Switched Mode Power Conversion
Prof. L. Umanand
Department of Electronics Systems Engineering
Indian Institute of Science, Bangalore

Lecture -1
Introduction to DC-DC converter

Good day to all of you, we shall now start this course on switch mode power conversion. It is a 40 hour lecture series, it will be handled by two people; the first 18 lectures will be handled by Professor V Ramanarayanan, from the 19th lecture onwards till the fortieth lecture, it will be handled by me. The first 18 lectures will handle the basics, review, the primitive convertors, discuss about the passive components, C L and the switches, power semiconductor switches and introduce you to the basic convertors and the and the design examples of few convertors.

Later on I will cover topics on modeling and control aspects related to switch mode power convertors. So, I shall discuss those topics from the nineteenth class onwards, after you have got sufficient back ground on the principles of switch mode power conversion.

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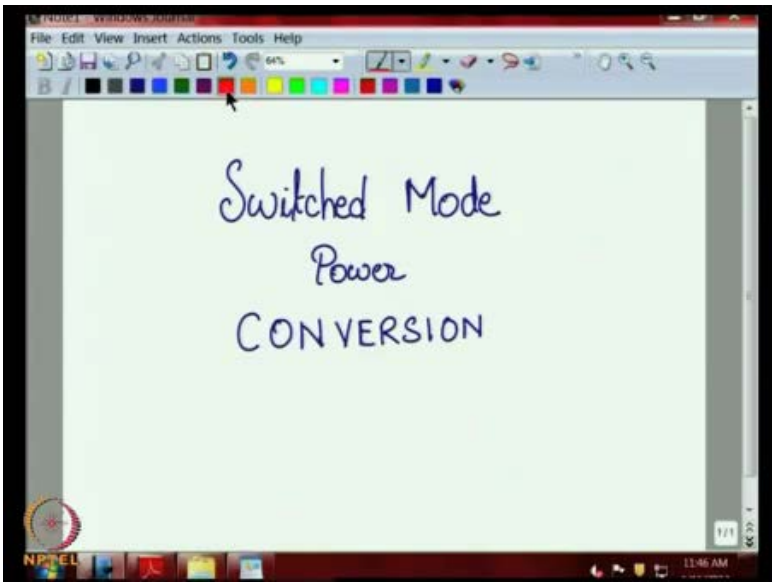

This is first of the 40 lecturers that will follow on switch mode power conversion. So, today we begin the first lecturer, which is an introduction to this topic of switch mode power conversion.

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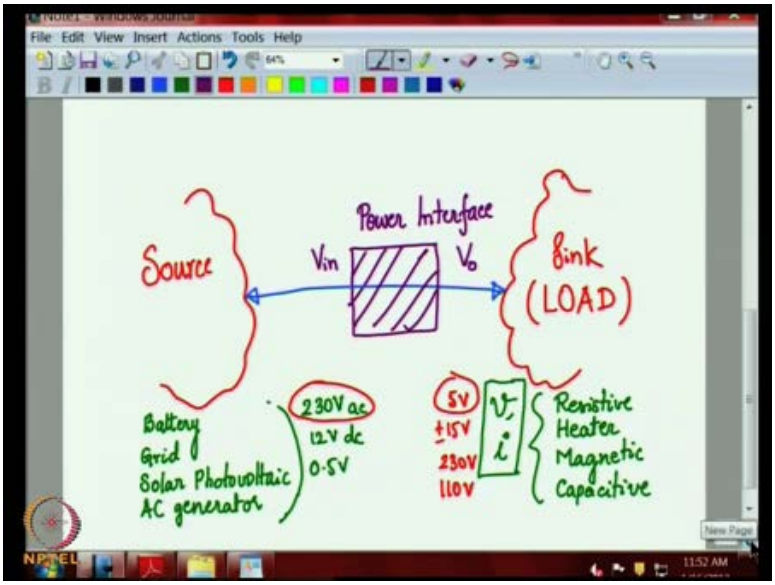

In most practical systems you have two aspects on one side, we have a source and on the other side we have a sink or more commonly we understand it by the term load power, has to flow from source to the sink. Sometimes from the sink to the source like in the case of the battery, if the load were a battery and then it was getting charged. When it is discharged, it could also flow in the reverse direction, so this is the situation in the most of the particle cases were we have sources and loads.

We need to connect these two together on the source side, we could have battery, you could have the grid or the means you could have the solar photovoltaic's any AC generator, so on and on. The load side you could have a resistive load heater type of load you could have. Inductive magnetic loads electromagnetic release electromagnetic machines motors DC motors, AC motors. You could also have capacitive type of loads many applications, which are used for heating application, lighting application, mass transport, energy transport, these kinds of things.

