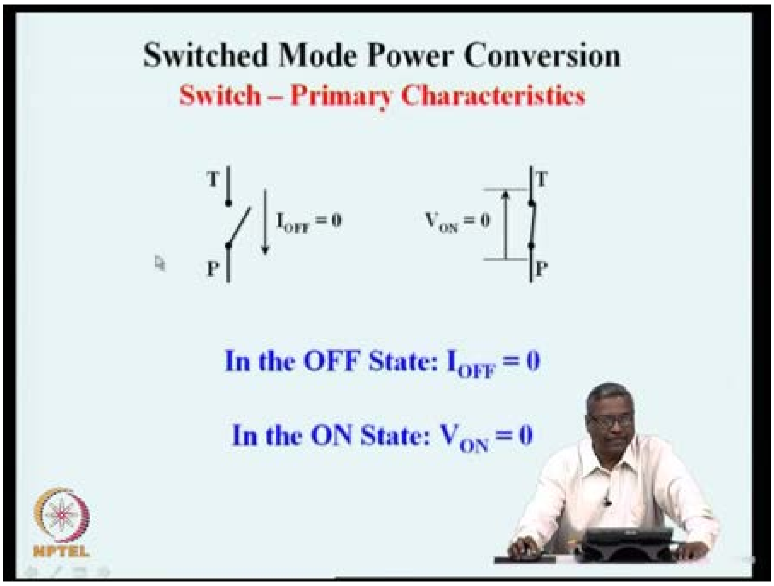

So, in the off state and in the on state the primary characteristics of a switch are that the current in the off state is 0 and the voltage in the on state is 0. So, it is very easy to remember the ideal characteristics most of the ideal features are 0 in the off state. It is a current through the switch, which is 0 and in the on state it is the voltage across the switch, which is 0.

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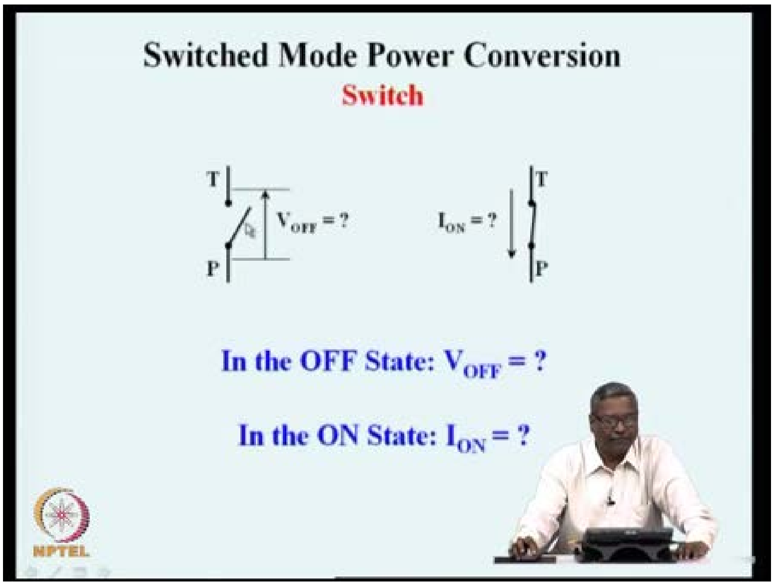

But in the off state and in the on state what happens to the other characteristics of the switch in any circuit element. We know that there are two circuit variables; one is the current through the element and the other is the voltage across the element. In this particular case, if we consider the off state switch, we know that the off state current through the switch is 0. The on state voltage across the switch is 0. The question is what about the off state voltage across the switch and the on state current through the switch this is the other variable in the electrical circuit quantities.

In any electrical circuit the two quantities that are of import ants or the voltage across the circuit element, which will be between the throw and the pole, and the current through the circuit element, which is from throw to the pole or from the pole to the throw. The question is in the off state, we know that the off state current is 0, but how about the off state voltage? In a similar way, in the on state we know that the on state voltage is 0, but how about the on state current.

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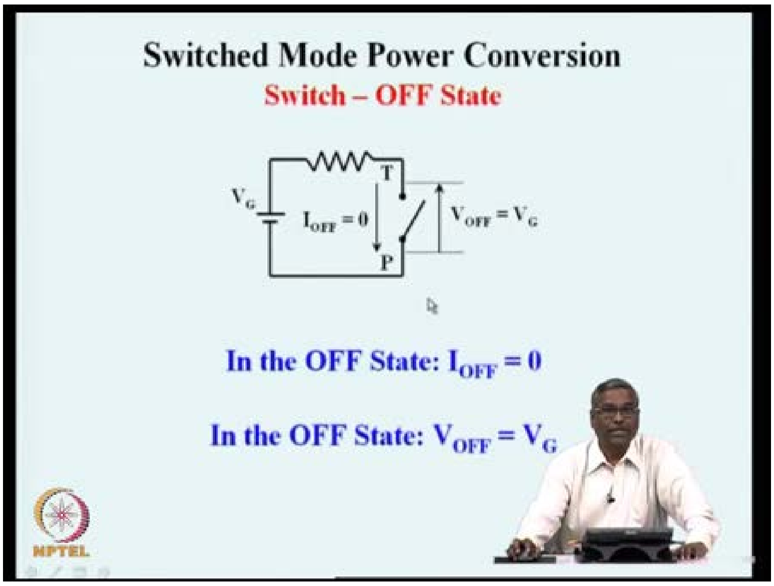

Now, the second characteristics of any switch state are related to the circuit in which it is connected. For example, in the off state the primary characteristics are that the off state current is 0, but in the off state the off state voltage or the voltage across the switch is not 0 and it is determine by the external circuit. For example, in the circuit that is shown here a battery is resistor and the switch are all connected in series and the switch is in the off state. The two defined quantities or the off state current and we know that it is 0 because that is the primary characteristics of an off state.

Switch the off state voltage is marked here that we do not know by knowing only about the switch, but because it is connected in the circuit and the circuit is known to us and an account of the fact that the current is 0. It is possible to say that the potential at T will be the same as the potential at this point the positive plate of the source. Because there is no current is flowing in hour and the potential at the pole is the same as the negative terminal of the source.

So, the off state voltage in this example is V G, which is the same as the source voltage. So, what we see here is in the off state one of the switch variables the current through the switch is defined which is 0. In the off state the other variable of the switch, which is the voltage across the switch is dependent on the circuit in which the switch is connected in this particulate circuit V G is the voltage across the switch in the off state.

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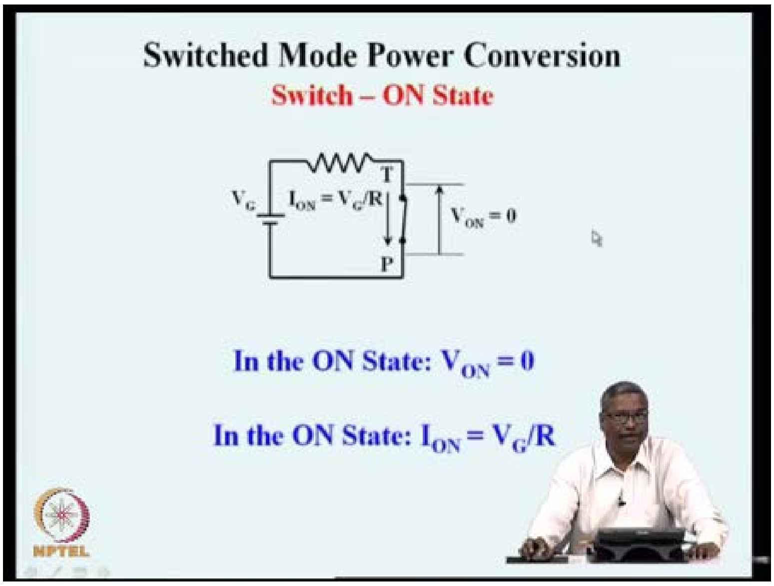

In the same way in the on state also the voltage across the switch is defined to be 0, but the current through the switch depends on the external circuit. In this circuit the same circuit as we had seen before, now the switch is closed the switch is in the on state an account of that a certain amount of current will be flowing the voltage across the switch is 0. Because that is the primary characteristics of the switch in the on state, so the full voltage V G will now be across this resistance. So, the current through the circuit is V G by R and that is the same current, which is flowing through the switch. Now, we see that in the on state the primary characteristics of the switch which is on state voltage, which is 0. But the next characteristics are the on state current is dependent on the source voltage and the load or the external circuit.

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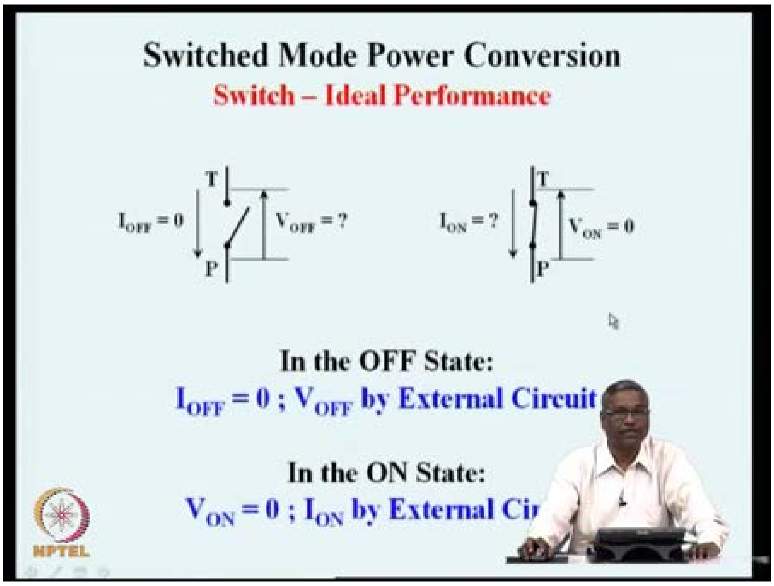

Now, this particular feature is very important to be notice that the switch which is the by stable element has two states. State is off state and then the on state in the off state the current is 0 and in the on state the voltage across the switch is 0. The off state voltage is dependent on external circuit and in the same way on state current is dependent on the external circuit. These are the primary characteristics of any switch that the current in the off state is 0 and the voltage is divided by external circuit and the voltage across the switch in the on state is 0 and the current is decided by the external circuit.

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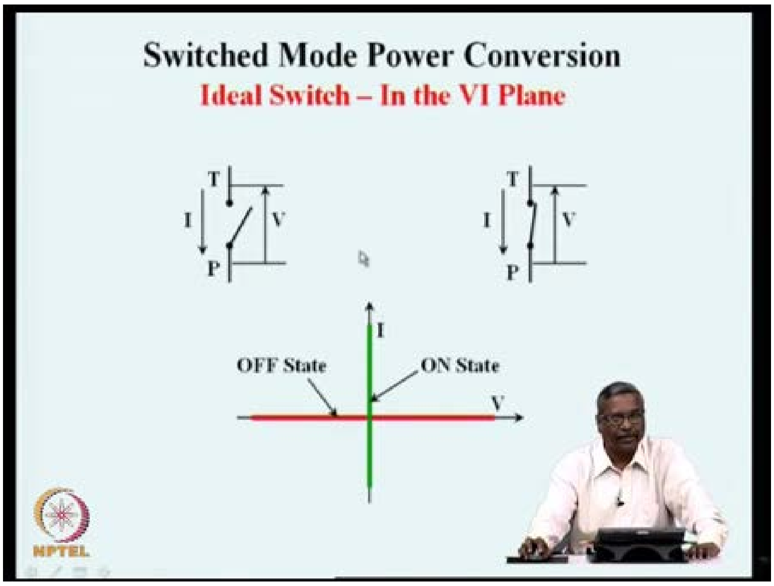

Now, any circuit element can also be seen in the V I plane, voltage and current plane. In a similar way just like we could plot the voltage and current across a resistor on the V I plane. In order to find out the operating points of a resistor it is possible to see the operating points of the switch for each one of its state the switch has an off state. On on state and in the voltage current axis, we can plot the operating points of the off state switch. We know that in the off state the current through the switch is 0, so you will find that the operating point of the switch under the off condition will all been lying along the voltage axis, on the voltage axis current is 0.

That is the characteristics of the off state switch, in a similar way an on state switch has the voltage across the switch is 0 and any amount of current can be flowing positive or negative. You see that the on state operating point of a switch will always be lying on the current axis the off state switch shown by the red line here, will always be on the voltage axis corresponding to 0 current. The on state operating point of the switch will always be on the current axis, indicating that the voltage across the switch is zero these are the primary characteristics of the ideal switch.

