Switched Mode Power Conversion

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Lecture - 4
Prior Art

In this is lecture we will see something about the prior art in the switch mode power conversion. In the earlier sections we had seen a over view of the switched mode power conversion, what kind of a goals are set for switched mode power conversion, what are the components that are used, what are the major features of switched mode power conversion, etcetera. Following that in this section of the lecture, we will see something about the prior art, how was power conversion done before the introduction of electronic switches? Power conversion was being done even before switches were invented and these were done historically through several means.

We will see the prior art just before switched mode power conversion came into existence, what kind of power converters were used. What were the principles of operation of this kind of converters and how it eventually evolved into switch mode power conversion. So, the question is how was power conversion from before the introduction of electronic switches.

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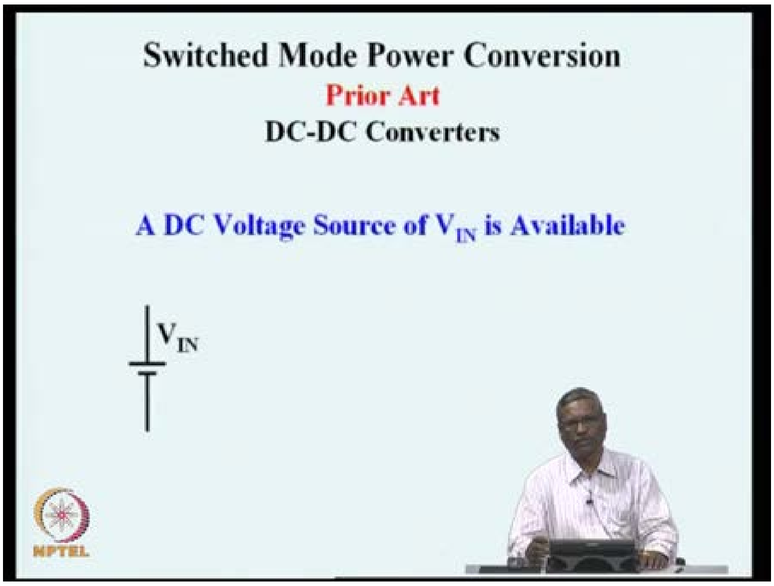

We had seen that the power converter interfaces between the source and the load. For example, here what I have shown is a DC voltage source whose magnitude is V IN or input voltage is available. The source has a voltage of the V IN, in the electrical power processing normally power is transferred in a circuit by the passage of current across a voltage drop. We defined power is the product of voltage and current, if charged particles flow at a certain rate coulombs per second is called Ampere. At a certain rate we say that that is the electric current, in electric current when it passes across the potential difference that results in electrical power.

Now, in this case electrical power is available from a battery whose voltages is V IN. A battery can be considered to be capable of supplying infinite amount of electrical charges all charged to a voltage of V IN. So, depending on the electronic charge and this voltage V IN, every electron that comes out of this battery is capable of transferring an amount of energy to the load. This energy is normally defined as electron volt, electronic charge into voltage. The product of charge and voltages is energy and we could say that a battery is capable of giving in finite amount of charge at a voltage of V IN.

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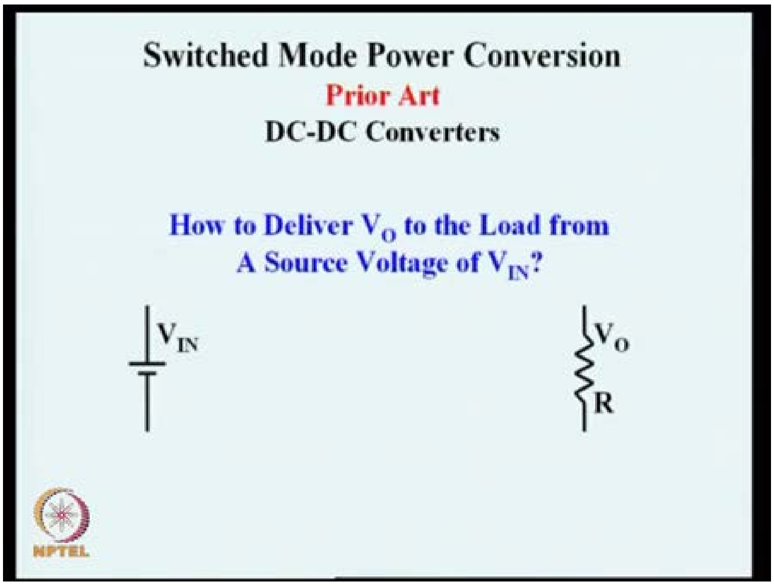

Now, if this power has to be transferred to a load of resistance are at a voltage of V naught which is a different from V IN. Then the question is how do we interface this voltage source of V IN with a load whose voltage requirement is V naught. In this case V IN and V naught are not equal to each other, so there is a difference in voltage. So, in such a case how do we deliver a voltage to the load V naught which is from a source V IN.

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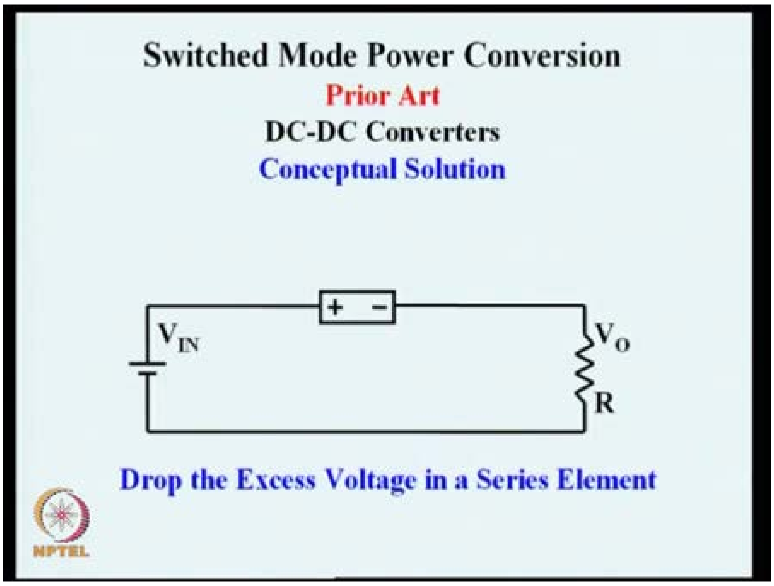

So, conceptual solution is to absorb this difference in a series element whose voltage drop is the difference between the two. For example, if V IN is the input voltage and V naught is the output voltage, then we can have an additional in between element which drops the voltage which is V IN minus V naught. So, that the desired voltage of V naught is delivered to the resistive load R, in this case the conceptual solution is to drop the excess voltage in a series element. We say excess voltage because in this type of power converters, the power converters which were used before the advent of switched mode power conversion used to provide voltage at the output, which will be less than the voltage at the input.

We can drop the excess voltage and deliver a voltage V naught to the load which will be less than V IN. The reason for this is that the additional element that we are using here is capable of only dissipating energy, not capable of providing energy. With passive solutions we can only drop voltage across the series element and an account of his drop here what is available at the output will always be less than what is available at the input. So, this type of a conceptual solution is what was prevalent before the advent of switch mode power conversion, whatever we had seen as series drop of excess voltage in an element.

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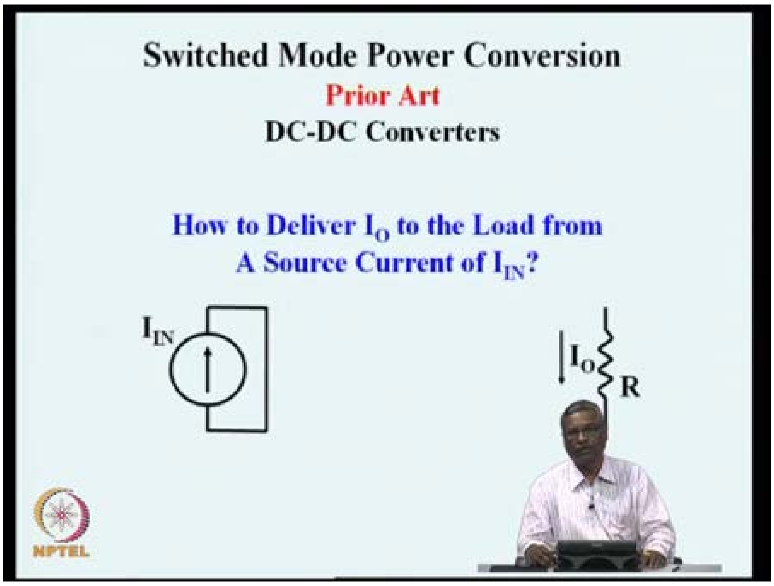

Can also be conceptually extended to a current source also, supposing a DC current source of I IN is available. A current source is capable of giving a constant current to the load against a variable voltage across the load. If the load available requires a certain current of I naught with a resistive value of R, from a source which is I IN then how do we interface the current source which is I IN higher than the load requirement of I naught.

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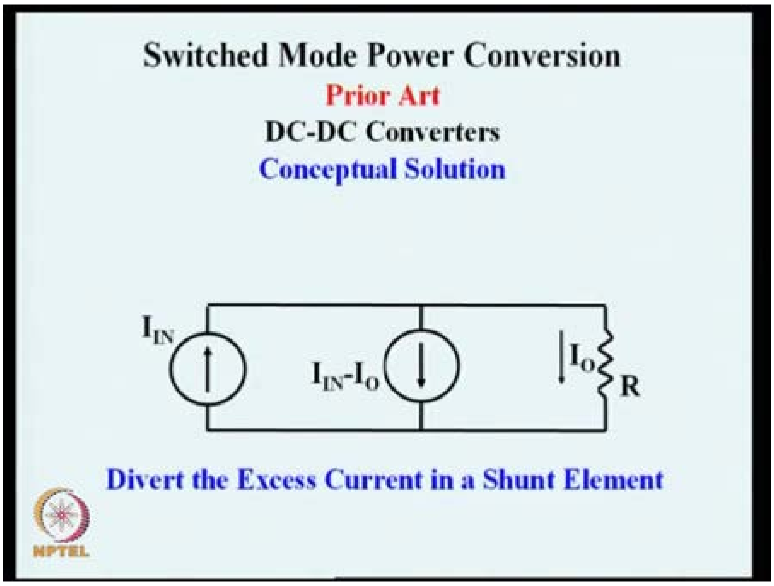

The conceptual solution is again following identical lines, we divert the excess current in a shunt element. You notice here that the input current a part of that input current is diverted in a shunt element, so that what is delivered to the load is I naught. The difference I IN minus I naught is diverted in a shunt element, just when we wanted to drop an excess voltage in a series element. This is a dual of that a solution excess current is diverted in a shunt element.