Now, these loads or applications demand voltage and current with some constrains on it. It should be 230 volts plus minus 10 percent, it should be 5 volts plus minus, so many people. It should be 3.3 volts or it should be 15 volts 12 volts. So, on the loads have been

redesigned or a specific input voltage. However, the sources may be design to give specific standard voltages like 230 volts AC could be 12 volts DC or it could be 0.5 volts from the photovoltaic things like that one. So, how do we match on the one side, the source voltages and on the other side the load voltages, which could be 5 volts 15 volts plus minus or it could even be 230 volts or it could be 110 volts.

Many of these loads have these kind of predefined voltages, so if you have a source, which is 230 volts AC and you need need to connected to a load, which is 5 volts, then they are not compactable. So, you need to make them compactable, you need to make the source and the sink voltages compactable and that is where, in between you have an interface box. This is a power interface and the job of the power interface is to make the voltage at the input compatible or connect to the voltage at the output, which is the load side voltage.

So, the load side voltage in the source side voltages or interface or connected by means of these power interface such that in compactable voltages in compactable source and sinks can also be connected together. So, that is the objective of this power interface and what is this power interface that is the scope of discussion for the entire course.

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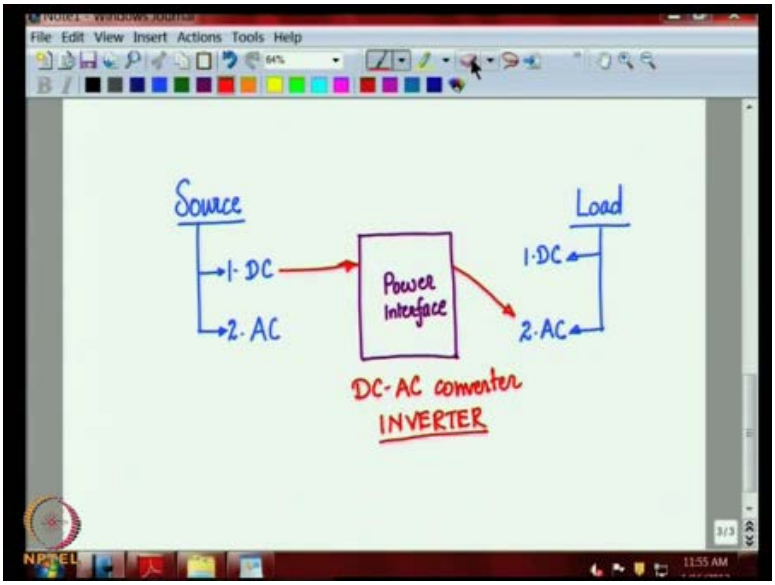

Now, let us say we have a source and let us categorized broadly into two possible categories one is that the source is the DC source, second it could be an AC source lot of possibilities, an on the load side you have two possibilities. Again, it could accept a DC

of some amplitude or it could accept AC. Our job is to make a power interface and this is the power interface. So, if we give from the source a DC input and we get a DC output, then it is called DC DC convertor. So, other possibility is we have a DC and we get out an AC, because the load may be an AC. You are using a battery and you need to dry AC fan or AC motor, so the power interface should do the job of getting out an AC in which case this is called a DC to AC convertor or more popularly known as inverter.

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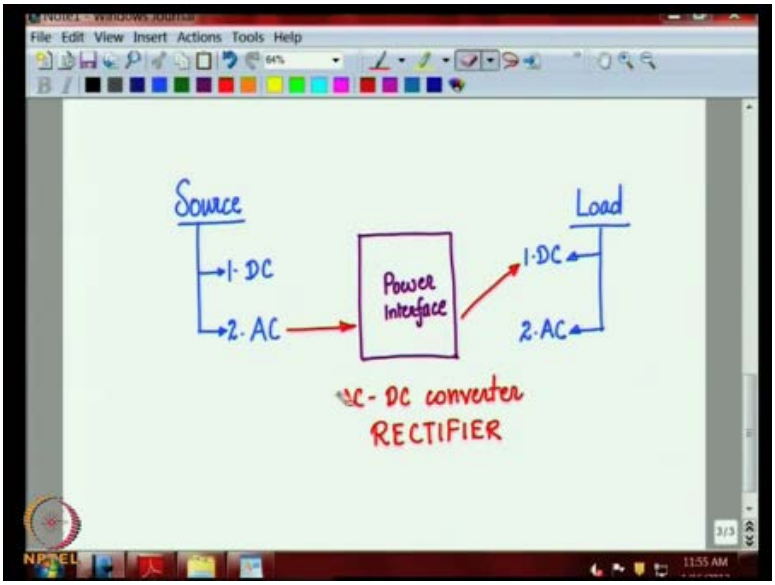

Now, let us take the option. You have an AC and you get out a DC you have an AC input may be from a 230 volts apply grids apply and the output of 5 volts or 15 volts DC supplying to a DC loads, which case you have an AC to DC converter more popularly called as the rectifier. Finally, you have the other possibility of giving an AC input and getting an AC output.