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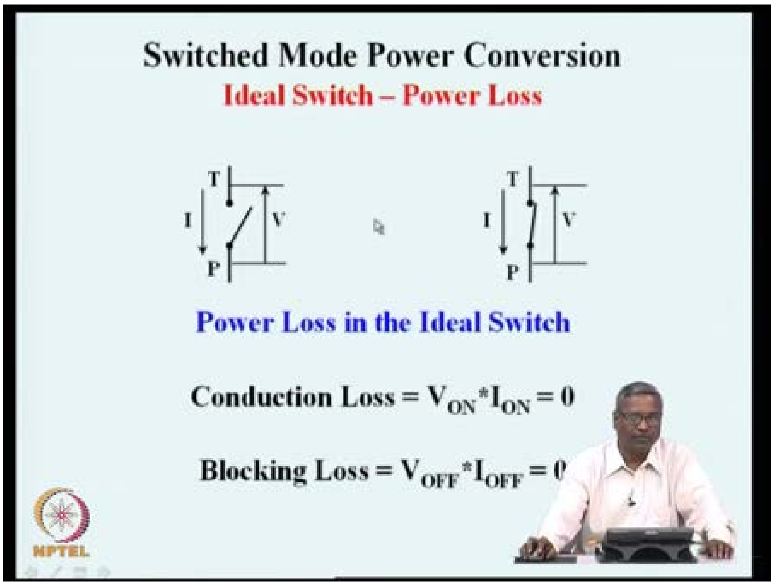

There are number of other characteristics, which we are interested in and one of them is the power loss how much power is lost in the ideal switch the conduction loss relates to the loss, when the switch is on in the blocking loss relates to the loss. When the switch is off in either case, you will find that the power loss in the switch is 0. The conduction loss is 0 because the V on state voltage is 0. No matter what, current is flowing through the switch the product, which represents the power loss is 0.

In the same way in the blocking state of the switch the current through the switch is always 0, no matter how much voltage the device is blocking? You will find that the product of V off and I off is 0. In an ideal switch the power loss is 0, in fact this is one of the reasons, why we are using switches for power conversion in an efficient way. Switch was selected to be a component for power converters mainly because in both the states ideally the power loss is 0 and that is what we see here.

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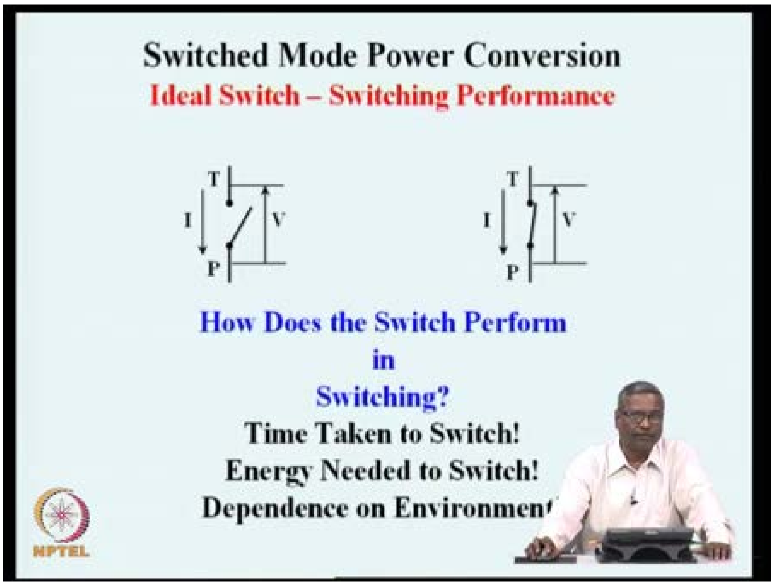

What are the other ideal performance characteristics of a switch? Now, a switch has several other operating features what are those features. How much time does it take to move from one state to another state? The switch has two operating states; the off state and the on state. If you want to switch from an off state to an on state, how much time does it take? What is the energy involved in moving from the one state to the other state? Then how the relative performance of the switch, how the various characteristics of the switch or dependent on the environment, environment conditions like temperature, pressure, altitude and so on. So, these are the performance characteristics of the ideal switch.

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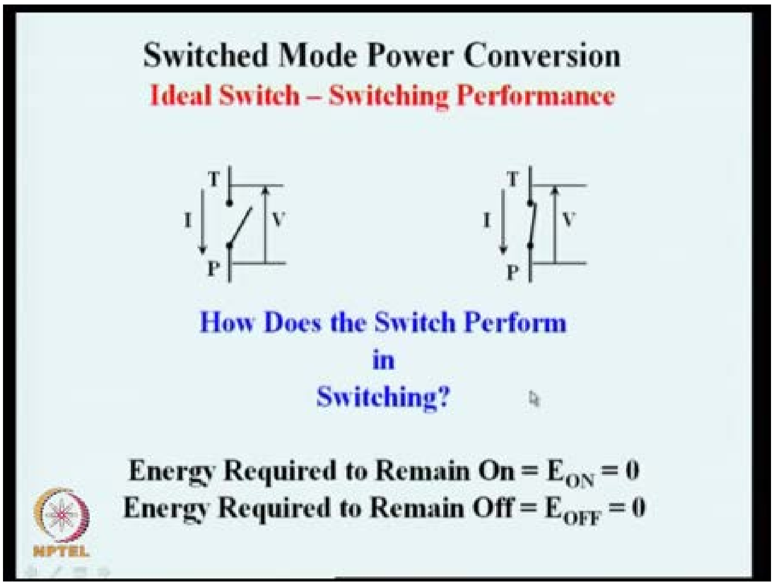

We will see that these characteristics also are related to our efficient power conversion. For example, if a switch has to be kept on to keep it in the on state, the energy required is 0. This is also an ideal characteristics, real switches may not satisfy this condition, we will see about those things a little later. Energy required to keep the switch in the off state is E off that is also 0. So, ideally the switch does not dissipate any power, the switch does not require energy to keep it in the on state or to keep it in the off state.

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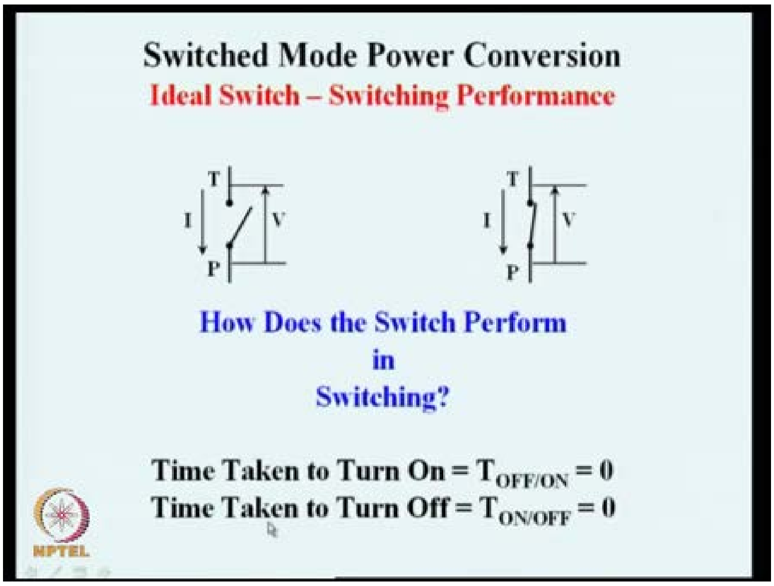

Further the time taken to move from one state to the other off state to on or on state to off, this time is also 0. The time taken to move from off to on or on to off, is also 0, I an ideal switch we will see later that in a real switch all these will be non zero and we will have some minimum requirement as given by the electronic switch that we use or that we employ for carrying out the switching function.

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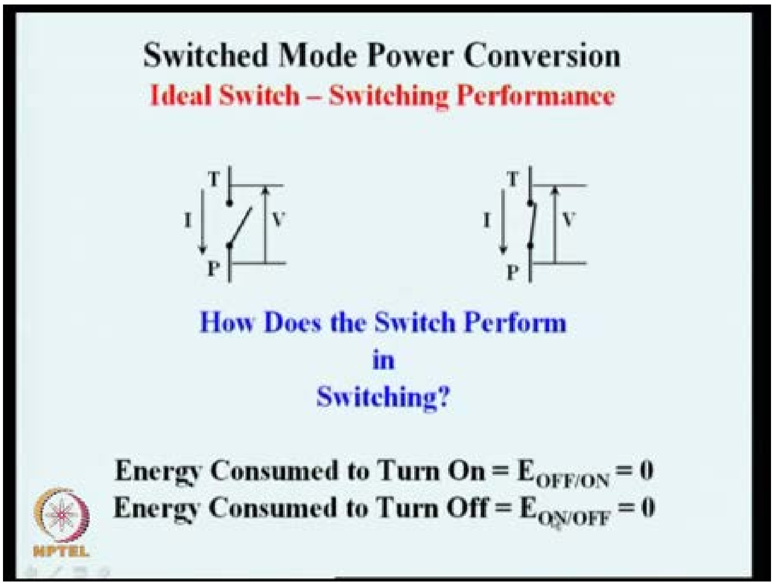

While moving from the one state to the other, state again some power may be dissipated, but in an ideal switch we will notice that the switch in the off state also has no power dissipation, in the on state also has no power dissipation, while its moves from the one state to the other state at every intermediate point also it has no power dissipation. The time taken is 0. These are all the ideal characteristics of a switch. What I have notice noted here is energy consumed while moving from off state to on state or energy consumed while moving from on state to off state is also 0, these are all the ideal performance characteristics of a switch.

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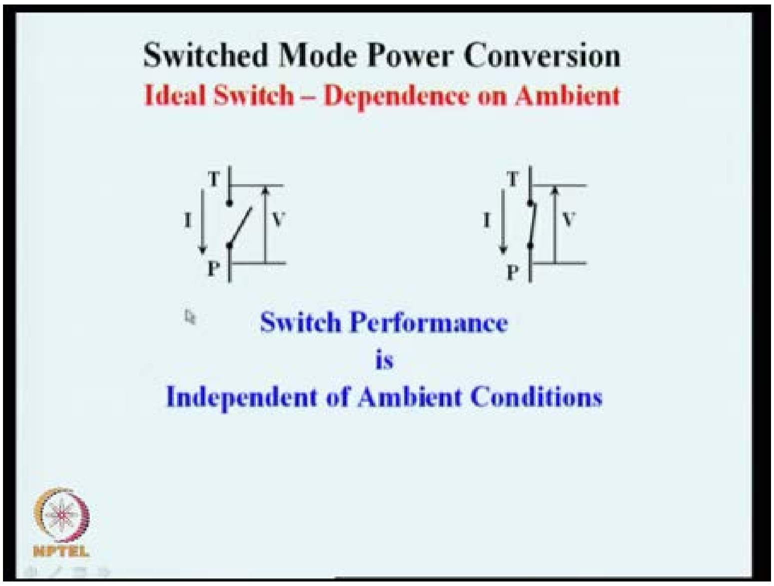

These ideal characteristics are totally independent of the ambient conditions, no matter whether the operating temperature is at freezing point or at boiling point or at any other temperature all these ideal characteristics remain ideal. Since, this is an ideal switch since we also wants to set up certain bench marks against which, real switches can be compared. The ideal characteristics are always always the best characteristics that one can wish for.

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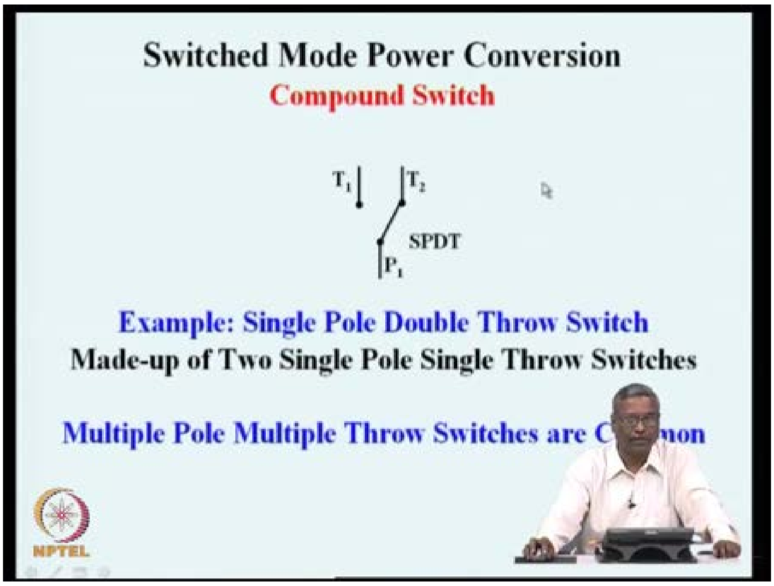

Now, what I see here is a compound switch. In many power conversion circuits a simple on off switch is not what we use we use a collection of switches, which are put in some combination to achieve a compound switching function. What I show here is a single pole, double throw switch T 1 and T 2 are the two throws of the switch and T 1 is the single pole of the switch such a switch is normally referred to as SPDT single pole double throw switch. In a similar way you could have a double pole double throw triple pole triple throw, triple pole single throw. Many possible combinations of poles and throws are possible and such switches are compound switches.