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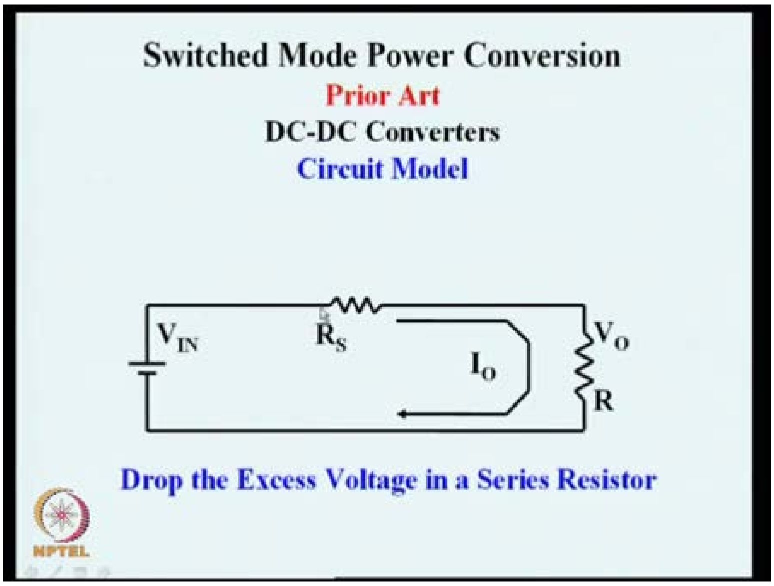

Now, the conceptual solution has to be understood in the form of a circuit solution and that is what we see in the next few slides. How do we drop this excess voltage in a series element? The simple solution is to use a passive element of a resistance R S, so that the current through the load I naught is now V in divided by the total resistance of R S plus R, but out of that I naught into R is what is going to provide V naught. So, you will notice that by adding an additional element here, a series element it is possible to drop a voltage across this element depending on what current is flowing. And once that additional drop in voltage is done V IN is available to the load after drop equal to V naught, the excess voltage is now dropped in a series resistor this is a passive solution. The solution involves some losses in R S and this element is a passive element.

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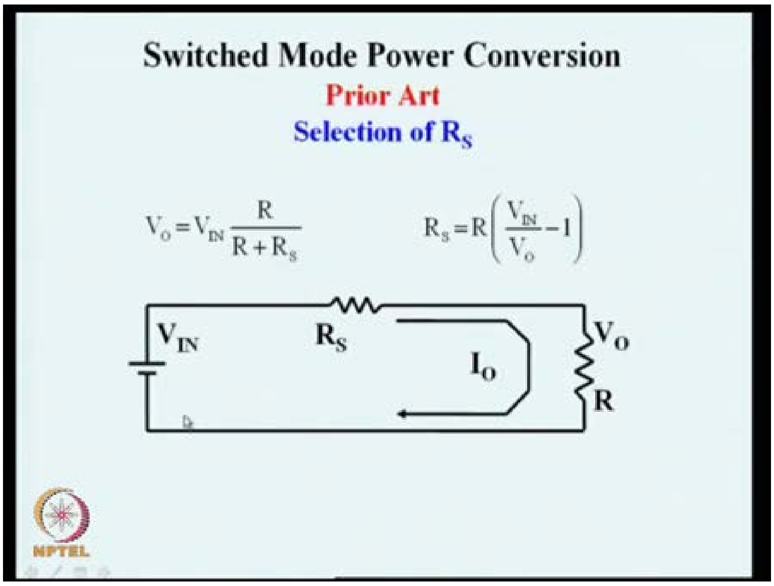

Now, if you mathematically try to relate what will be V naught output voltage in terms of V IN, this is a simple potential divider kind of circuit. We know that the output voltage is the input voltage multiplied by the resistance ratios, the resistance R divided by the total resistance R plus R S. The same equation can be rearranged in the form of the required series resistance in order to control the output voltage will V naught, from a source voltage of V IN, for a load résistance of R. All the known quantities can be put on the right-hand side, so the unknown quantity R S can be represented in terms of the load résistance multiplied by whatever is inside this bracket, which is the ratio of V IN divided by V naught minus 1.

An important point notice here is that this will result in positive numbers of R S only if V IN is greater than V naught, this is something which we had earlier seen that with passive solution, passive resistance solution here V naught will always be less than V IN. So, that V in by V naught is some number greater than 1, so whatever is in this bracket is a number which is positive multiplied by R again R S a positive quadratic. And this type of power conversion is possible if the required voltage is less than the input voltage by using simple passive resistive solution.

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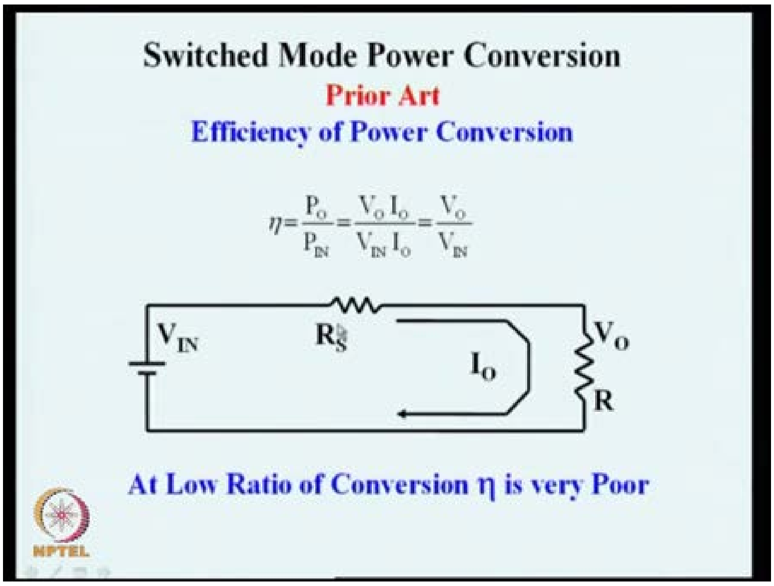

If we see how the power conversion is done and what kind of losses are involved, the efficiency is defined as the output power. Whatever is the power in the load related to the input power which is V IN multiplied by and I naught. The same current is flowing through the complete circuit, so the input power is V IN into I naught output power is V naught into I naught. And you can see the that this ratio efficiency is same as the ratio of V naught by V IN. One of the important consequence of this relationship is that, if you desire very low output voltage from a high input voltage the efficiency necessarily will be very very low. And low ratio of conversion, conversion ratio V naught by V IN if it is a very low number efficiency will be very poor. This is one of the distinct disadvantages of the passive voltage converters.

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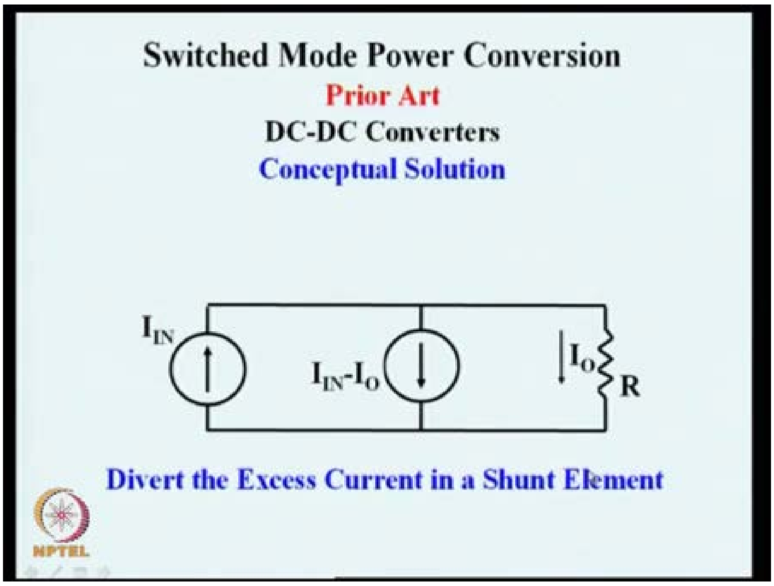

If we extend the same ideas to a shunt converter and we had seen that this is a dual of the series voltage converter. You have current which is available at I IN and the diversion current is I IN minus I naught, so that the required current I naught is delivered to the resistance R the additional current is diverted in a shunt element.

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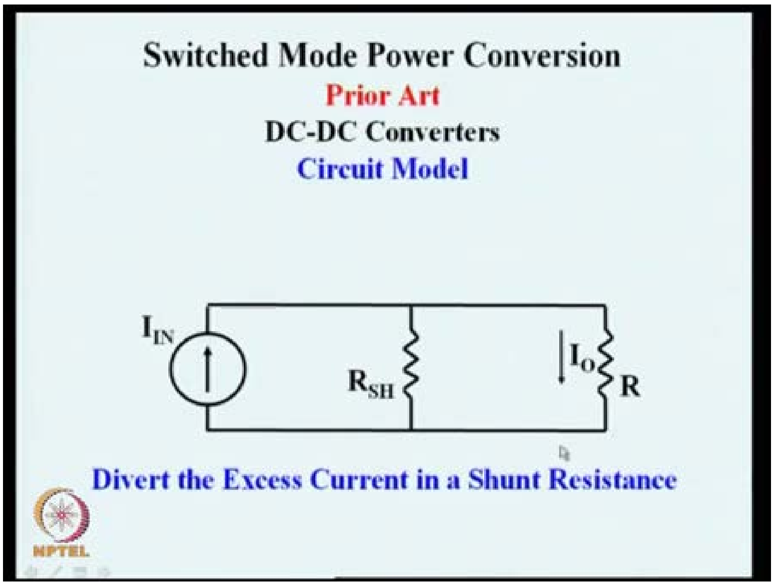

The solution of this will be again through a passive resistance which is now connected across the load called R shunt. This shunt resistance diverse the excess current in this path so that a portion of I IN is now delivered to the R as decide by S, this we call as the circuit model of a shunt power converter.

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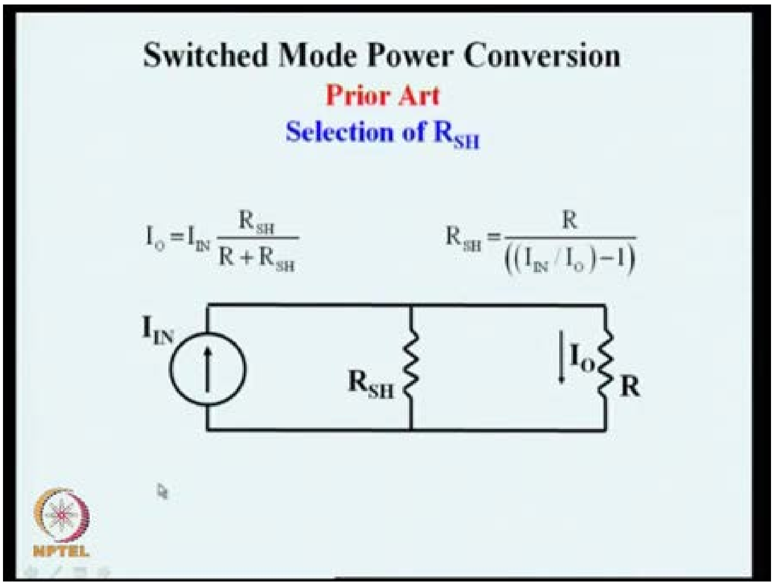

In the same way as before it is possible to relate the output current I naught as a fraction of the input current I IN. This fraction is the shunt resistance divided by the total resistance R plus R SH. Just as before depending on what current we want at the output, what is the load resistance and what is the input current that is available. We can find out what is the required shunt resistance as a function of all these known quantities, namely load resistance, load current and the input current. This relationship again shows that for a positive number for R SH, this denominator has to be a positive quantity. Which indicates that the input current has to be always greater than the output current. Just like the series voltage converter, in a shunt current converter also the output current has to be necessarily less than the input current. This is because this external element traditional element is a passive element and it is not capable of adding any additional power it will only dissipate power.