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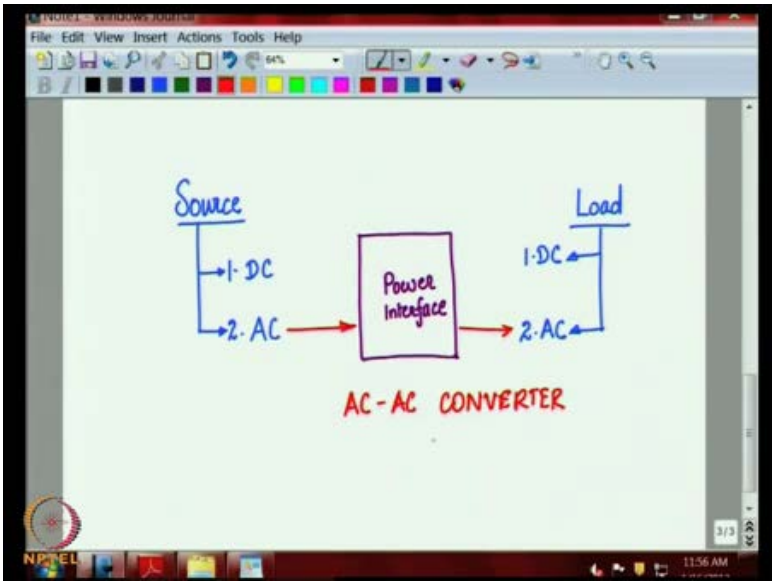

So, you have AC to AC converter, so these are the 4 meter categories of converter that you can, we search. You can see and we will be focusing mainly on DC to DC, DC DC converter only one among the four.

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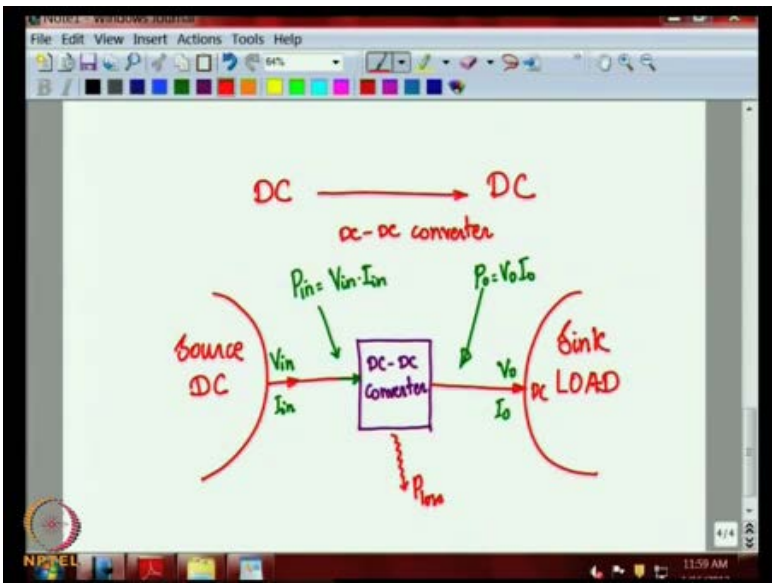

So, the DC DC converter all about it it is an introduction, they analysis the way you go about synthesizing designing and designing the controller. All those will be discussed in other course of this 40 hour lecture course. Now, if you take the DC DC converter, you have the source which is a DC, you have the sink or the load which needs DC input at

some voltage V naught the source is at some voltage V. We need to interface the source and the load, which may have in compactable voltages different amplitude of the DC V. In amplitude may be different V naught amplitude may be different.

We need to interface this by this DC DC converter. Now, the moment you pass through a converter, the power that is fed at the input P in is equal to V in into I in those are same. The power that is coming at the output P naught, which is equal to V naught I naught. There is an input current associated with this coming out to the source, there is an in output current, I naught associated with the load load current there will be some loss P loss. So, if you put in this equations P in the input power should supply the output of course, plus the loss component.