In many power conversion circuits we will use compound switches, but these compound switches will be made up of several simple switches. For example, a single pole double throw switch that is shown here is made up of two single pole single throw switches. The poles are connected in common and throws are kept separately. You will see that a single pole double throw switch can be realized with two single pole single throw switches. In the same way, the single the simple switches that we have seen the simple on off switch that we have seen up to now, can be combined in order to get any number of multiple pole multiple throw switches. In many real applications multiple poles multiple throw switches are quite common, okay?

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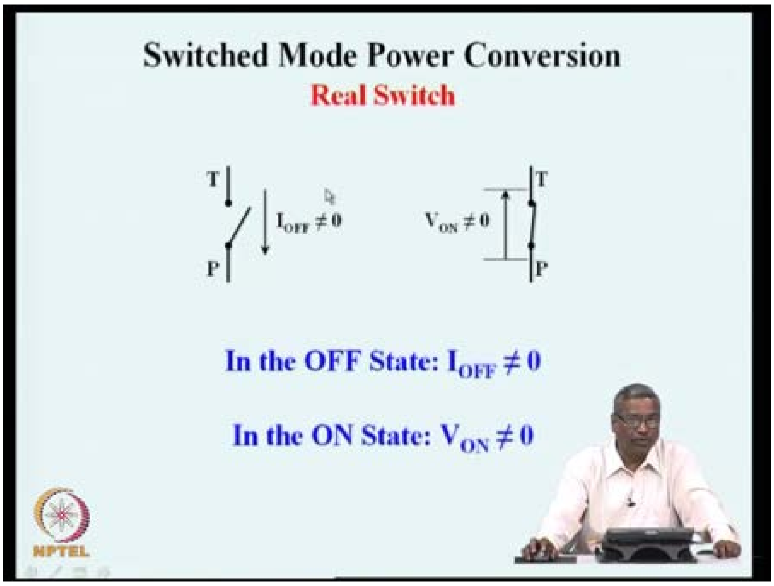

Now, we come to real switches which are used in power conversion. The real switches or the electronic switches made up of components silicon components, which have functions of turning it on turning in off the control functions are also integrated into the switch. Function such switches are real switches, there are several of them and we will see them one by one. So, what we see here is the first real characteristics of the switch? What we had seen as the off state current and the on state voltage which were 0. In the ideal switch in the non ideal or in the real switch both these quantities are non 0 when the switch is off, some small leakage current will be flowing from throw to the pole or pole to the throw one way or the other.

But some small leakage current will be flowing, this leakage current will not be 0 and this off state current we say is not equal to 0. In a similar way in a real switch, when the switch is in the on state the potential of the throw and the potential of the pole are not absolutely equal an account of that the voltage across the switch is not 0 in the on state, but it is a small non 0 quantity. This is the first and the fundamental difference between the real switch and an ideal switch in the off state off state current is not equal to 0. In the on state on state voltage is not equal to 0 the right.

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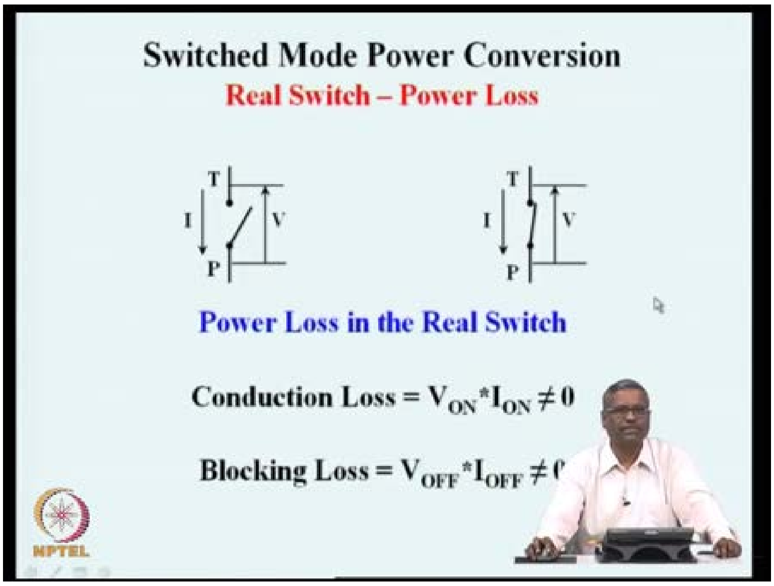

The consequence of this non ideality the consequence of this feature of real switches results in power loss in the device. Ideally the power loss has to be 0. But in real switches, we will notice that the conduction loss is the product of on state voltage and on state current and the blocking loss is the product if off state voltage and off state current. Now, in this real switch the off state current is not 0, but something which is slightly more than 0. Similarly, the on state voltage is not 0, which is a non 0 quantity an account of that both the conduction loss and the blocking loss. Now, will not be 0 an account of that weather the switch is now in the off state or in the on state. You will find that there is a small amount of power loss in the real switch, this is the first and for most difference between a real switch and an ideal switch.

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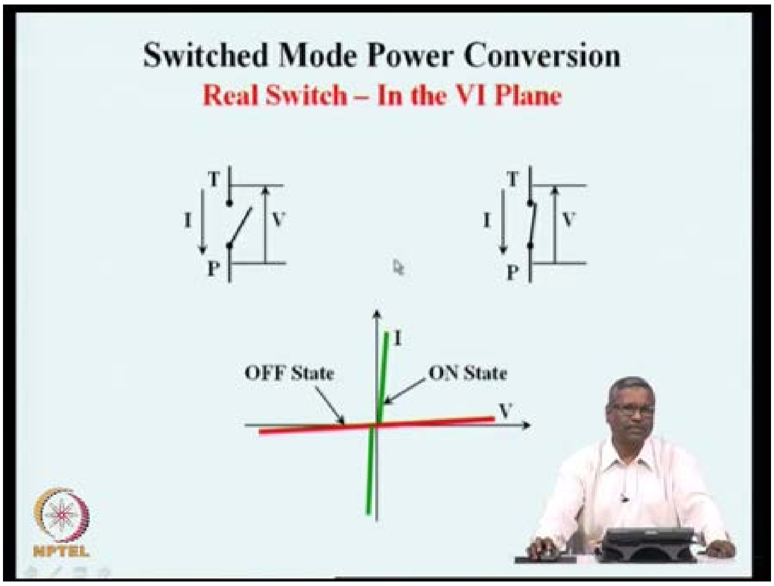

We can also see the operating points of a real switch in the V I plane. We had earlier seen that the ideal switches show the operating points along the voltage axis for the off state and along the current axis for the on state, but real switches have the characteristics very close to the voltage axis and very close to the current axis, but not exactly on the axis. You will notice that when a switch is on there is a small amount of voltage drop when the current is flowing through the switch. Similarly, when the switch is in the off state and it is blocking large amount of voltage, a very small current is flowing that current is a leakage current.

The voltage when the switch is on is known as the on state voltage both these quantities or not 0 and an account of that you will find that on the V I plane. The real switch operating points will now be close to the axis, but not exactly on the axis the off state will be very close to the voltage axis in the on state will be very close to the current axis. You notice that the characteristic shown here as both sections on the positive current and negative current positive voltage and the negative voltage.

So, this kind of operating on all four quadrant positive voltage positive current negative voltage positive current and in a similar way bipolar voltage operation and bipolar current operation give rise to an idea of a switch being either a single quadrant, switch or a two quadrant switch or a four quadrant switch and so on.

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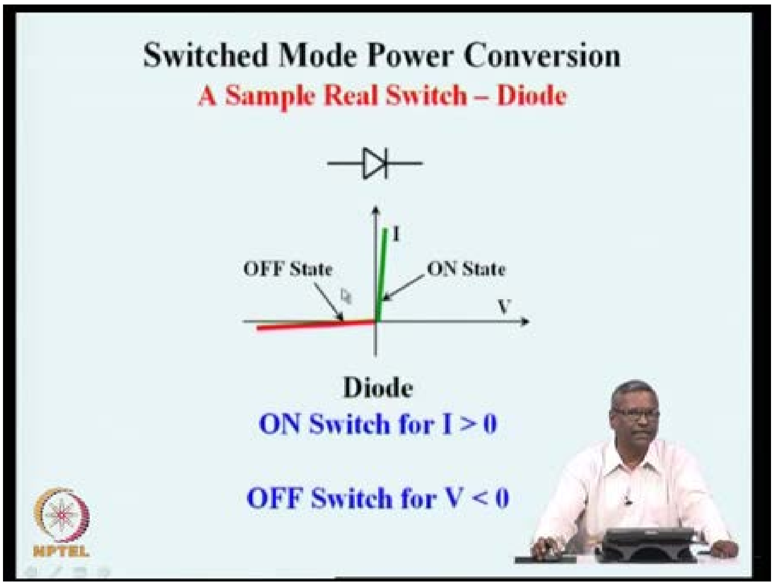

So, what we see here is a one of the real switches a sample real switch which is a diode. A diode has a characteristics, which is shown approximately here in terms of straight lines here a linearised characteristics. It has a section which is in the third quadrant for negative voltages. There is a very small negative current flowing and for positive currents a very small positive voltage drop is there the green line, that you see here is a on state and the red line you see here is the off state characteristics.

Unlike the ideal switch or the real switch with four quadrant capabilities, a diode has characteristics only along the positive current and along the negative voltage directions. The on state of this switch is automatically decided, there are no controlled features control possibilities a diode turns on or turns off, depending on the circuit conditions. There is no control effect that is given to that a switch is on if the current throw that is in the positive direction, the switch is off if the voltage across that is in the negative direction.

So, we see that this diode is behaving like an on switch if the current through this diode is greater than 0 and it behaves like an off switch when it is blocking negative voltages.

What you see here as red line is the blocking state, very small leakage current for very large blocking voltages. What you see here as the green line is the conduction state or the on state where a very small voltage is drop for large amount of current that is flowing.

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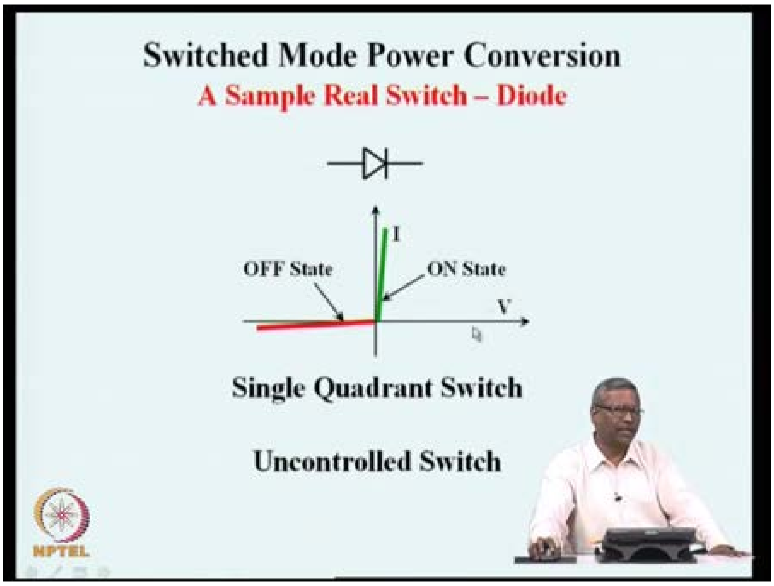

The switch has capabilities to pass positive current and block negative voltage. On the current it is capable of operating only in one direction, positive currents on the voltage it is capable of blocking only in one direction, which is negative voltage. So, this diode is defined as a single quadrant switch, it is capable of only passing positive current blocking negative voltage. We have four quadrants of operation relating to blocking capability of positive and negative voltages passing capability of positive and negative currents.

But in this particular case, you see that the diode can pass current only in one direction block voltage only, in one direction. So, this is a single quadrant switch and another important feature is that in a diode there only two terminals and there are no control possibilities. This is an uncontrolled switch the on state or off state is decided by the external circuit to which this diode is connected.