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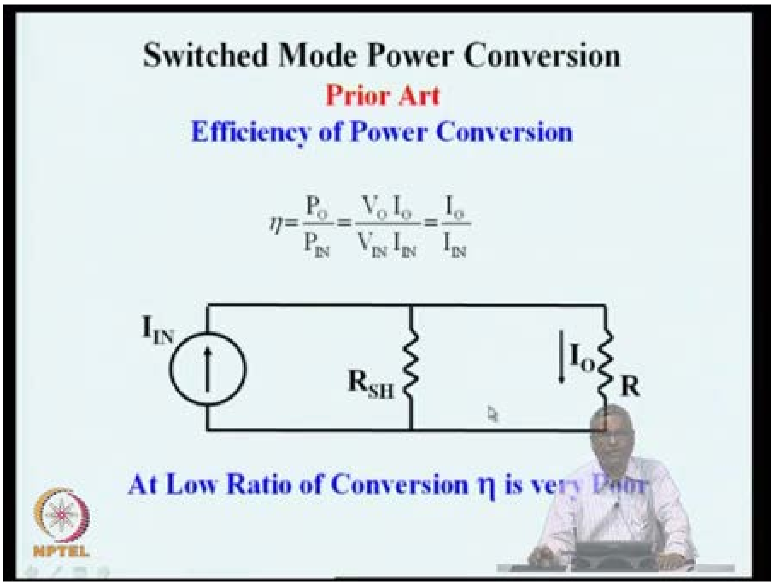

If we can extend the idea to find out what is the efficiency, which is the ratio of power delivered to the load, to the power that is supplied from the source P naught by P IN. This can be rewritten as the product of V naught, I 0, the product of V IN, I IN and in this circuit the voltage is common throughout. So, these two terms go away so we find that the efficiency is a ratio of delivered current to the supplied current.

Just as in the voltage converter we saw that the efficiency was low for low conversion ratio, here also when the conversion ratio if I naught by I IN is low the efficiency of power conversion is very poor. This is one of the a disadvantageous of the earlier generation of power converters, where we use passive elements in order to convert power available either as a voltage source or as a current source to a load that desires power at a different voltage or at a different current.

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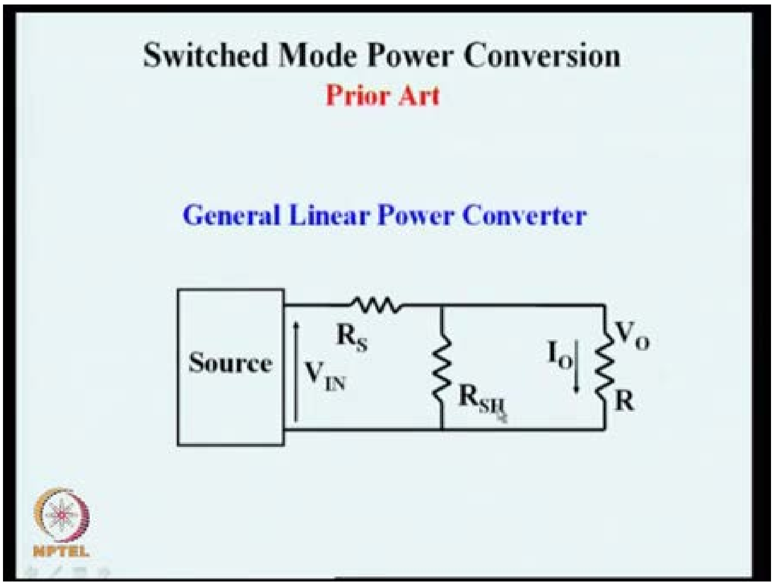

Now, in general these converters are classified in the name of linear power converters and they follow this idea. That if there is an excess voltage in the source you drop it in a series resistance and if there are excess currents that are available you divert it in a shunt element. So, the general canonical model of a linear power converter, a power converter takes energy from a source and delivers it to the load with all the flexibility of controlling the load voltage and load current will have these elements, a shunt element and a series element. Now, it is possible to control the power flow through the control of the shunt element, a variable resistance R SH in such a case, such a converter is known as a shunt controlled converter.

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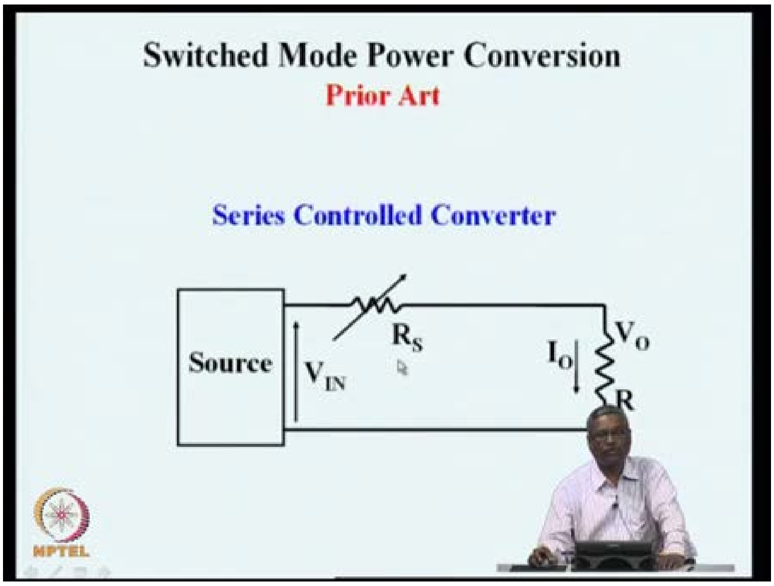

In the same way it is also possible to do the control through this series element of R S, in which case these converters are called series controlled converters. So, in effect we have two types of linear converters, one of them is a shunt controlled converter, the other is the series controlled converter. In general the canonical model of control is having elements, which are a shunt voltage dropping element sorry, a series voltage dropping element and a shunt current diverting element. This gives us a full flexibility of controlling the load voltage, as well as a load current and in many applications one might use either a shunt controlled converter or a serious controlled converter. In such converters it is possible to take in power from a source whose voltages is at V IN and delivered to the load at a voltage of V naught by controlling the series element. This is the basic principle of the linear power converters, which were common before the switched mode power converters came in to (( )).

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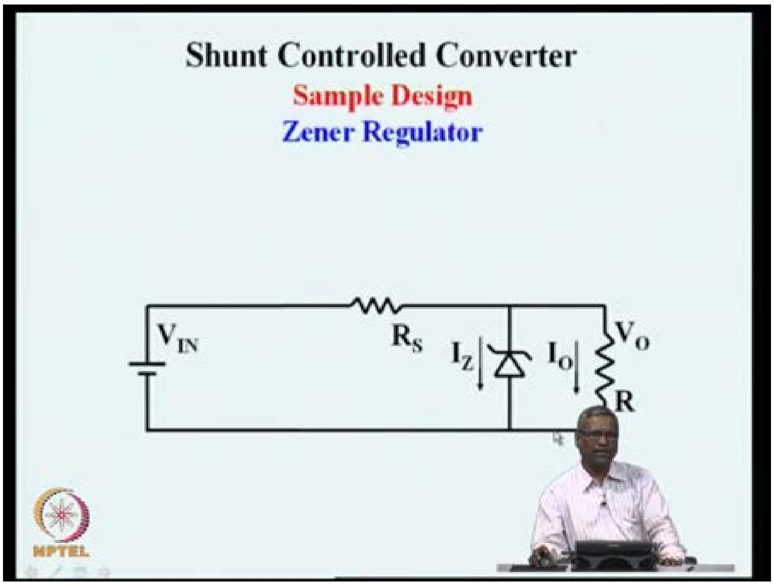

We will take an example a sample design very low, this is known as a zener regulator, this is a shunt controlled converter. It has a source at a voltage of V IN it has load of R which requires a voltage of V naught and there is a series element RS, which will drop the excess voltage between V IN and V naught. Now, this type of converters are the simplest of the voltage regulators, simplest of the power regulators, which has a shunt element, which is a zener diode. We will see graphically how the operation of such a converter works. We will also see some of the mathematical relationships, but more than that I would like to introduce some graphical methods which are very helpful in understanding the operation of many of these power converters.

Then not only the operation these graphical tools also help one to design these power converters very successfully through simple graphical aids. One of the reasons these converters are called linear converters is because all the elements that are used in these converters can be modeled as linear circuit elements. These linear circuit elements are voltage sources, current sources, resistors and so on and combinations of resistors. And in all these cases it is possible to relate the output voltage and input voltage, output current and input current, through certain figures through certain lines drawn on the plain.

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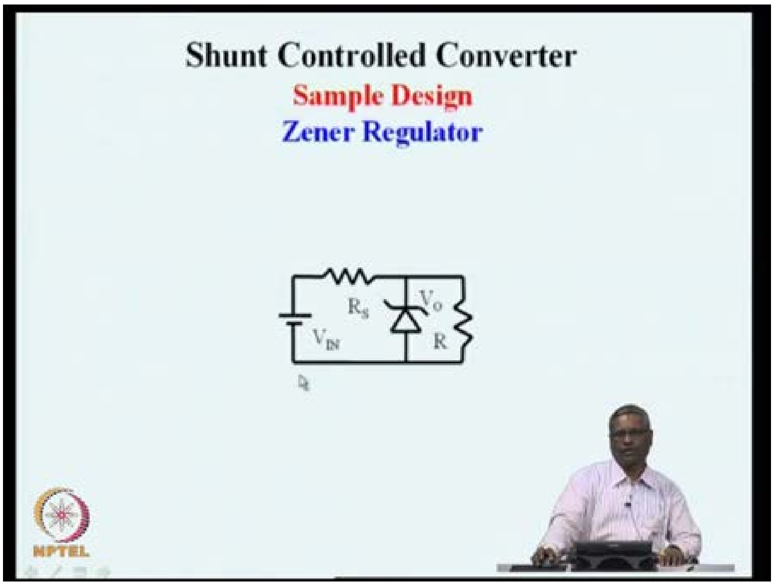

We will see in the following few slides, some design aspects of a zener regulator and later on we will go on to see more versatile converters of this the family of linear converters. So, what you notice here is a source V IN and a series dropping element R S which is a resistance and a shunt controlled element which is a zener regulator and the load which is a demanding power at a voltage of V naught whose resistance is R.

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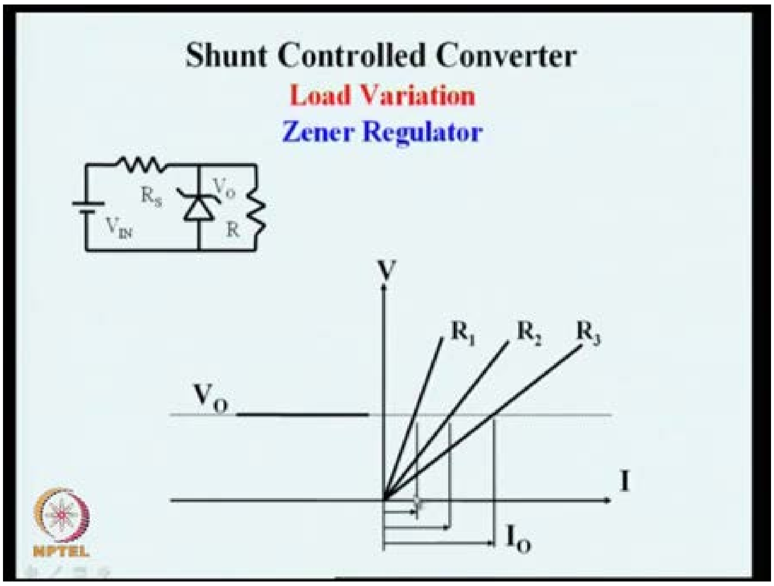

Now, the operation of the zener regulator can be understood through several graphical constructions. So, what you see here is the circuit with V IN, R S, V naught and V Z and then the resistive load. So, what I have drawn here is an x-axis of current and a y-axis of V and in this we can represent many of these operating points and make some constructions, which will be very helpful in understanding the zener regulator. For example, if I want represent this R and V naught, R we know is a circuit element where the current through this R is proportional to the voltage through the resistance. So, I can now represent this load as a line on the V I plane as a line whose slope is same as vertical distance is V horizontal instance is I.