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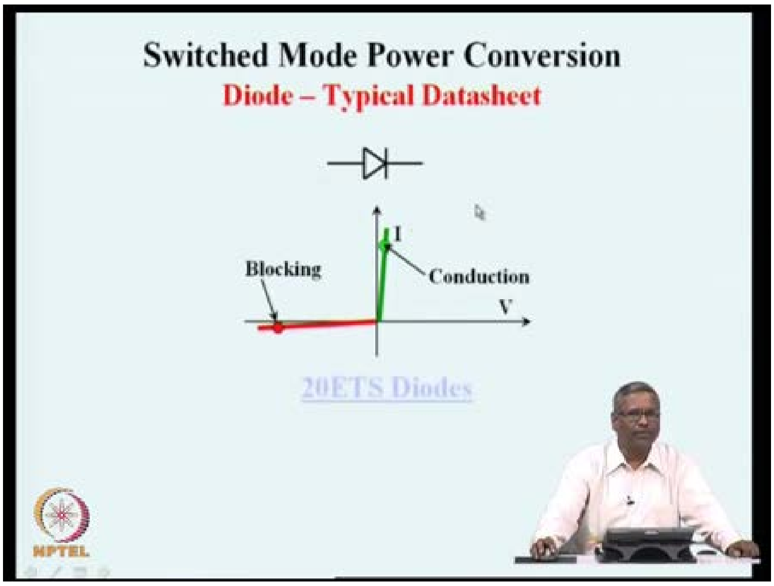

The operating points as you see here you could have a conduction state very large amount of current is flowing with a very small voltage drop, or a very large voltage is blocked with a small current flowing. What I have marked here is the data sheet of one of the diodes in many of these applications reading a data sheet are trying to see what are all the data that is given on a switch, will help us to understand many features of the switch and many application possibilities of the switch?

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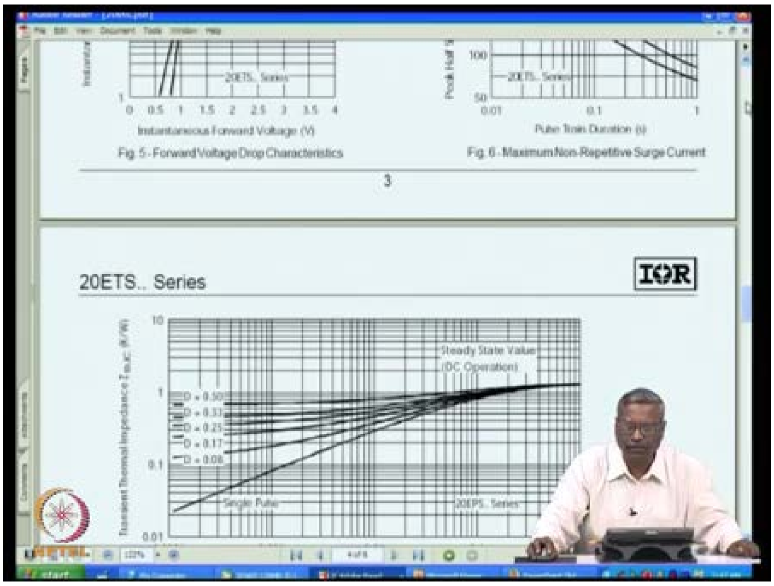

What you see here is the data's data sheet of one of the diodes here, which is designated as 20 ETS series.

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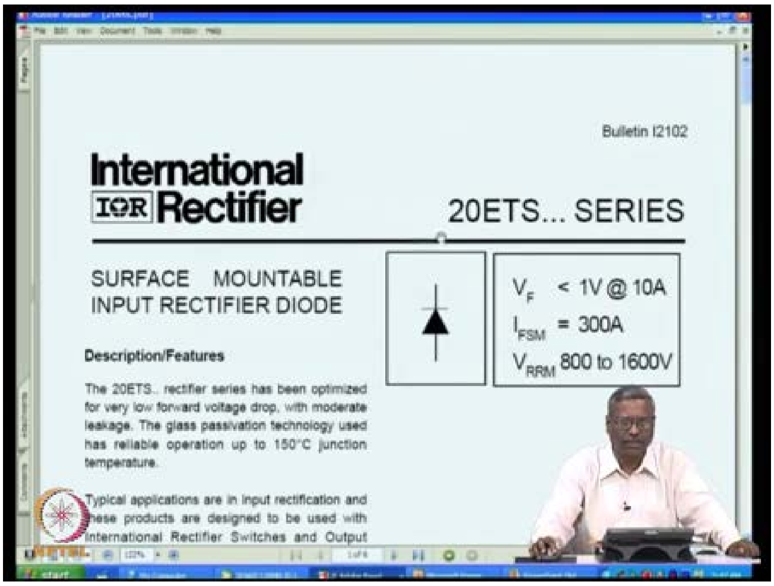

Whenever you see a data sheet, you will see the symbol of the device and you will also see just a small very short description. For example, this device has a forward voltage of a about one volt at 10 amperes this is the conduction state. A conduction state is the condition where for a low low voltage drop a devices capable of passing large amount of current. Then what you see at the bottom line here is the reverse blocking voltage. This devices capable of blocking voltages rise from 800 volts up to 1600 volts in this 20 ETS series. There are several diodes, there is diode which can block 800 volts and in the same series there will be some other type number, which can block 1600 volts. If you see the diode characteristics, the shape of the device is seen here.

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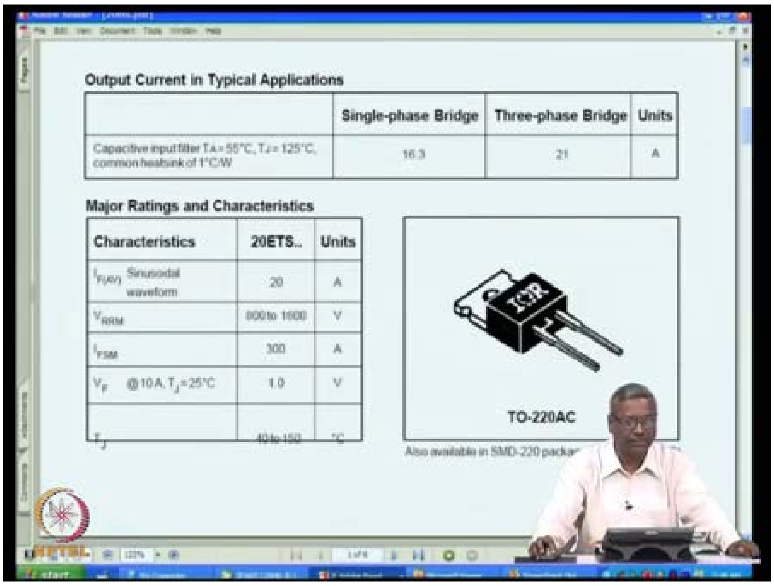

You can see that this device is capable of passing an average current a sinusoidal current with an average value of 20 amperes. It can block a voltage of anywhere between 800 to 1600 volts and it can take a surge current IFSM, a surge current which is almost 10 to 15 times the rated current. Then you see the on state voltage when the switch is conducting the voltage when the current is 10 amperes is about 1 volt. This is about the environmental condition that the switch is capable of operating anywhere from 40 degrees to 150 degrees. If you again see a little more on the on the data sheet on the next page.

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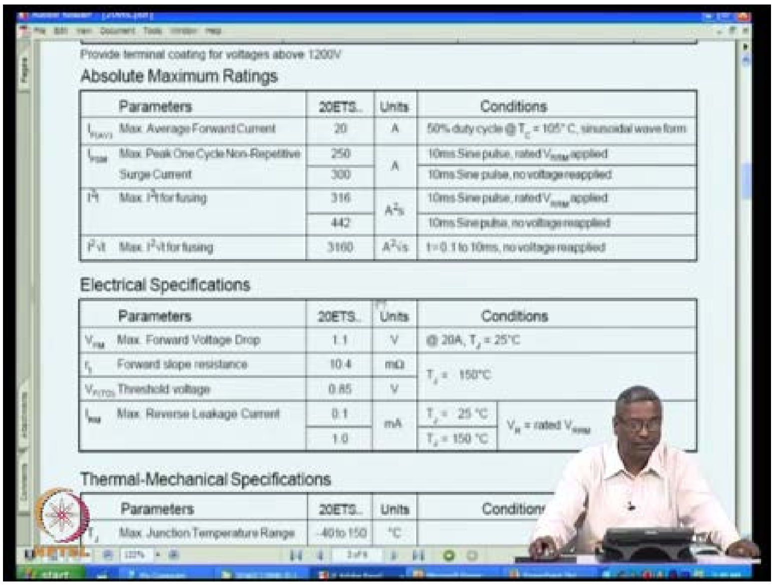

You will see that the electrical specifications maximum forward voltage is 1.1 volt at 20 amperes. Normally, this particular line corresponds to the on state of the switch or the conduction state of the via switch, when 20 amperes of current is flowing the voltage drop across the switch is about 1.1 amperes the bottom most line here, that you see here. It says the reverse leakage current when rate at voltage is applied when 800 volts is apply, this will have a reverse current of about 0.1 milli amperes at 25 degrees junction temperature or 1 milli ampere at 150 degree junction temperature. Now, these are the short features of the diode.

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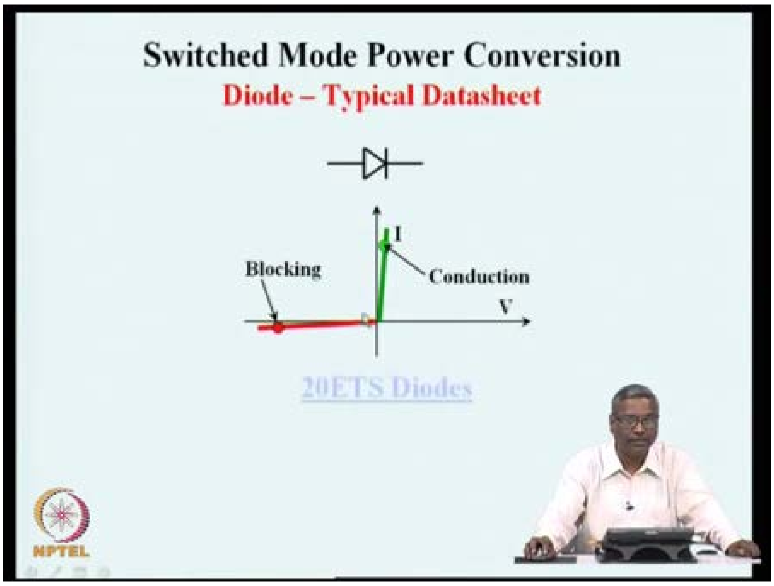

As we had seen in the characteristics the conduction point 1.1 volts at 20 amperes and about 1 milli ampere at about 800 volts. These are the important characteristics, there are few other things which we will see a little later. So, a data sheet of the devices is a good recourse material from which many things one could learn we will come back to this data sheet a little later.

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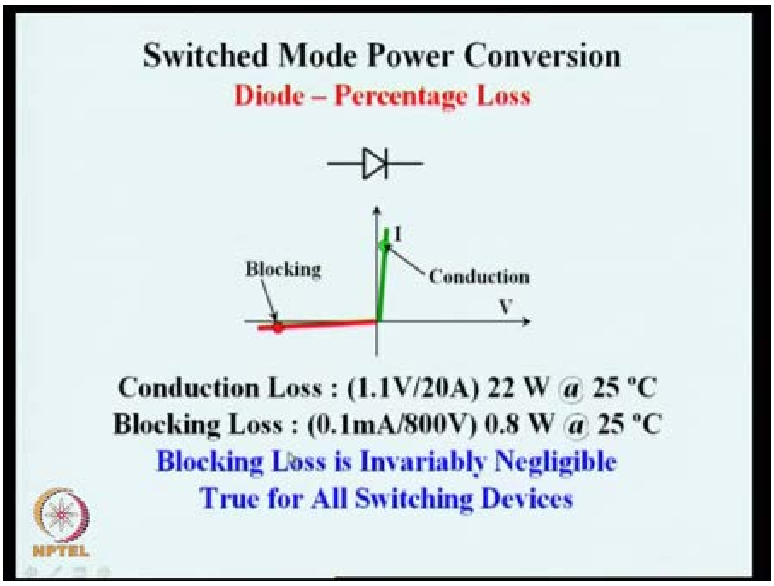

Now, we have seen that in this particular data sheet the device has a drop of 1.1volts than passing a current of 20 amperes at a temperature of 25 degrees and the blocking current is about point 1 milli amperes at 800 volts at 25 degrees. So, you can see that the loss in the device during conduction and during blocking can be seen here as 22 volts when the device is conducting and 0.8 volts. May be devices blocking. Another important thing that we can see this switch is capable of switching 10 20 amperes and blocking 800 volts, so in a way you can save that the switch can switch a power of 20 into 800, which is equal to 16,000 volts a 16 kilo volts of power can be switched by the switch.

That is you can block a voltage of 800 volts. Under that condition you can switch a current of 20 amperes, so that is equivalent to a power of 16 kilo watt being controlled 16,000 watts is being controlled by this diode, but you can see that in relation to 16,000 watts. While the device is on it drops just about 22 watts, which is less than about or just about one tenth of 1 percent the conduction loss is one tenth of 1 percent. So, you can say that this diode is almost as good as an ideal switch it is controlling a power of 16,000 watts.

But the loss inside the switch is just about 22 watts in conduction, but in blocking that loss is even less it is about 20 times less than what we had seen before if the conduction loss was one tenth of 1 percent. This is again one twentieth of that, so roughly the blocking loss in almost all types of switches will be definitely a few orders of magnitude less than the conduction loss in many cases, blocking loss is invariably totally negligible in comparison with conduction loss. So, we will consider almost all the switches to be almost ideal in blocking and a little less than ideal in conduction.

Even in conduction you see that the dissipation is only 22 watts in comparison with 16,000 watts, which is being controlled. So, this type of comparative numbers in terms of losses in comparison with power process is important because that is what is going to decide the overall efficiency of the power converter. This is a point which one has to keep in mind, okay?

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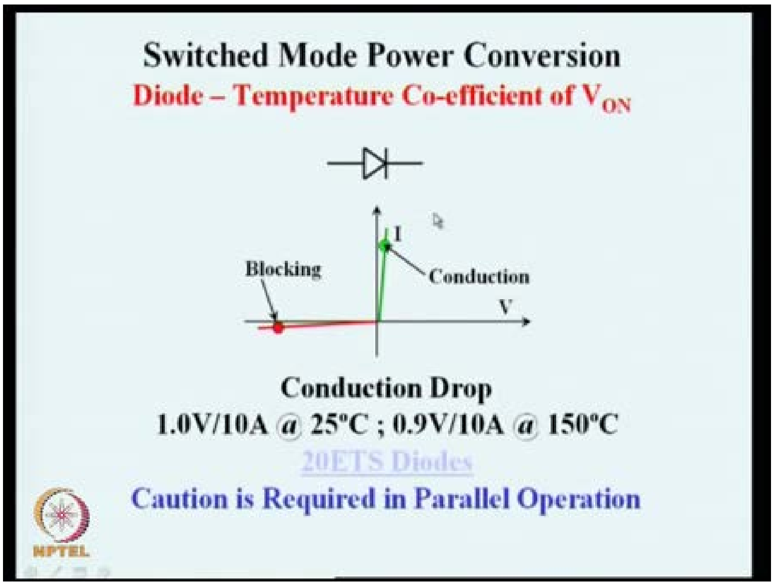

So, now there is another little feature which one has to see what I had shown here as the temperature co efficient of the on state. From the data sheet one can see that, at 25 degrees the conduction drop is about 1 volt at 10 amperes and the same device at one fifty degree junction drops 0.9 volts only at 10 amperes. So, this is a feature which is seen by the fact that as temperature goes up for the same current the voltage drop falls. This has a very important significance, because if you put several diodes in parallel and try to pass larger amount of current.

Suppose, I put 2 20 ampere diodes in parallel and try to use it for 40 amperes, then this temperature co efficient is an important feature, because it has a negative temperature co efficient. That is as the temperature increases the voltage across the device drops parallel connected devices will not have stable operating points. For example, if one of the devices becomes a little hotter that device will have a smaller voltage drop. So, it will draw still higher current and it will become even hotter and eventually one of the devices will fail. Now, this is a feature one has to keep in mind whenever parallel operation is done diodes have negative temperature co efficient. This is an important feature when you wish to operate devices in parallel.

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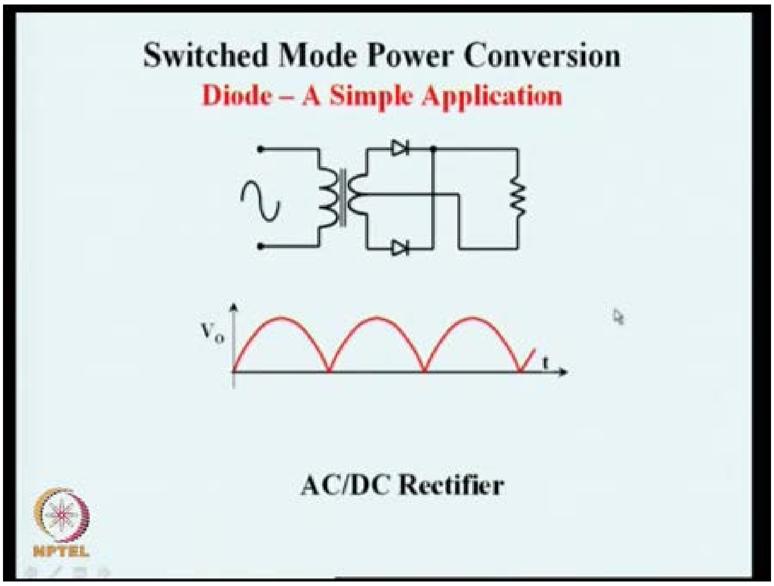

This is a very simple application of a diode as a switch, what we have here as the input is an AC source through a transformer given to a secondary, which has a centre tap which is connected here. The two secondary output points are connected through two diodes to common points and connected to the load. This is normally refer to as the full wave rectifier single phase input full wave rectifier, so the AC quantity which is vary in both positive and negative by this certification action is available to the load as a purely, as a purely unipolar voltage.

This will have certain average voltage and that average voltage is what is now across the resistor. So, this application is an AC to DC rectifier. The rectifier is the generic name for any power converter, which converts AC to DC and this is a simple diode rectifier operating as a single phase full wave rectifier.

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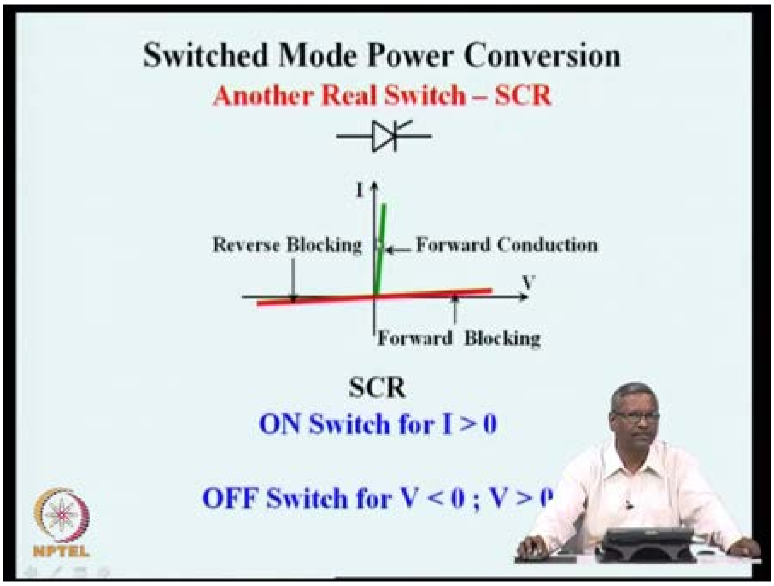

We have now the second real switch of a whole family of switches. This is another real switch which goes by the name of silicon controlled rectifier or in short SCR. It has the same symbol as a diode along with a control grid, control gate connected to that. This is a switch which has some control possibilities, it has an anode and a cathode two terminal just like a diode, which are the power terminals. It has a pair of control terminals, which is the cathode plus the gate. This cathode is a part of power terminal as well as control terminal anode is the power terminal and the gate, which is the third terminal is a control terminal.

The V I characteristics of an SCR has three sections, a one line which is crossing both positive voltage and negative voltage region for very small amount of current and this particular line is the blocking state of the device. Both reverse blocking and forward blocking. This is one stable state of the SCR. SCR also has another name know as thyristor. So, thyristors have one stable state which is the off state. In the off state, it can block positive voltage as well as block negative voltage. So, that is the blocking state very close to the voltage.

Axis very small amount of leakage current and a large blocking voltage, the SCR has an another state, which is the forward conduction. State current in this can only flow in one direction from the anode to the cathode, which is the positive current. There is no characteristics corresponding to negative current. So, the positive current section has a very low voltage drop this section of the characteristics is when the operating point is on the very close to the current axis and with very small voltage drop. So, this switch SCR is an on switch for positive current if it has been gated on. We have gate terminal here if a small current is injected into the gate with respect to the cathode, a device will turn on. Once it is on, it is in the on state in the on state it has a characteristics, which is very close to the current axis.

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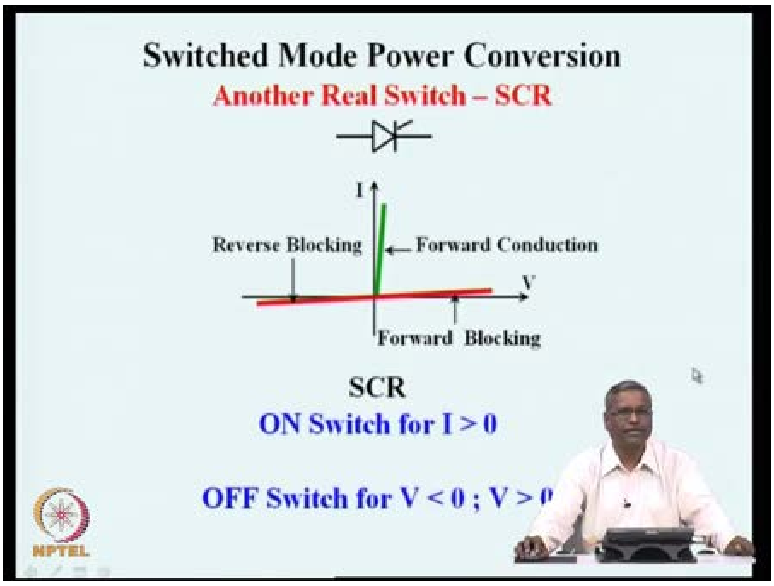

In the off state is when in the off state the device has not been triggered on the gate. The cathode are connected together or no current flows to the gate and cathode and the device is in the blocking state. In that state both positive voltage and negative voltage can be blocked so this is an on switch for positive current and off switch for both positive voltage and negative voltage.

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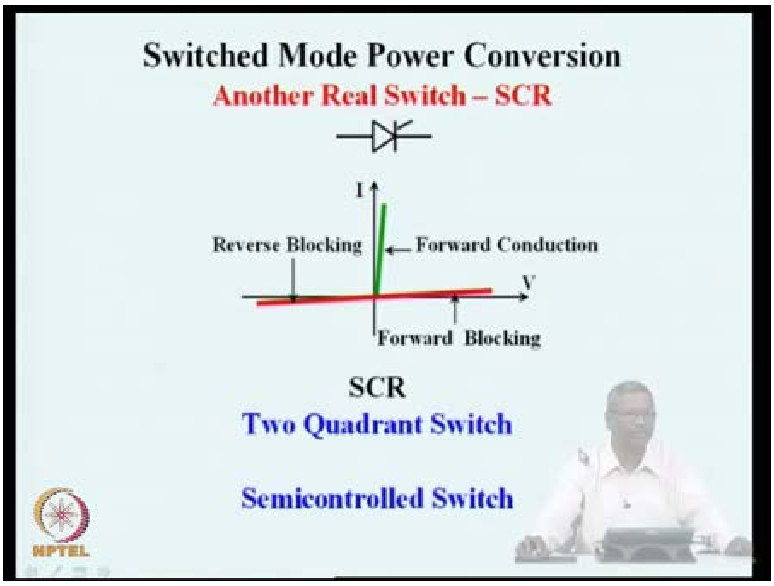

So, you can see that this is now a two quadrant switch, it can block both positive and negative voltages, but it can pass only current in one direction, so it is a two quadrant switch. This is also called as a semi controlled switch because the control can be only in one direction. You can by giving a pulse to the gate you can turn on a thyristor, but you will not be able to turn it off once it is in the on state. So, it can be turned on but it cannot be turned off.

To turn off a thyristor, it is necessary to make the current through the device go to 0, so that the device will regain its blocking characteristics. So, in that way a thyristors switch or a semi a silicon controlled rectifier is a semi controlled switch. It can be only control to turn it on, but you cannot control it controlled to turn it off and it is a two quadrant switch because it can block voltages both positive and negative, but it can pass current only in one direction.