So, the slope of this line is equal to the value of the resistance. So, in this figure right now I have represented the current axis, the voltage axis and the resistance which is the load line. If the output voltage corresponds to a particular point here, you can draw a vertical line the horizontal line where it meets this line and if you produce it down wards the current seen here will be the current in the circuit. So, this is the load line representing the resistance on the V I plane. Now, on the same plane I have now introduced the voltage of this zener, a zener is a circuit element whose voltage is constant irrespective the current through that.

So, I have represented a line which is a constant voltage line, this line represent the voltage across the zener and we assume that the zener is an ideal device, so that the voltage across that is constant. Now, when I mark this line to indicate the output voltage immediately, because the resistance is connected across that, the current through this resistance can be formed out by extending this line here and finding out this vertical. And what you see here is I naught this would be the current that will be flowing in the resistance R. So, what we have now is a horizontal line representing this zener, a load line we started with and this horizontal line represents the voltage across the load and on account of voltage across the load the current in the load is I 0 which is also represented here.

So, there is a current which is flowing in this I 0, there is a current flowing in this zener, there is a current flowing in this R and there is a source voltage. So, we have now seen the load voltage, zener voltage and the load current as resistance line which is the load line, the output voltage which is the zener voltage and the load current which is I naught. Now, if the load résistance is changed to different values R 1, R2, R3 what you will see is that the load current will change, because the load line is having the same slope as the resistance. If R 1 is the resistance, this is the load line and the load current is now I naught 1, if the resistance is changed to R2 the current is now I 0 2, the resistance is changed R 3 resistance is I naught 3. So, 3 different resistance I have shown here this is to indicate that on this V I plane, if the load résistance changes it is possible to represent the load current in this.

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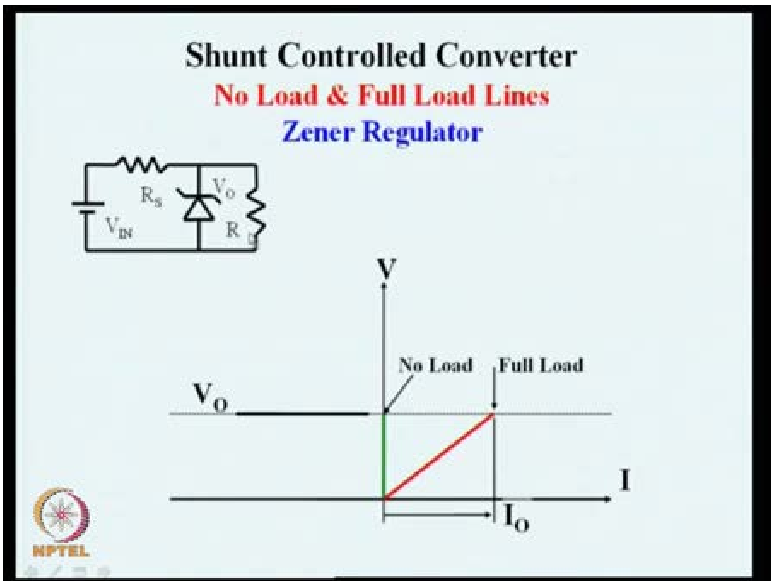

Now, for a fixed value of R which is the full load condition, R is represented by this slope line. If supposing load resistance is infinity then that load line is a vertical line, so correspondingly you will find full load current is I naught and no load current is 0, so these are the two points that are shown on this. So, what you see here is the variation of the load current right from 0 to I naught corresponding to the load line changing from vertical line for no load and a slanted line with the slope of R for the full load condition.

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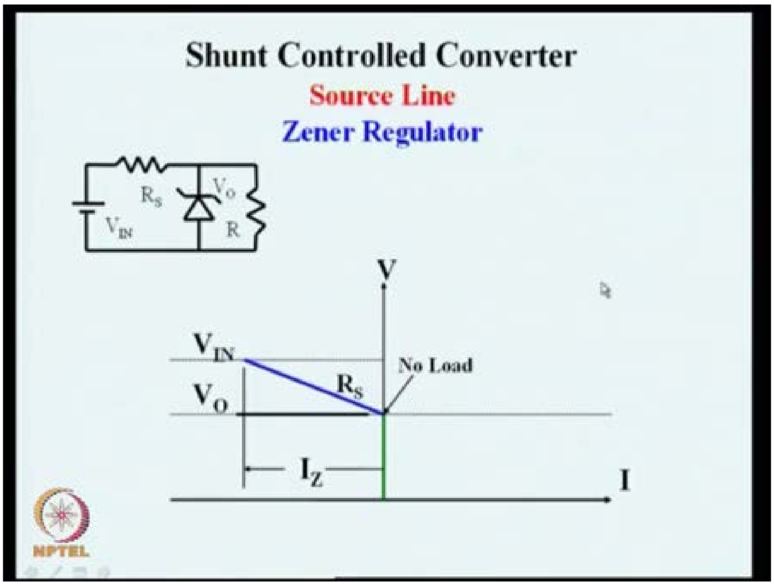

Now, the same V I plane I have introduce now the résistance of R S on another line. What you notice here is the voltage on the left hand side V IN is the voltage on the R S and the voltage on this right terminal of R S is V naught. So, the current through this branch through this r s is given by V IN minus V naught divided by R S. In this figure if I also draw a line corresponding to N IN which is this vertical horizontal line above V naught, the difference between them is V IN by V IN minus V naught and if that voltage is divided by R S what you get is the current in the zener. This I have plotted on no load condition so that there is no current in the load, load current is 0 under that condition V IN minus V naught divided by R S is completely zener current because nothing is going into this.

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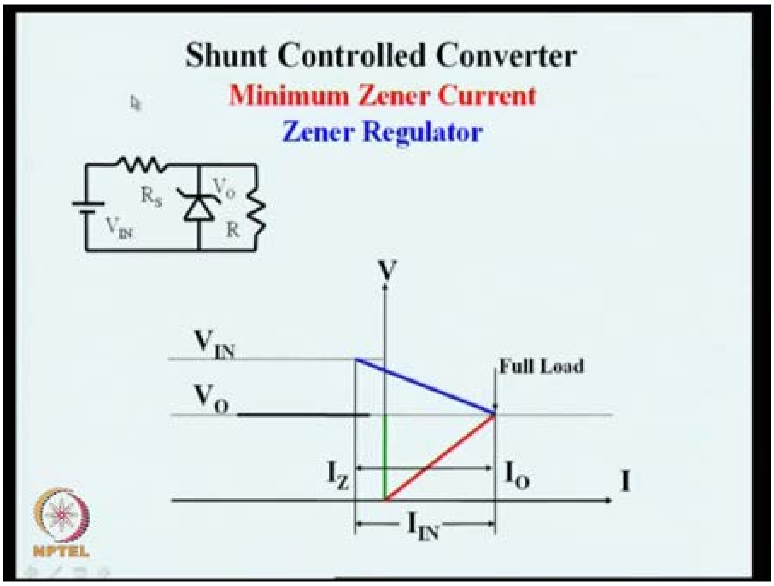

Now, if I simultaneously introduced both of them, there is a load full load which is I IN full load which is I naught, because of this load line. Now, the current that you see here is I naught which is in this direction and then the current in the R S is V IN minus V naught divided by R S. Which is this full length here shown as I IN and I IN minus I naught is a current which is going in the other branch. If you see this load current coming in minus current going out is what is into the zener.

So, the zener current is what is seen here as this I Z. Now, in this represents the operating point of this complete circuit where this line V IN is the source voltage, this line V naught is the load voltage and V naught by R is I naught V IN minus V naught by R S this entire length here is I IN and I IN minus I naught is I Z. Another words I Z plus I naught is I IN I Z is represented in this direction, I naught is represented in this direction so the sum of these two represents I IN.

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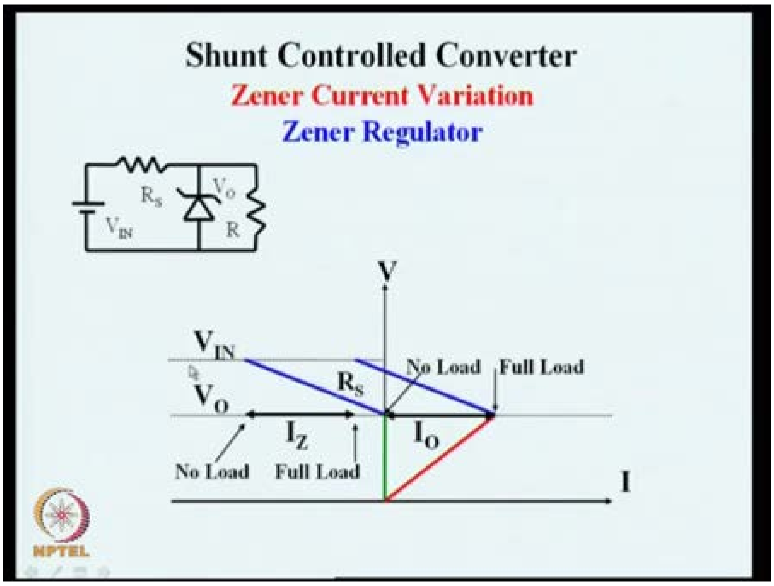

Now, I have added one more condition, if the load varies from no load to full load you will see that I naught varies from 0 this full value. If I naught varies by this amount the V IN minus V naught by R S, I IN remains the same value because V IN also has not change, V naught also has not change. So, you will find that the zener current will always write from no load condition from full load condition. When the output load current is minimum the zener current is maximum this right from here to here. When the load current is maximum corresponding to this point, zener current is minimum full load condition.

So, in effect because V IN and V naught are fixed the current through R S is always constant and that current through R S these the input current. Out of that input current if the load current is 0, the entire current goes into the zener which is what you see here. If the load current is some finite value then V IN minus load current is what is going into the zener current. So, what you see as the variation here maximum zener current to minimum zener current occurs at no load to full load. When the load is minimum zener current is maximum, when the load is maximum zener current is minimum. So, this graph helps in a way how we should go about designing such converters

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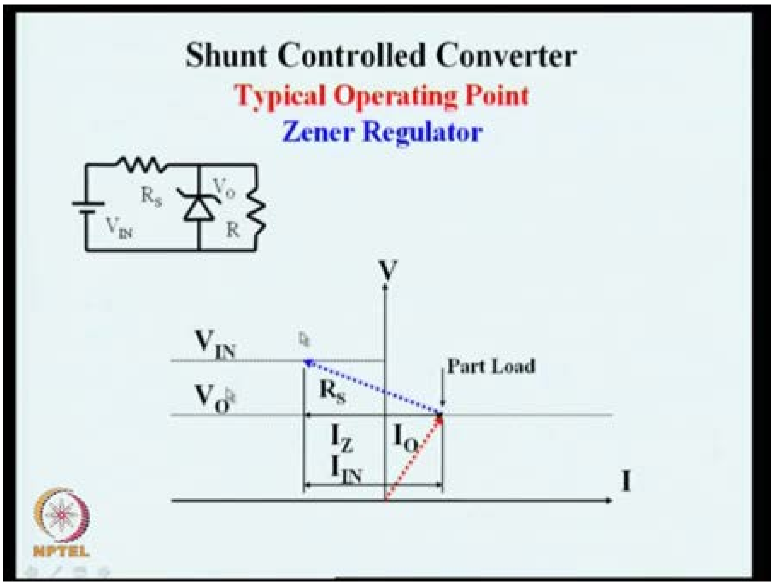

Now, this figure what I have shown here is a part load, neither the full load condition nor 0 load condition a part load condition where I naught is somewhere in between. So, you will see that the I IN is again as before the full value that I IN minus I naught is the zener current which is now in between the previous cases. Earlier we had seen that this is the range in which the zener current was varying and in this example into some value right in between. So, this picture completely represents the entire operations that are taking place in this circuit. One can do it through equations, but doing it graphically gives us a better insight into the conditions that the maximum zener current accurse, when the minimum load current is occurring.