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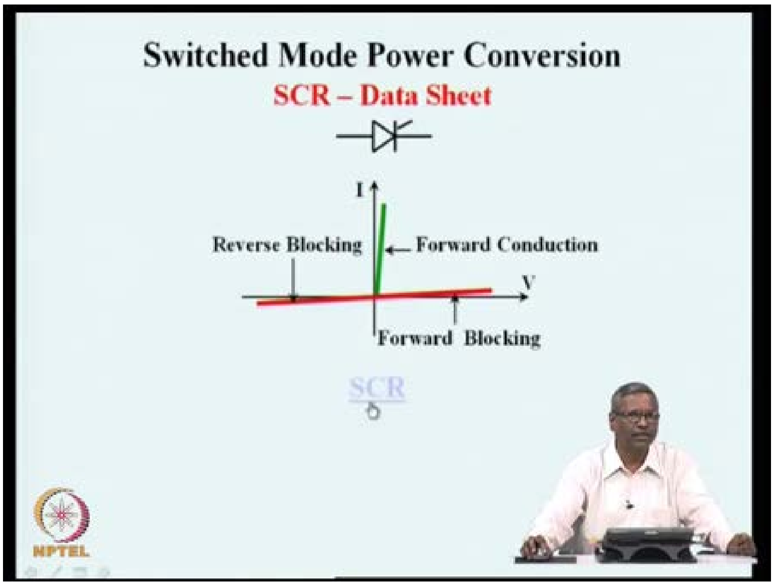

So, what we see here is a data sheet for a thyristors similar to a diode. The thyristor has an on section here and an off section, which is both positive and negative. There is a data sheet which is available for the thyristor.

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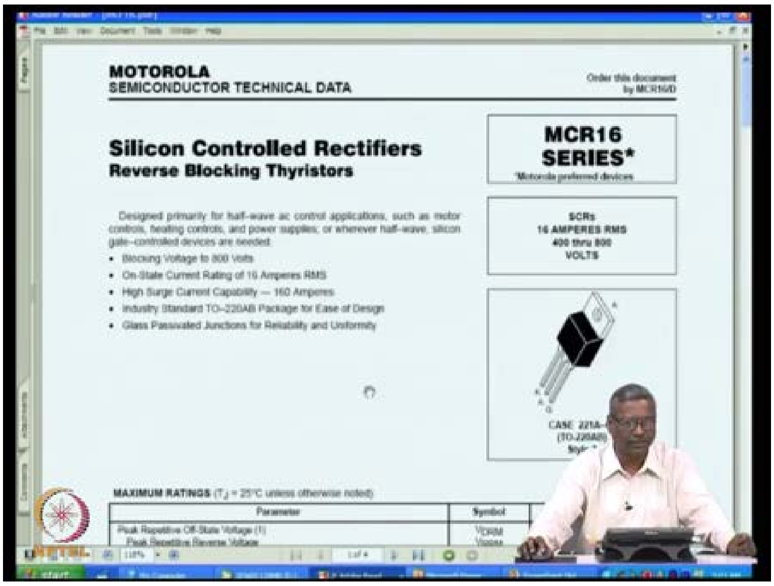

This is made by the semiconductor manufacturer Motorola, it goes by the series name MCR 16 and you can see the short feature of this switch SCRs 16 amperes RMS 400 to 800 volts. So, this device is capable of blocking voltages anywhere from 400 to 800 depending on the type number in the series one of the lowest series number will block

400 volts and a highest series numbers will block up to 800 volts. But all these devices can pass 16 amperes of current and this is how the package is the device is packaged it has a for anode, k for cathode and g for gate.

This tab which you have here is also connected to the anode. You will see a little later about the heat dissipation part. Some of the important specifications are here, blocking voltage up to 800 volts on state, current ratings of 16 amperes RMS high surge current, capacity which is almost 10 times the rated current. Industry standard package, this kind of package is known as to 2 20 package, which is very popular package and other features are relating to the process which is done.

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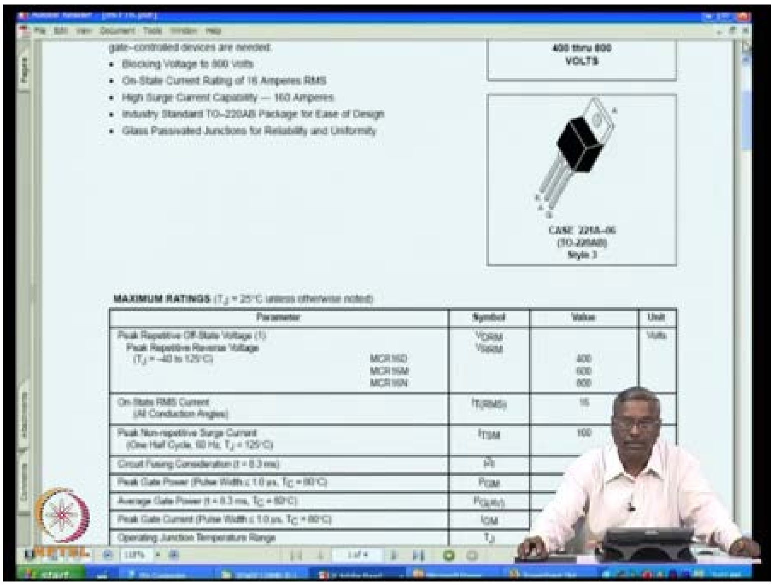

Let us see a few points, for example, this series MCR 16 D can block 400 volts, MCR 16 N can block 800 volts that is what is met by 400 through 800. In this series you have three types MCR 16 D, MCR 16 M and MCR 16 N and they correspondingly block 400, 600 and 800.

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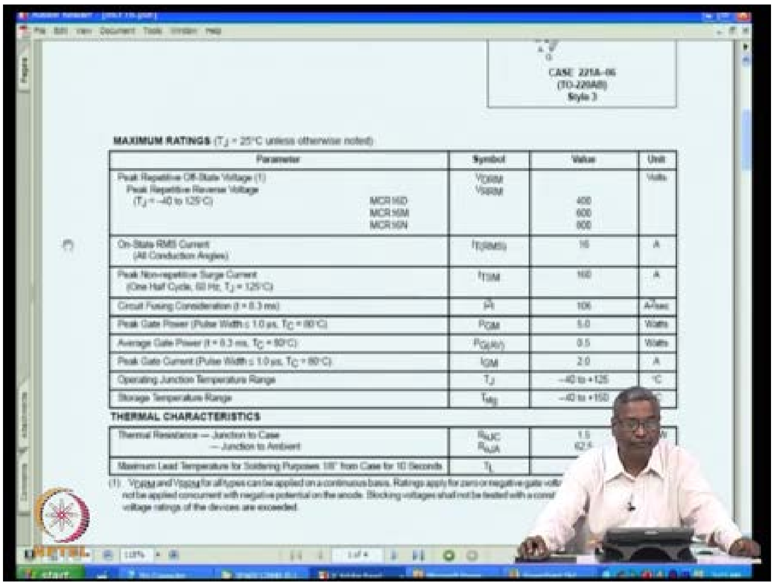

What you see in the next line is the on state RMS current is 16 amperes. It can carry a current whose RMS rating can be SIS 16 amperes. Peak non repetitive surge current that is currents, which are not repeating, repeating continuously, but for one time a large amount of current which is of the order 10 times rated current is is a loud in such devices. You will come back to this specification a little later.

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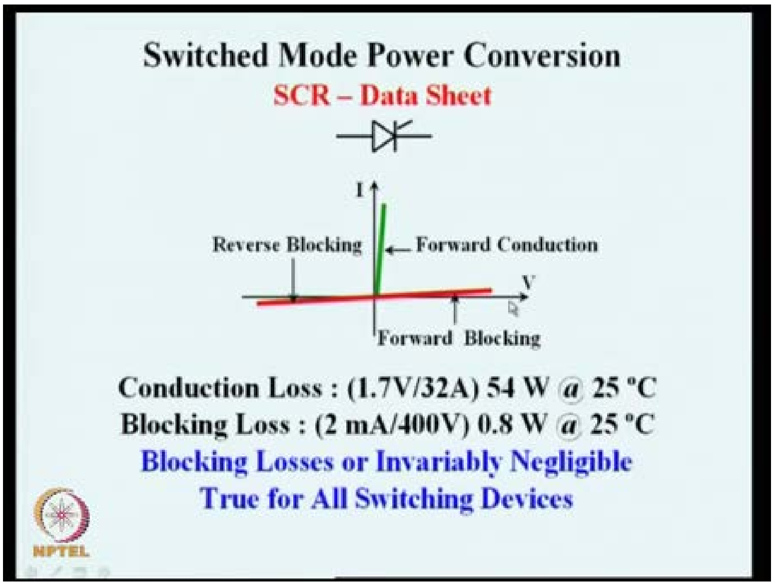

So, what we see here is a two quadrant switch; blocking positive and negative voltages, passing positive current, additional feature of controls in one direction. So, from the data sheet it is possible. Let us go back to the data sheet and look at one or two of these numbers on the losses.

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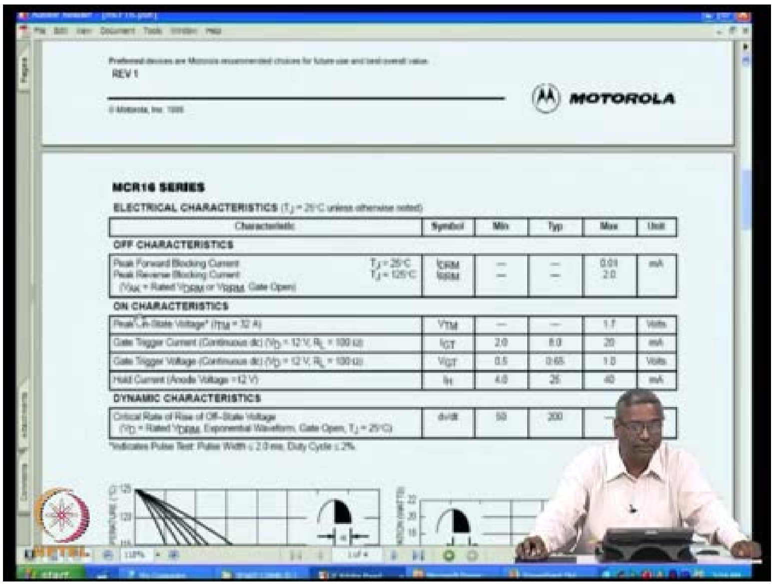

For example you see that peak on state voltage at a current of 32 amperes is 1.7 volts. Then the peak reverse blocking of 800 volts and whatever is the rated reverse blocking voltage the current is of the order of 2 milli amperes at 125 degrees and 0.01 milli amperes at 25 degrees. These are the important points, so if we go to the next one you can see that conduction loss is now 1.7 volts at 32 amperes corresponding to 54 volts. 2 milli amperes at 400 volts corresponding to 0.8 volts, but the power that can be switched is the product of full voltage and full current, 400 volts and 32 amperes.

That is almost 12 kilo vat of power on 12,000 volts the dissipation is only 54, which is less than 1 off of a percentage less than off of one hundredth, 1 by 200 times. The power that can be transferred through the switch is what is lost in the switch itself during conduction. During blocking, it is even less if 54 volts conduction loss is 1 by 200 times the full power. The blocking loss is even almost 1 by 50 times the conduction loss. So, as I said before the blocking losses are almost always 0 for all switching devices. This is true that in blocking you might consider that all switches are rectically idea.

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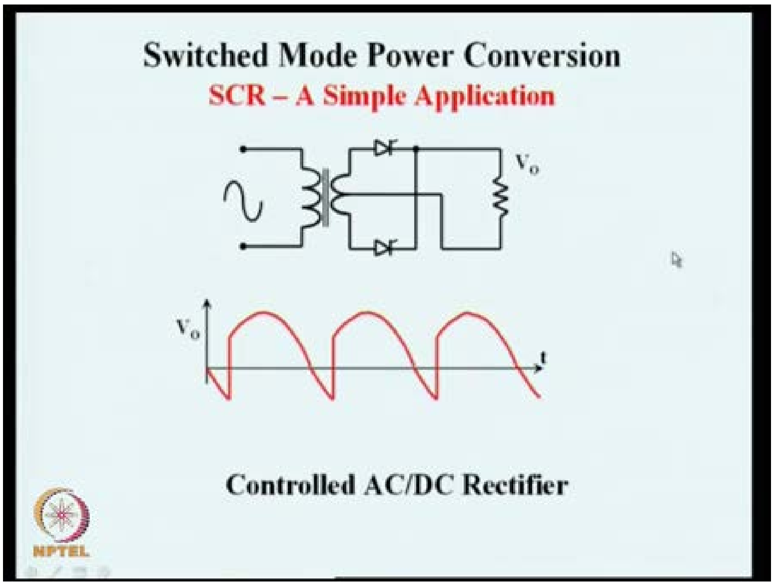

So, this is an application of a controlled AC to DC rectifier. What we had seen a rectifier is a device which converts AC to DC the same kind of circuit, the diodes are replaced by thyristor and the load is an inductive load. So, it is possible now because of the gate control that is available, instead of allowing in in the case of a diode conduction is always at the start of the cycle, because diode has no controls. But in the case of a thyristor, we can delay the point at which the thyristris turned on.

So, by delay in that it is possible to get a controlled voltage, which is the output voltage here. This controls angle decides what will be the output voltage, the output voltage can be controlled right from full positive to full negative through the gate control. This is a controlled AC to DC rectifier. The silicon controlled rectifier in this particular application is working as an AC to DC rectifier with a controlled output voltage.

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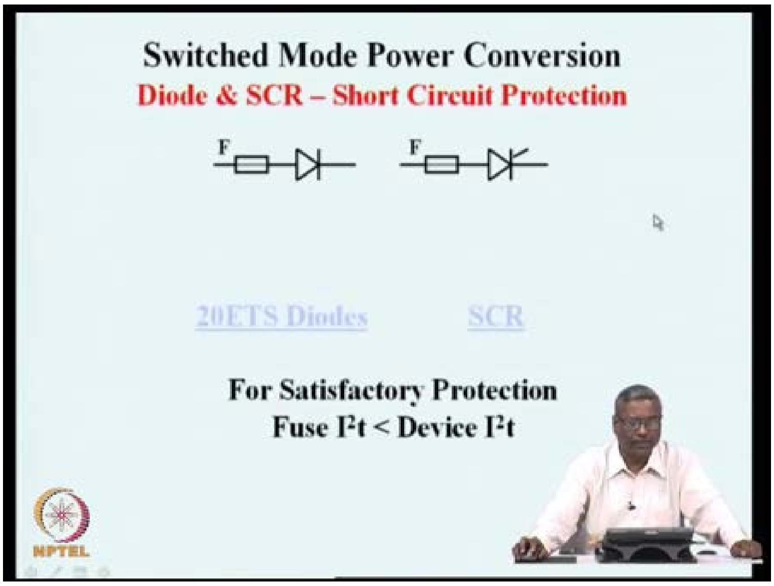

Now, another important point in the data sheet that I wanted to showed to you is, what is seen here is I square t rating.

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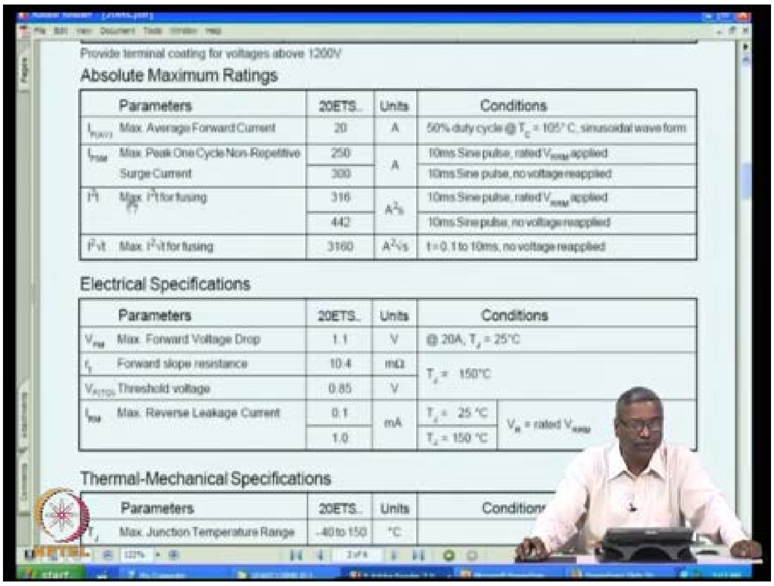

In all the data sheets of semiconductor devices like diodes and thyristors, you will see one number known as I square t is for fusing and that number as given as about 316 amperes square second 442 amperes square second for different kinds of conditions. Now, what this particular data is important? It is important for protecting the device.

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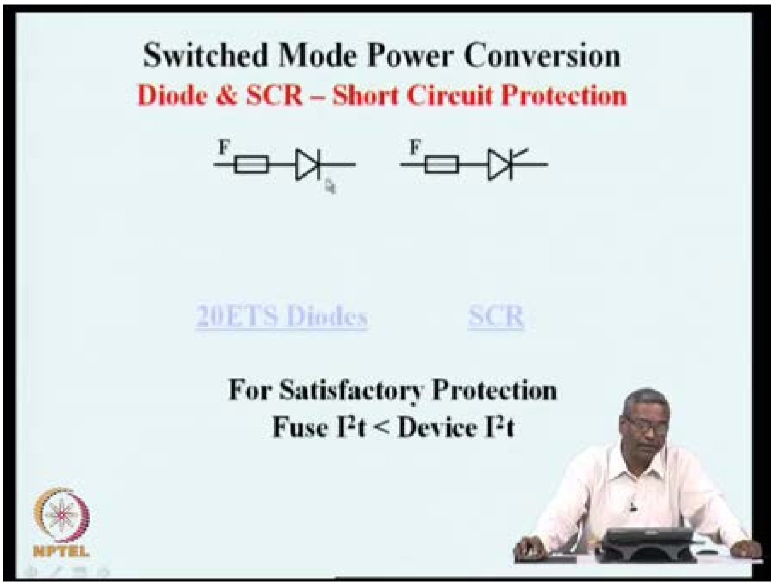

For example, if I wish to protect a diode or protect a thyristor, we had seen that this diode is capable of carrying a surge current of 320 amperes. The thyristor what we had seen was capable of having a non repetitive peak current of 160 amperes. What have once if still larger amount of current flows through the device, the device will get damage. So, in such conditions it is necessary to provide protection to the device and what we show here is the fuse protection. Is fuse is connected in series with the device, a fuse is connected in series with the device, fuse invariably is just a piece of metal, which will melt when a large amount of current is flowing through that by melting and opening it will protect the device.

By using a small inexpensive piece of fuse wire it is possible to protect the expensive device by using an inexpensive fuse wire. That is a principle of protection here. In such protection it is necessary to make sure that the I square t rating of the fuse; that is the quantity of the product of square of the current and the time for which the current is flowing that is what is known as fuse I square t. Whenever a fuse specifies that it has certain I square t, you can take it that when the I square t exceeds that number the fuse will melt and break. The device I square t is the number, which will damage the device.

So, if you put both of them in the series if the fuse I square t is less. Then the device I square t, so even before damage occurs to the device the fuse will kill itself, will destroy itself. But, protect the more expensive power device that is the principle of protection and both for the diodes the I square t numbers, which are given are useful for such protection.

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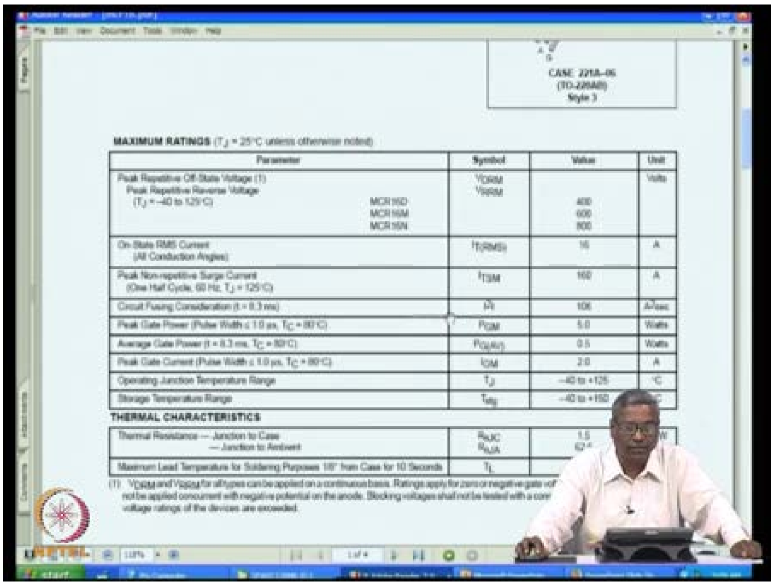

In the same way for the thyristors also you will find a number which is known as I square t circuit fusing consideration I square t 106 amperes square second.

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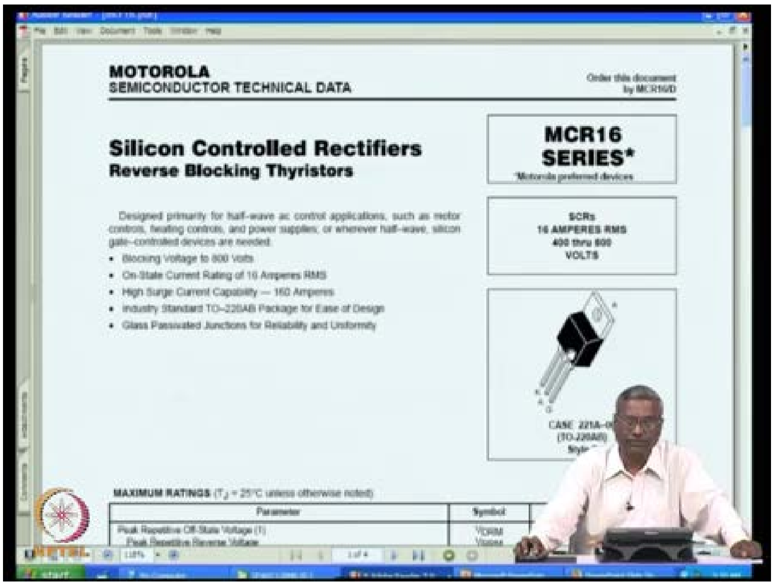

So, this is the i square t for this device, so long as we use a fuse whose i square t is less than this number…

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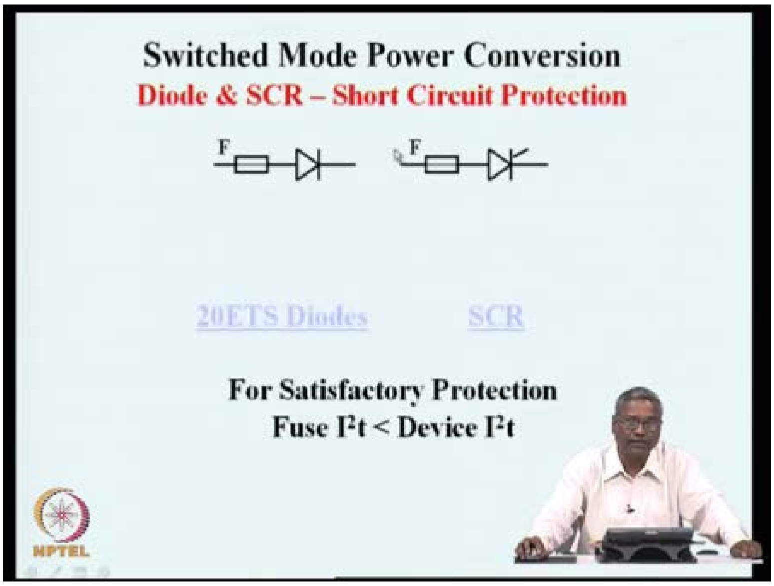

Then in a connection like this, this the fuse will protect the device this is the principle of protection for the device.

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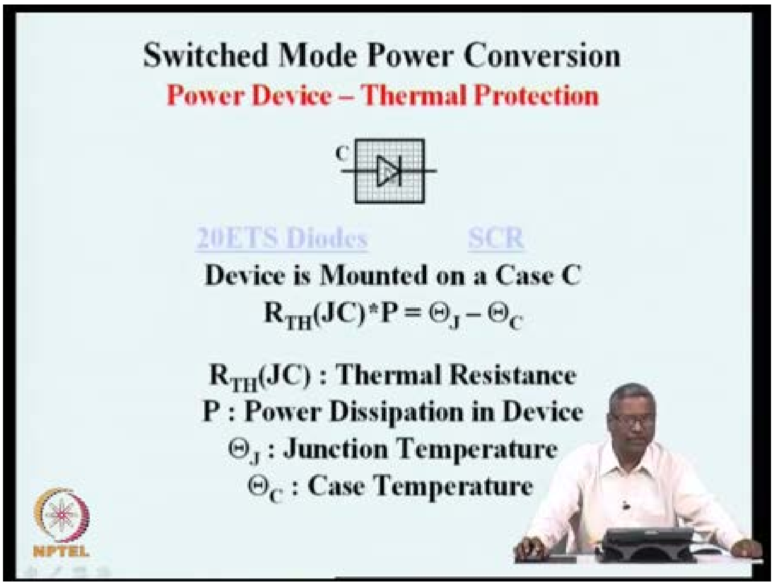

Now, there is another important characteristics which one has to take care of what we had seen is that, these devices ideally should not dissipate any power. But we had seen that the diode was dissipating about 22 watts 1.1 volts at 20 amperes or the thyristors was dissipating about 54 watts 54 watts, which was about I think 1.7 volts, so what about 30 amperes current. So, in all these cases, there is a large amount of power dissipation taking place in the device. The power dissipation is not large when compared to the power that is deliver to the load, but it is large in itself compared to the mass of the device, compared to the size of the device, the dissipation that is taking place in the device.