In the minimum zener current occurs in the maximum load current is occurring in many of these things are graphically obvious in this conditions. Now, if you see the output power here we see that V naught is this vertical distance I naught is this horizontal distance. So, the product of V naught I naught is the area I have shown here in green color is the output power, the output power right now in this particular operating condition is this rectangle area. If you now see the input the full voltage V IN and the full current I IN minimum to maximum the area of this rectangle is the input power. So, naturally the efficiency is the ratio of the smaller rectangle here divided by this bigger rectangle and you see that the efficiency is quite small it is not close to 1.

A substantial amount of power is dissipated, power is wasted the red color what you see here is all the wasted power in the smaller rectangle is what is really delivered to the load. This wasted power has one component which is the shunt component and one component which is in the series component in effect the efficiency is quite low.

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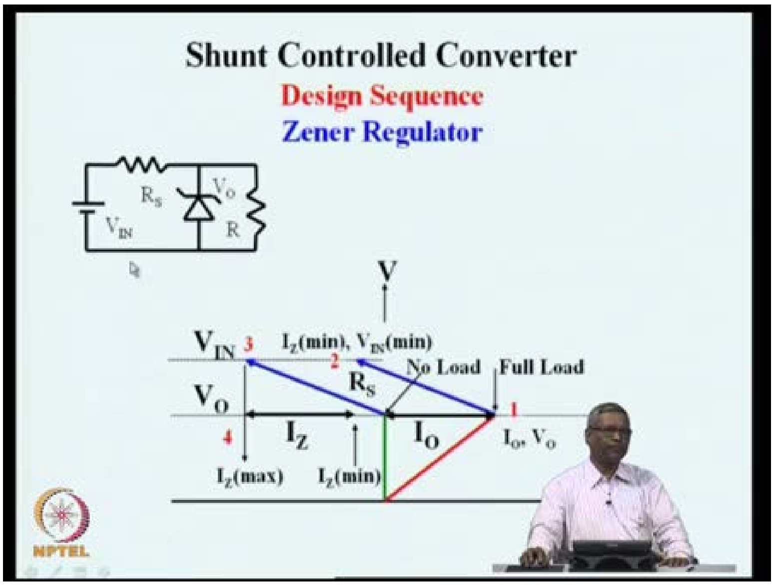

Now, if you wish to go through a design sequence of this type of a controller, the drawing I have put this equal the steps in the number here. what we first construct a V plane and an a I plane and on this plane we first draw the full load line, which is red line here and the no load line which is the them here is the I naught condition. We lay down V naught output voltage line, which is a horizontal line here, so this with what you see here is I naught. So, from the full load condition if you draw these V IN there is a minimum zener current, the zener element, the zener diode is a element whose voltage is fixed when the current through that is in a certain range.

For example, if you take a 1 watt zener, 1 watt and 10 volt zener its rated current may be about 100 milli amperes. A 100 milli amperes, 10 volt zener will have a total power dissipation of 1 watt. Its rated current is 100 milli amperes, but it will work as a regulated zener only when the current through the zener is at least 10 percent of the rated correct. So, for example, 10 milliampere to 100 milliamperes are some value of I Z minimum to I Z maximum this will work as a nearly constant voltage element. So, in this figure we mark I Z minimum in this I Z minimum and I naught are connected together that line will be the R S line, the resistance line. If you find slope of that that will tell you that decide resistance.

Now, under that condition if you draw a line parallel to this blue line corresponding to the minimum load condition, what you see here is this point number three vertically produced down words that will give you the maximums zener current. In a zener current variation will be minimum to maximum when the V input is changing at this point, V IN minus V naught divided by R S is the total current minus the load current will give you the zener current which is this point. In the full operating condition zener current will vary from a maximum of I Z max to a minimum I Z minimum.

Using this construction one can find out in such converters what is the zener that is to be used? What is the resistance that is to be used? What is the maximum zener current and because of that what will be the maximum power rating of the zener? If we know the range of a load current that is to be supplied and the voltage that is required at the load current so on. This is one example of a shunt regulated voltage regulator, it has an element a control element which is a zener which draws a variable current depending on the load variations. This variable current which is varying in this range ensures that the total current through this R S is nearly constant, so that you get from a V IN the decide voltage of V naught.

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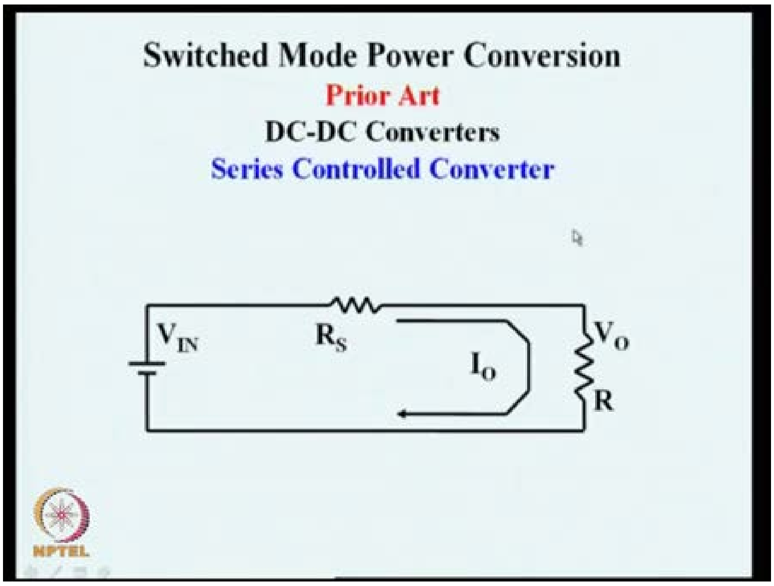

Now, here serious controlled converter unlike a shunt controlled converter does not have a shunt element. We have only a series element which is R S, we change this R S in order to obtain the required V naught from the source V IN for a given resistance R. This type of regulator is a serious control regulator, the control is on the resistance that is here right on R S. So, let us find out what are the graphical methods of understanding the operation of this converter and probably we will also look at how these are realized in real life.

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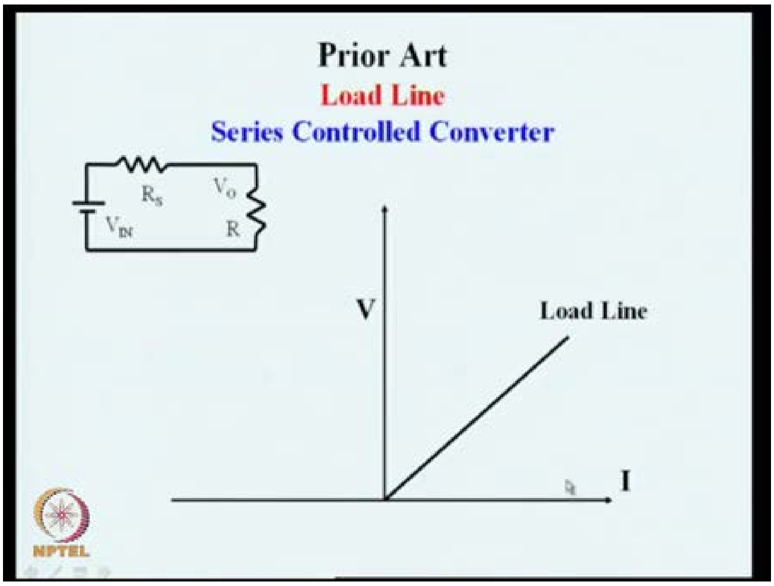

Now, we follow a very very similar graphical approach, we represent this circuit by the series element and the load and the source. And we show on this V I plane a load line this line has the slope of the resistance, at any point if you fix what is the voltage across the load. Where ever that line cut this load line will tell you what is the load current.

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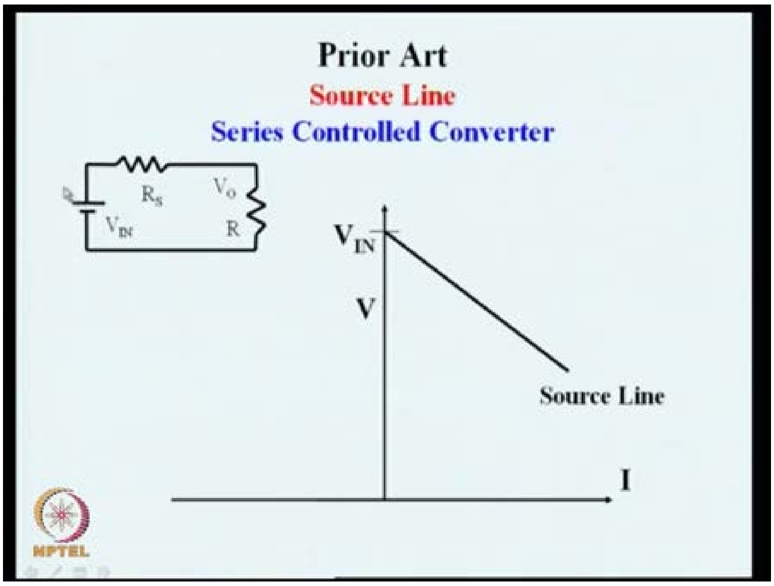

Now, on the same V I plane we can represent this R S and V naught in a slightly different way. For the same current that is coming out we can find out what will be V naught, when different current is swing through this R S. If 0 current is swing through this R S, V naught will be same as V IN which is this point. As the current through the circuit increases the voltage at this point will be V IN minus I into R S, which is this line. So, just as a we head drawn a load line starting from 0 on this site, we can row source line starting from V IN from this site. See this load voltage is starting from 0 here, so the load line will be a line starting from the origin. The source resistance is dropping a voltage from a voltage of V IN, so this line starts from V IN and as we draw more current the voltage the output voltage is dropping.

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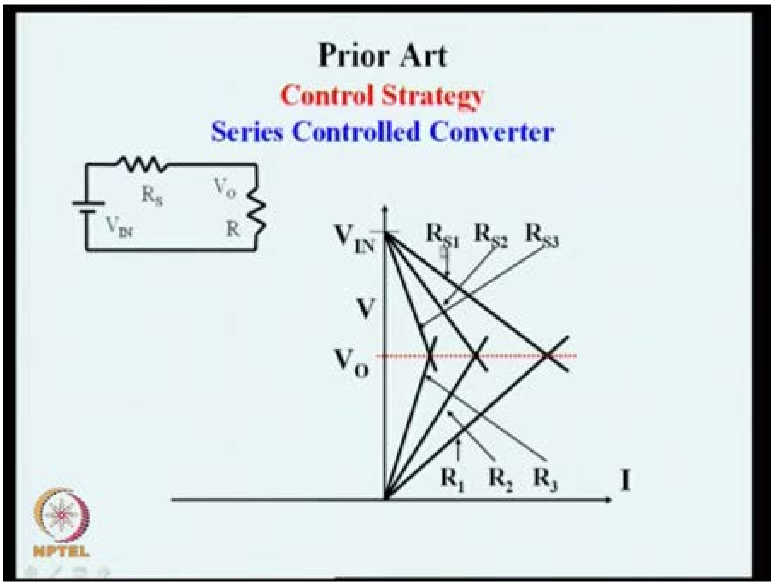

Now, both of them are present when you draw the load line and the source line the meeting point decides what V naught is this is source line. This is a load line the both meet at a voltage V naught and what you see here as this V naught intercept that is the load voltage here. If you produce it down and whatever you see here will be the current in the circuit. Now, for different value of load lines if they want keep the output voltages constant it is very obvious that for every value of load line there must be a source resistant which is different. So, this is the difference between a shunt controlled converter and a serious control converter.

In a shunt controlled converter at all operating points the series resistance remind constant. In a series controlled converter for every operating point the series resistance will change, corresponding to this load line in order to get an output voltage of V naught the required R S source resistance is having this slope. If I know change the load resistance to a new early of R S, the source resistance also has to be change to a new value, so that they both meet at the required V naught. Now, in a serious control convertor the strategy is very simple, as the load résistance is varying, if I wished keep the voltage constant my source résistance also has to vary. This is the principle that is followed in a serious control converter.

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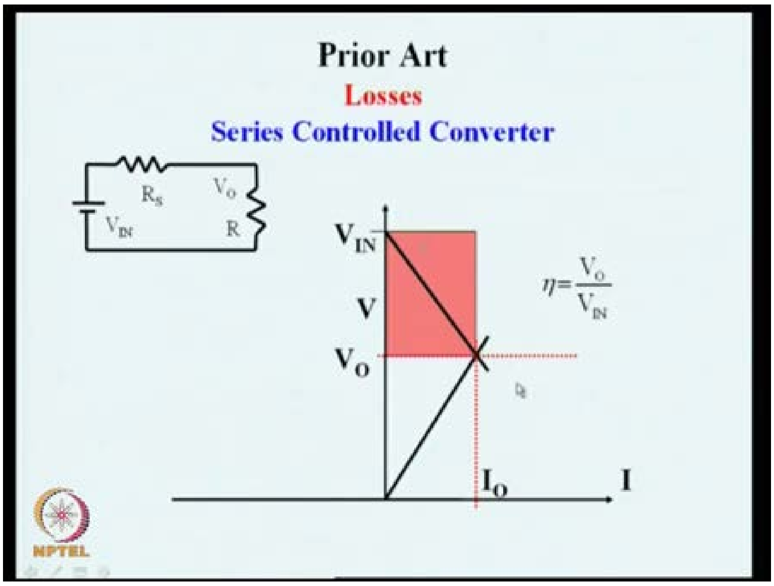

Now, we can look at what is the output power? What is the input power and so on? At the operating point the rectangle that you see here, product of v naught vertical, I naught horizontal, the product is this area V naught, I naught. That will be a power that is delivered to the load or we call it is the output power. The input power is V IN multiplied by the same current, because this does not have any other shunt element. The current in the source resistance, current in the source, current in the load all are same, same current is flowing in the circuit. So, you find input power the rate rectangle is full voltage V IN multiplied by I naught, this is the rectangle. Now, the V naught into I naught is the smaller rectangle here that is what is the power delivered to the load. Efficiency defined as the output power by input power, because the current is same it will be the ratio of the output voltage to input voltage.

You can see very graphically here, for a given V naught if V naught comes down, for a given input voltage if V naught comes down you can see that the useful power delivered keeps on reducing and the efficiency is directly the conversion ratio. We had earlier seen that the conversion ratio if it is very low efficiency is also very low and a very poor power conversion efficiency is one of the disadvantages. Now, if you see the losses whatever was delivered to the load is a output power, from the input power if I remove that output power, what is remaining are the losses. You can see that the loss is a rectangle which is from this operating point everything up words or from the operating points everything till the a y-axis or till the V IN.

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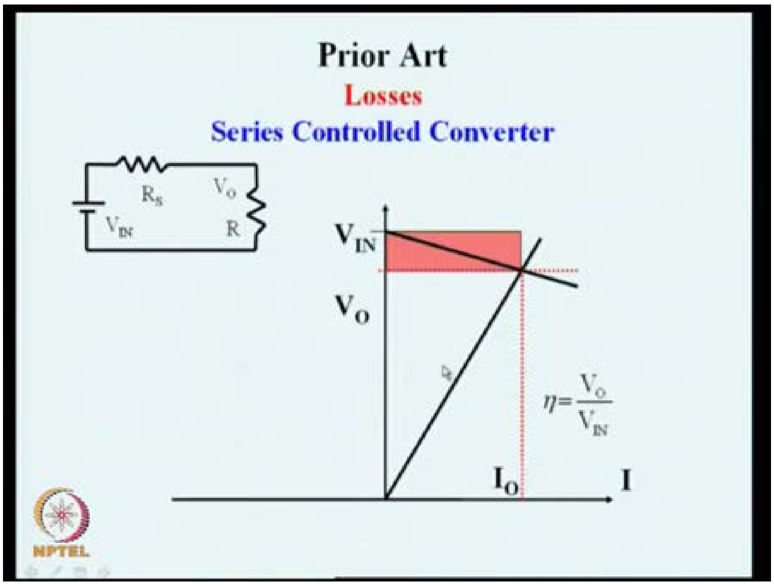

For example, if my output voltage increases the losses come down, you can see that the output power has increased input power is what we have seen as before. So, you will notice that the loss has reduced in comparison with the previous one, right?

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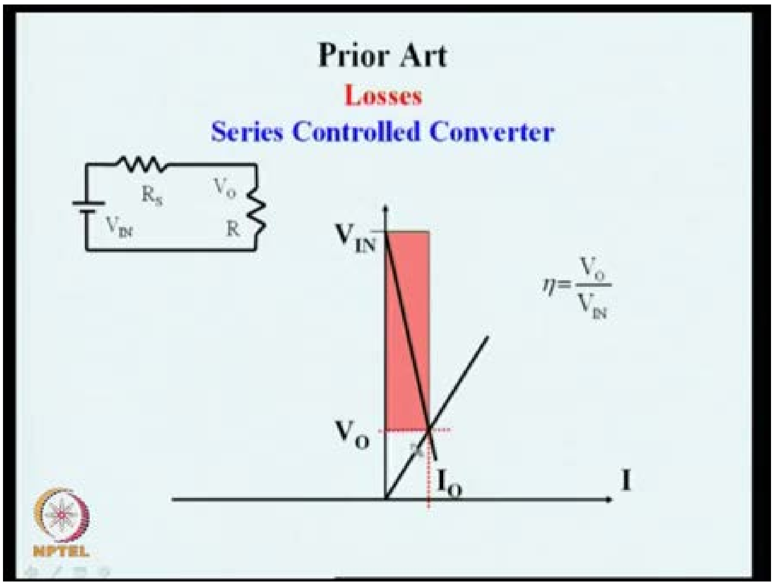

If I go to the next condition when this output current is also reduced you can see that the loss has reduced, in comparison with the previous condition. So, there are there are two conditions one should see.

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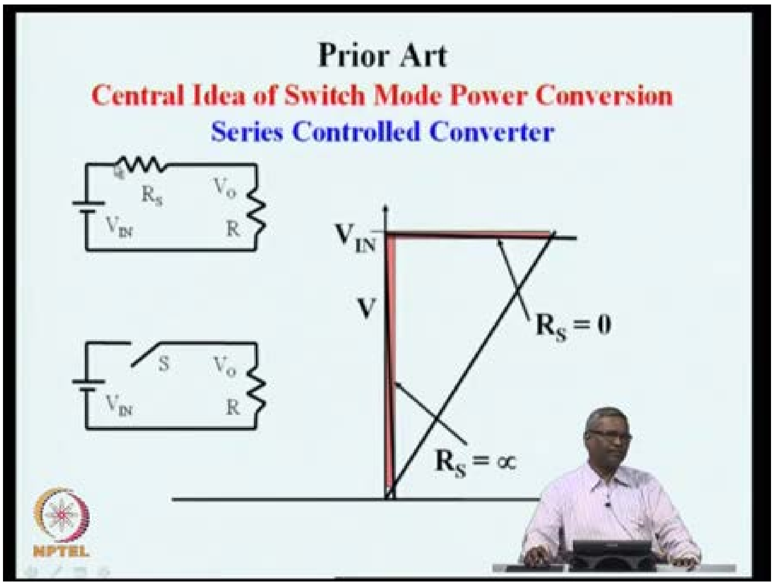

When the R S is very close to 0 also the losses are very small. And when the source resistance is very close to infinity that is perfectly vertical line here, then also the losses are very small. In this case when R S is infinity loss is very small, but delivered power is also very small. In the case R S equal to 0, loss is very small, but delivered power is very high, but if one does not worry to much about delivered power. In the serious controlled converter we can identify to conditions, when R S is very large corresponding to this condition loss is very low. When R S is very very small corresponding to this condition loss is very small.

So, these are the key issues when one tries to understand how the switch mode power conversion developed? For example, when R S is 0, then also we have low losses, when R S is infinity, then also we have low losses. So, it is possible to replace this resistance by a switch, when the switch is closed it corresponds R S equals 0 and then there are no losses, when the switched is open it corresponds to a condition when R S is infinitely then also be have very low losses. We notice that the key idea the central idea of switch mode power conversion can be seen here that the serious controlled converter has to extreme conditions of 0 resistance and in finite resistance indicating low losses.

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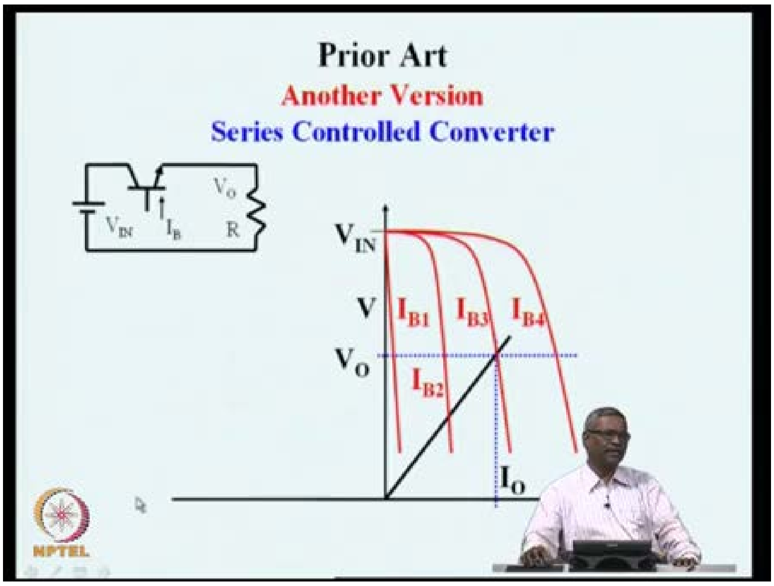

These are the idea as which are responsible for what follows in switch mode power conversion. We will just take a small detour and then see how exactly this series controlled converters are realized. So, what I have shown here is that this resistance is not normally realized by a resistor, but an effective resistor a transistor is nothing but a transfer resister. So, B J T a by polar junction transistor is used at as a series element, whose characteristics or not exactly a straight-line like resistor, but which has a shape of this. This is the characteristics of the transistor, that when no current is flowing through that the voltage is V IN and when current is flowing through that depending what the base current is there are different vertical lines here. Base current 1, base current 2, base current 3 and so on.