A 54 watts in the case of this SCR or 22 watts in the case of this diode is quite large. So, it is necessary to protect the device against such large power dissipation the consequence of a large power dissipation is that this large power will get converted into heat on the device and this heat, if it cannot be carried away will heat of the junction of the device. When the junction reaches the maximum limit the device will get damaged. So, in all this cases to protect the device from large increase in temperature junction temperatures, we use what is known as a thermal protection device or what is known simply as a heat sink.

The devices mounted on a large piece of metal, which will carry away the junction heat to itself. Then transfer the heat to the ambient over a period of time so such thermal protection requires a heat sink to be mounted on the device the device will transfer its heat to the heat sink. Heat sink will throw the heat to the ambient, in such cases the data sheets again will tell us some quantity, which is known as thermal resistance of the device for example, let me see this diode.

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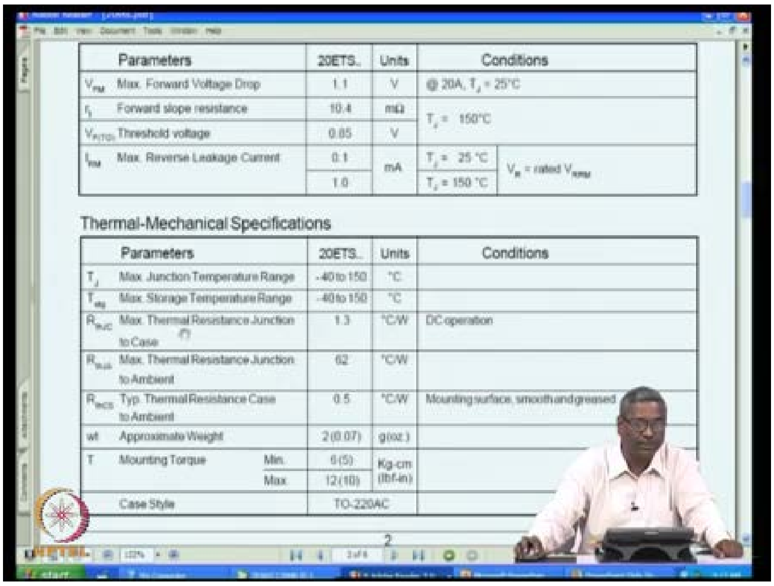

The diode has thermal resistance of junction to case, which is one point three degrees per watt. So, what this mean is that if 20 degrees 20 watts of power is dissipated in this device? 20 watts into this 1.3 degree centigrade per watt, which is 26 degrees 20 into 1.3 26 degrees will be the temperature difference between the case and the junction. So, if you wish to dissipate that kind of power it is necessary to maintain the case at a temperature, which is satisfied by this condition and for that purpose only we mount it on a heat sink. Now, we can go back to this and see the condition.

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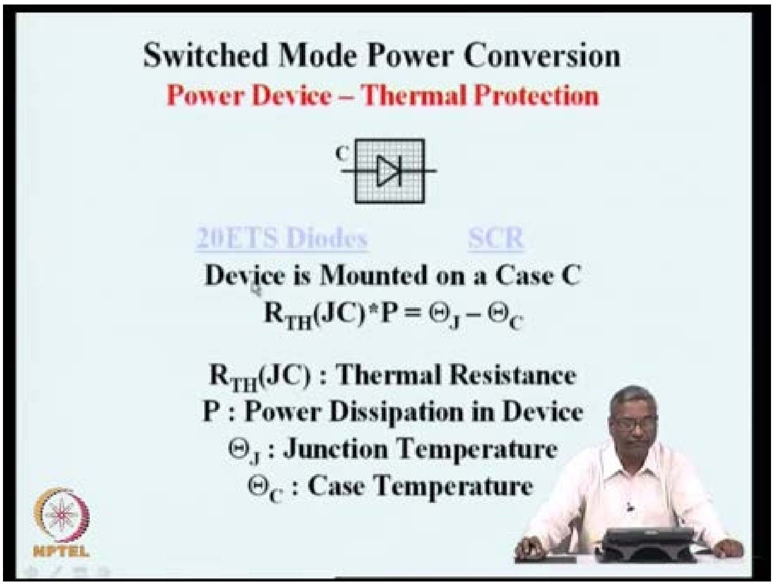

Supposing, if the device is mounted on a case the thermal resistance of junction, to case multiplied by the power dissipation will be the temperature difference between junction. Case this is a mathematical relationship between the junction temperature case temperature power dissipated. Also, what is the device characteristics, what we had just now seen as 1.3 degree centigrade per watt. This R TH is defined as thermal resistance P is the power dissipation in device, theta J is the junction temperature, theta C is the case temperature.

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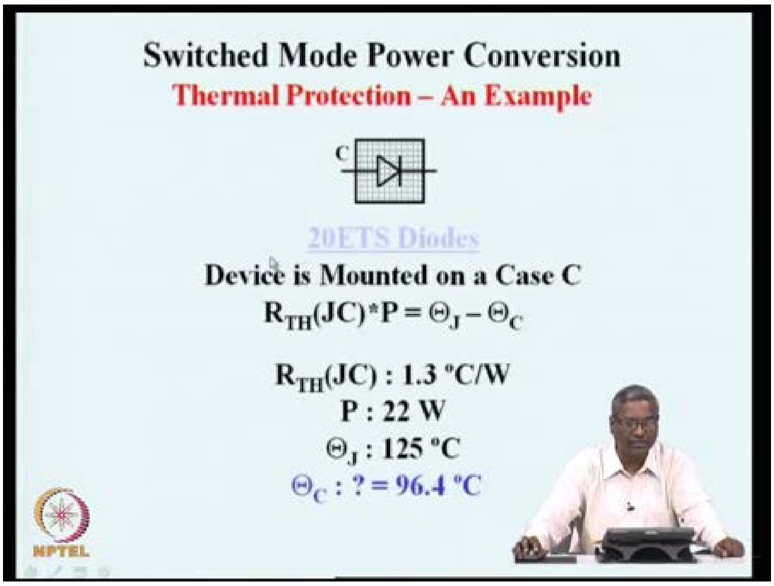

If we come to this particular example, where the thermal resistance of the junction to cases 1.3 degree centigrade per watt and power dissipated is 22 watts and we also know that in this particular case, you can see that the junction temperature can go as high as about 150 degree centigrade, a maximum junction temperature is 150 degree centigrade. So, we might like to safely operate the junction at 125 degrees, which is a little 25 degree less than the maximum.

In such a case this relationship tells us that the case temperature should not be more than 96.4 degree. So, if you mount a piece of heat sink, which is capable of maintaining the temperature at or below 96.4, the device will be thermally protected. Later on we will see a little more about the thermal designs as we get to know about circuit design through examples.

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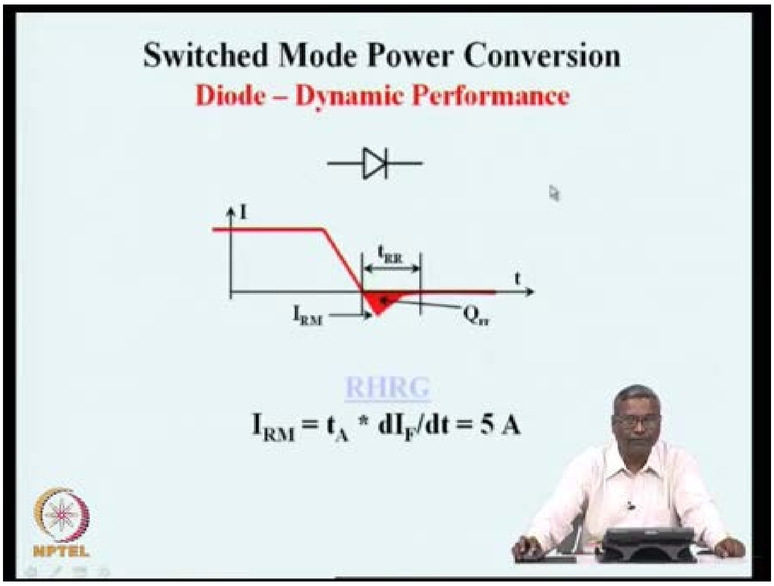

Now, another dynamic performance that one has to take care of is in the case of diodes is what is known as the recovery time? The conduction and blocking or the performance relate into steady state, but whenever a device a diode moves from an on state to an off state, we notice that this is not an instantaneous process there is a time required when the positive current comes down to 0 for a duration, which is known as reverse recovery time. The device does not block the device continuous to current continuous to pass current in the opposite direction for a small time.

This opposite current flows for a duration known as reverse recovery time. During that time negative current flows through the device that is current in the opposite direction to the arrow flows for a very short duration, which is reverse recovery time. During that time some charge storage is taking place in the junction which is Q RR. Now, this properties or again related to the dynamic performance, how long does it take for the diode to recover from this instant when you have decided to stop the current? The device takes certain amount of time which is known as reverse recovery time.

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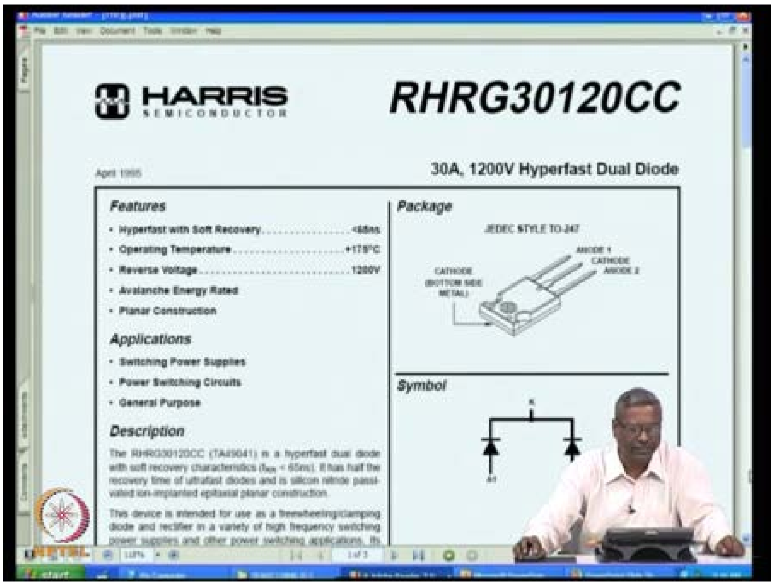

For example, in this data sheet, which is a fast device you can see that the recovery takes 65 nano seconds. That is the time taken for the device to recover. This is one of the important characteristics of the device, which one has to remember. As you start using at higher and higher frequencies, this reverse recovery time becomes important, because whenever a device stops conducting before again it can carry current, you must allow sufficient time for the recovery to take place. For example, in this particular case the device recovery is given by, let me see the data sheet yes, the recovery process is shown here.

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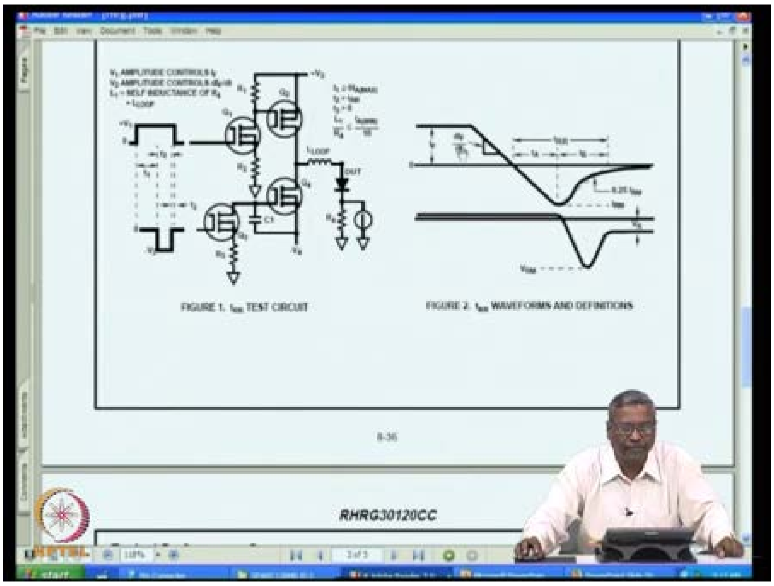

With a certain DIF by D t with a certain slope here and A time, so these numbers are all given for this device in the data sheet, so from this given numbers you can see that when the device recovers, this is a 20 ampere device. Let me see, yes. This is a 30 ampere device, so you can see that during recovery it passes current in the opposite direction for almost 5 amperes. So, we will stop here now with this session where we have seen about the ideal and real characteristics of the switches, diodes and SCRs and some of the dynamic and steady state performances. In the next session, we will continue with the same topic and go on into controlled switches, 4 quadrant switches and so on. So, that will be in the next session.