So, depending on that where ever the transistor characteristics and the load line meet that will be the required output voltage. The same idea of what we had earlier seen wherever is the source resistance line which was a straight-line, in the case of resister, which is now a kind of non-linear characteristics in the case of a transistor. But the meeting point of the transistor characteristics and load characteristics will be the output characteristics. How exactly do we realize this?

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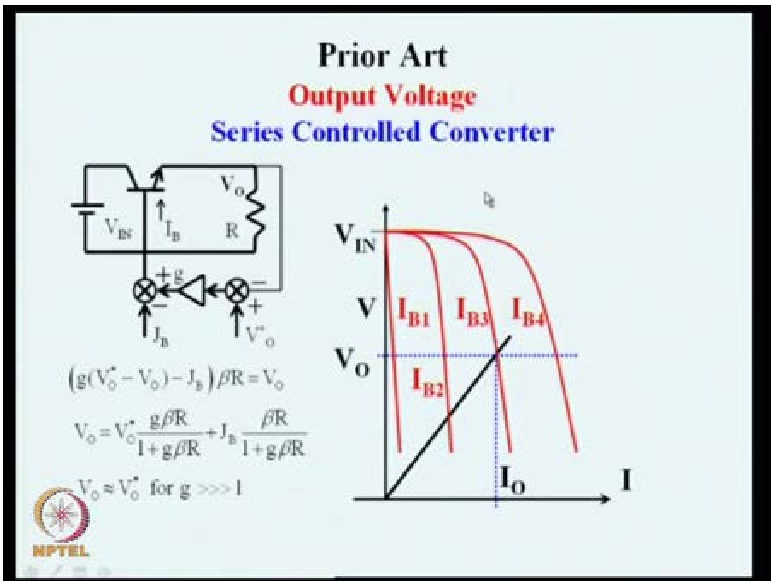

If you see this resistance is not manually varied, it is done in a close look fashion. The output voltage V naught is compared with the required voltage V naught star. The error is amplified with a number g, this is the gain g, then it is added to bias current J B and the some of these two current is feeding the base current. Base current multiplied by the current gain of the transistor will be the emitter current, emitter current multiplied by the resistance will be the load voltage. So, if you mathematically represent these quantities, what you notice is the first relationship is that V naught minus V naught plus V naught star multiplied by g, which is this first term. From that you subtract J B, which is this bracketed term and the current that comes out here multiplied by beta is approximately the emitter current, that multiplied by R is V naught on the right-hand side.

So, left hand side also has V naught term, right-hand side also has V naught term. We separate all the V naught at one side and shift all the other term on to other side. You will find that the output voltage in this circuit is we knot start multiplied by one gain number and J B this other input multiplied by another gain number. The first gain is g beta R divided by 1 plus g beta R, the second number is beta R by 1 plus g beta R. In these designs this is close loop amplifier, g will have a gain which is very very high, very much large compare 1. In such a condition the coefficient of J B will be a small quantity because is g is in the denominator, the coefficient of V naught star will be nearly 1 because this is also g beta R, numerator is also g beta R so approximately output voltage is same as this we knot star.

This is a principle of series controlled converter which is done automatically through a feedback control mechanism, but the most important point that is of interest to us is at, whenever this resistance is very large losses or low and whenever this resistance is very small the losses are low.

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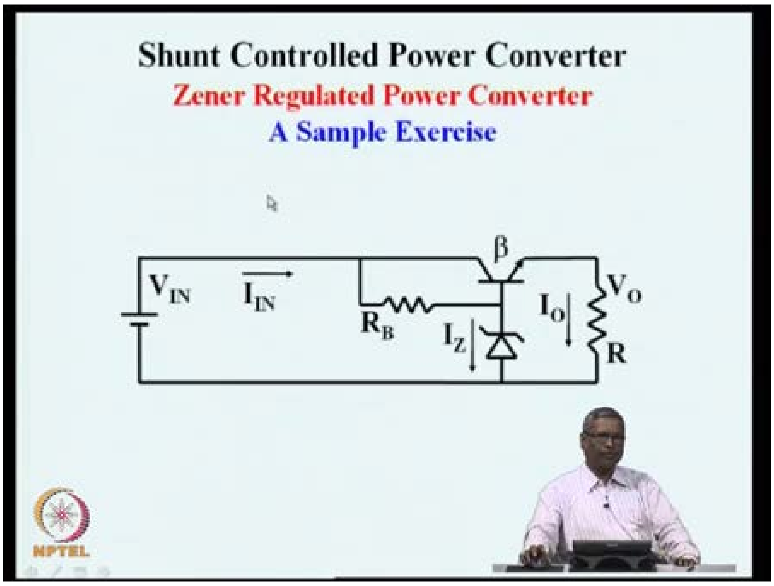

So, what we would see or what we would conclude from what we have seen up to know is that, the key idea the central idea of switch mode power conversion is that. If you use a switch the losses are low and if the losses are low efficiency is high. And in switch mode power conversion first and four most goal is efficiency. So, what we notice in what we have seen up to now is that the prior state of the art suffered from very poor efficiency depending on the conversion ratio and this poor efficiency is because of the losses in the series element and the shunt element. What we have now observed is that the loss is very low if the series element or the shunt element represented by switches, either 0 resistance or in finite resistance.

These are the two conditions when the power loss is practically 0 and this is the central idea of switch mode power conversion. Now, what we have to see next will be how this can be exploited in bringing in the idea of switch mode power conversion what are the element used and so on. So, just before we do that we will take a small a detour and then do one small exercise, a sample exercise of a shunt converter which is slightly different from what we have seen before. This is also a zener regulator power converter, but you will notice that this has a serious transistor which acts as a variable resister. In the earlier case we had a shunt regulator and a fixed resistor and we saw how the regulations was achieved.

The example that we wish to followed now is a slightly more versatile power converter, in the sense that if shunt regulator can be used for powers only for fraction of the words. This converter can be used for slightly higher level of power dissipation. In this particular example it is possible that we may be able to use a one word zener in order to control a load which is about 10 watts. In the earlier example that I had shown probably to deliver one word you may require one word zener also. The power that is last in the zener will be as much as the power that is deliver that to the load, so that efficiencies quite low. Where as what we see in this sample exercise has certain features, certain positive features which reduces zener current substantially in relation to the load current.

So, let us just look at in the next 5 minutes, let us is look at the operation of this converter we can follow the same kind of graphical approach as we had done before.

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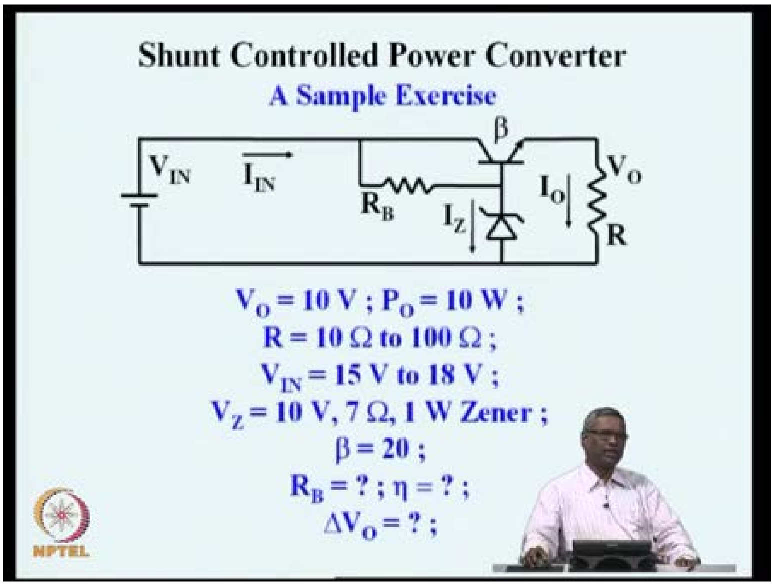

I am now writing down the specifications of this converter, output voltage required is 10 watts and input voltage power required is 10 watts, output voltage required is 10 vaults and the resistance load resistance varies from 10 ohms to 100 ohms, an input voltage varies from 15 volts to 18 volts (( )) for different values of R we would like to have an output voltage which is constant at 10 volts. We have a transistor whose current gain is

20 and we would like to know what should be the value of R S and also like to know what efficiencies this will operate. We also like to know what will be the kind of regulation, that is when the load varies right from minimum power to maximum power, 10 ohms to 100 ohms.

V naught will not be perfectly constant there will be some minor variations, to what extent this variation will be the delta V naught. We call these things the required series resistance, the operating efficiency and the regulation. Regulation when input is varying from 15 volts to 18 volts regulation when the load varies from 10 ohms to 100 ohms. In this entire range of variations, what will be the change in delta V naught and what will be the change in efficiency and so on.

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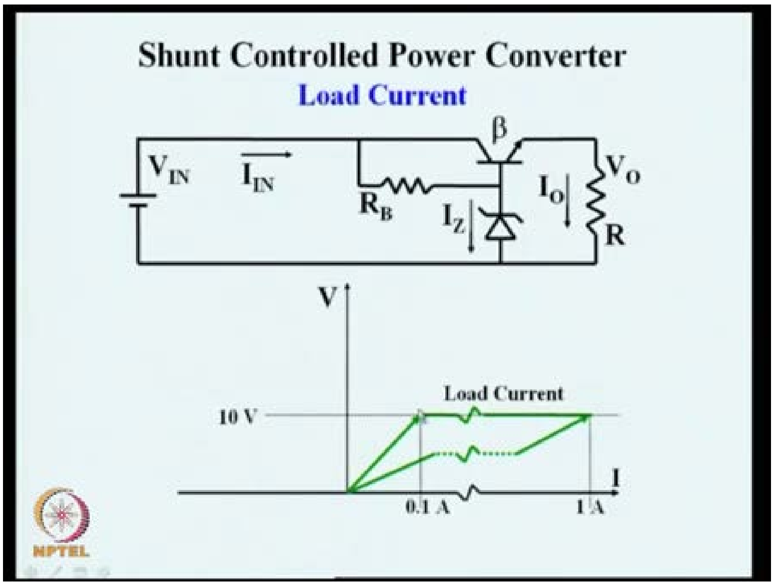

So, let us follow the same graphical approach, what I show here is now a vertical line which is the voltage line, the horizontal line which is the current client. I have shown two conditions a resistance line corresponding to 1 ampere, that is 10 vaults, 10 ohms, 1 ampere current and a resistance line corresponding to 100 ohms were the current is 0.1 ampere. This is a range in which load current is varying and we wished to have 10 vaults a server voltage at the output. Ideally the diode drops circles are negligible, so that zener voltage and output voltage are same. So, you would say that we can use a zener whose voltage rating is 10 volts.

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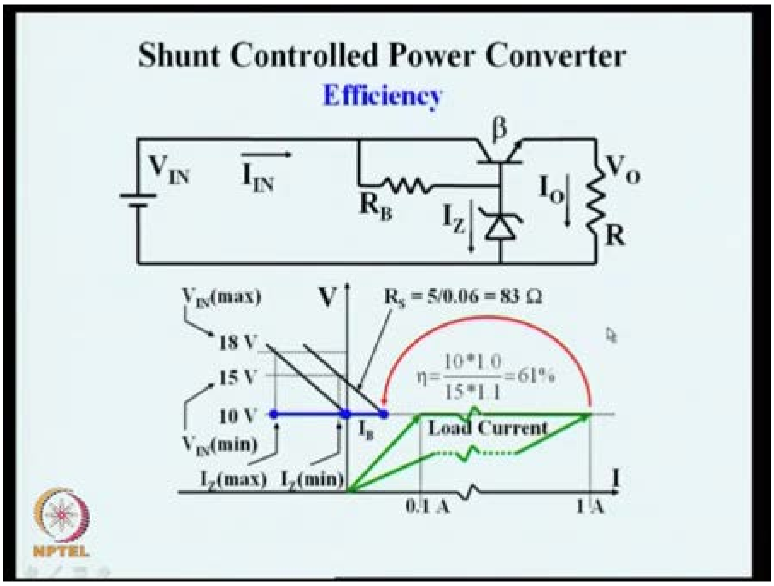

So, if we do that we also understand how the current distribution is occurring here, this is the load current, because the current gain is beta I naught divided by beta will be the base current, zener will have certain. Then the voltage at this point is a same as V naught, V IN minus V naught by R S is a current in this branch. So, let us go back to the scurve, because the base current or the current required at the base is the load current divided by beta. Now, this would be the current which is going out of that, out of these note this point into the base. It is unlike the simple zener regulator it is a load current divided by beta plus 1, because a load current is emitter current, emitter current by base current in any circuit has ratio beta plus 1.

So, this current is divided by beta plus 1 to find out the range in which base current is varying, corresponding to point 1 ampere, point 1 divided by beta of 20 will have a current of about 20 milli ampere or so. 1 ampere divided by 20 will have a current of about 50 million ampere, this is the range in which I B is varying. If I know add the condition as before, when the load current, when the current going into the base is maximum and connect our 15 volt condition, which is the minimum a source voltage divided by 10 connecting this points will give me the required R S.

If I find out the slope of that it also to be 83 ohms, so the kind of ohm resistance that we have to use here is 83 ohms and this is the condition corresponding to fifteen volts. Now, under this condition if the operating point has minimum load, then we will see that extending this line parallel to this further and connecting of 15 volt line and 18 vault line. We will see that the zener current varies right from minimum to some value corresponding to this voltage, some value corresponding to 15 volts and full load, 18 volts and minimum load and 18 volts and full load. So, you have a range in which zener current is varrying, minimum zener current, maximum zener current and 15 is the nominal voltage we input, 10 voltage of 15 is the minimum input voltage, 18 is the maximum input voltage.

On this same graph you can see that the output power is this I naught into V naught, which is this rectangle and input power is the rectangle of V into I along with the zener you see this big red rectangle. The efficiency is the ratio of these two areas, efficiency is a ratio of these two and in this case it is about 61 percent, typically linear regulators will have only about 61 percent or 60 percent or 50 percent or 70 percent efficiency.

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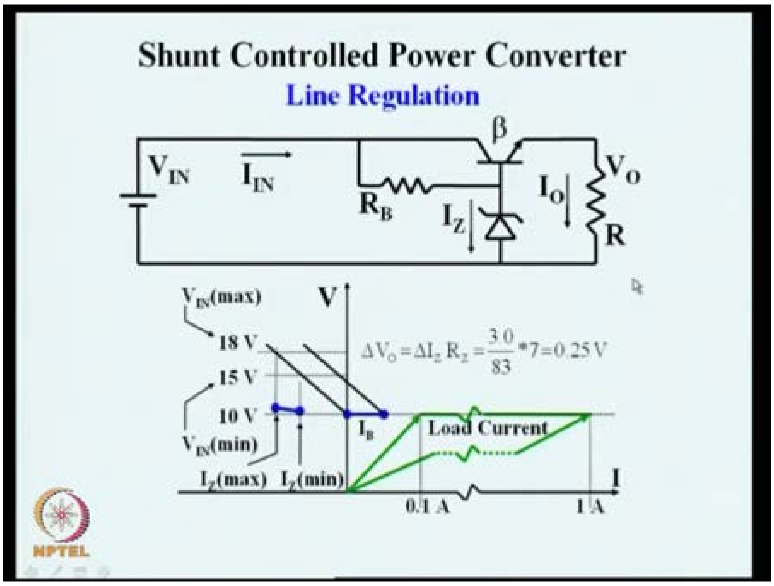

Now, the next is the load regulation is when the load alone changes, when the load changes if a zener has a perfect voltage characteristics it voltage will be 10, but zener has a dynamic resistance which in this case is about 7 ohms or so. You see that this line is now having the small slope corresponding to zener resistance in we see that a regulation of 0.3 volts is the load regulation. The line regulation is when the line alone varies for a given load and that is given by 0.25 volt.

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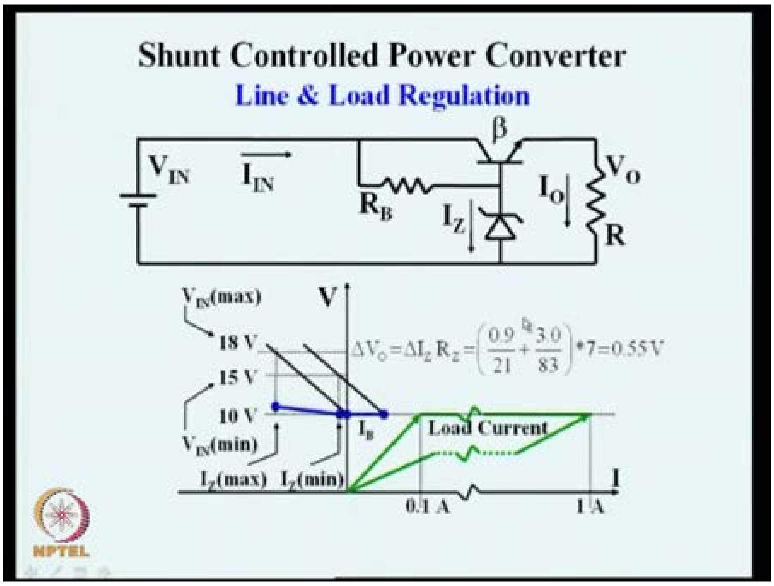

The full line and load regulation is the complete variation, in this case it is about 0.55volts on a 10 volts regulator, the regulation is 0.55 which is roughly 5 percent of the output voltage. So, this kind of regulation what you will get in a zener type of regulator and this regulation shown as a band here, minimum voltage to maximum voltage as a red line that you see here.

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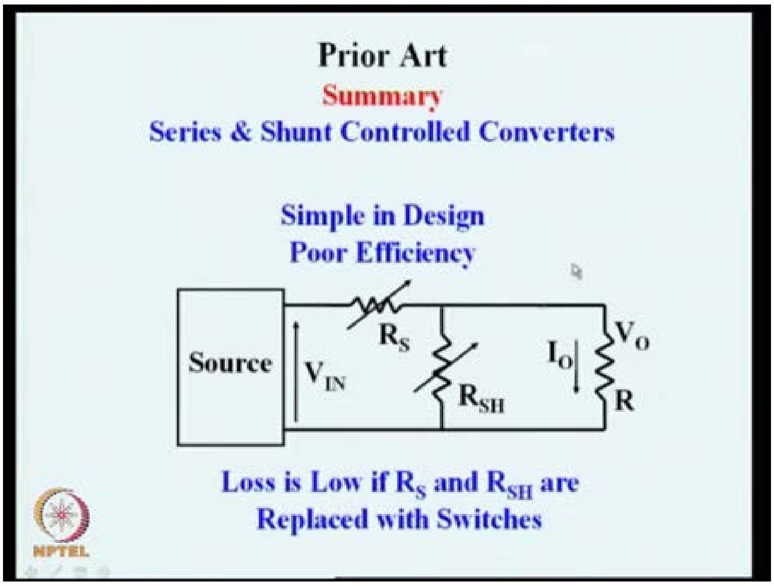

So, in summary if we want to put down what we have done up to now is to see the series and shunt controlled converter as the prior art. The general linear converter has a serious control element and a shunt controlled element. And it is possible to use a simple design with only controlling the series element or only controlling the shunt element it is very simple design, but very poor in efficiency. But the important point is we note is the losses low when R S is 0 or R S is infinity.

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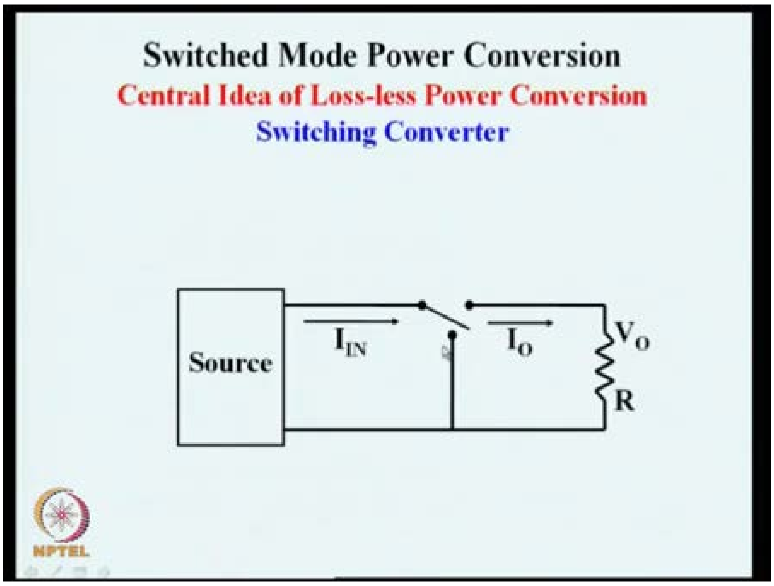

So, these are the points which give rise to the central idea of low- loss power conversion, which are switching convertors. So, we can have a switch which is connecting to the source or connecting to the ground or alternately another type where the current is supplied to the load or short circuited.

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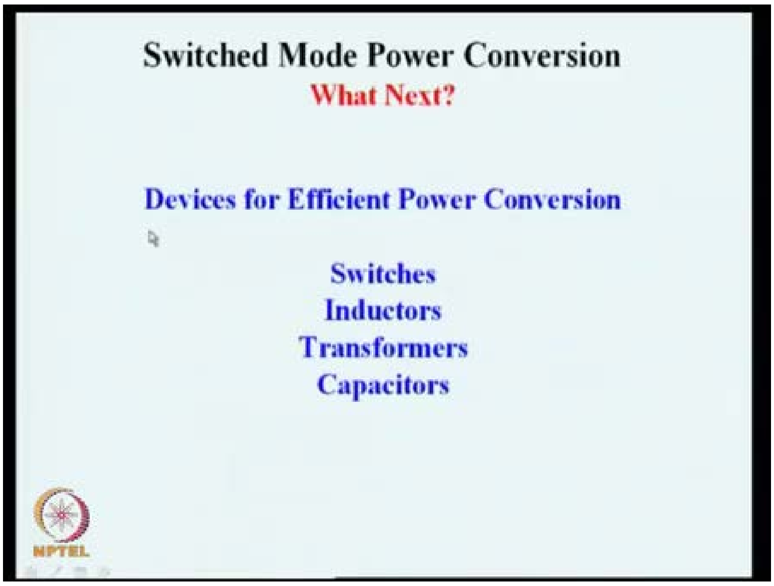

So, this is going to be our next topic exactly, how exactly we are going to learn about the devices the switches and various other elements and then see the characteristics of these elements. How they all will be connected to do the switch mode power conversion. If I again just want to say it one a simple slide here, the summary of the priorities or series are shunt controlled converter they are simple, but poor in efficiency. The important point is the elements have losses, in these losses are low when we have R S, the resistance either 0 or infinite. This gave rise to the introduction of switching power conversion and that will be the subject matter of our entire length of this course. We may have nearly thirty to forty lectures, but all of them will go on to extend this idea off switch mode power conversion. So, that is a materials which will following the next lectures, the device for efficient power conversion will be our next set of lectures, switches, inductors, transformers and capacitors.

Thank you very much.