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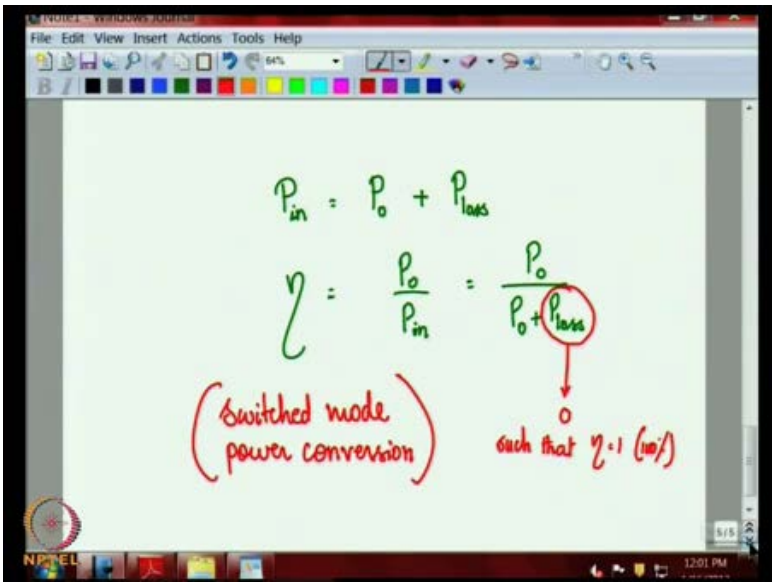

So, the efficiency is P naught by P in or P naught by P naught plus the loss component of the power the whole focus here is to see that this goes towards 0, such that efficiency is 1 or 100 percent in terms of percentage, so to meet the loss 0. The concept of switched mode power conversion is employed the switch mode power conversion basically uses the following concept.

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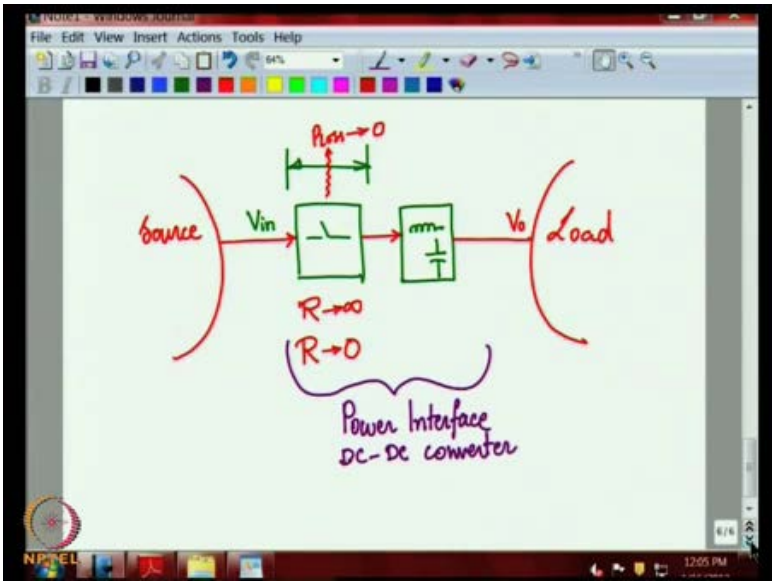

So, let us say you have the source; you have the load. Now, this source is at V in instead of having a linear device inside. Let us say you have some kind of switch device, which will either go on or off the reason being that the power loss across this P loss should 10 to 0. So, when will P loss 10 to 0 either when this series element is having are the series element has an impedance or which tends to infinity in which case current i is equal to 0 and the volt and the drop across the element is negligible. Other case is when the impedance is training to 0 and the voltage across the series element 0.

Then also the P losses 0, so we would like to have the series element has a switch such that it has only these two states or infinite or 0, wherein the both the cases the P losses 0. Then ideal since goes and this is followed by some kind of a filtering with non dissipative elements like inductor and capacitor and the filter output is the v naught that is given to the load. So, this is the basically the concept that will be employed throughout you will be using switch, which can take only these two states on the losses minimal and you will be use the filters based on inductor and capacitors, because they are non lossy.

This together composes compose together is the power interface. As this is DC to DC matching in it is called a DC to Dc converter, so this is essentially what we will be a trying to discuss in the course of this. This 40 hour lecture series we have sources DC source and we have a load which expect DC voltage and we want to match the source to the load by means of this power interface. The power interface in order to have minimum

loss will be composed of switch and filter elements they filter elements and non dissipative no resistive type.

Therefore, overall the loss of the power interface will be minimum, so how we go about building the different circuit topologies. What are the component that go to make up these power interface that is the switch, which is the normally a power semi conductor switch. How to design the magnetics for the inductors and the captaincies? The analysis the equation and the design, how we go about doing the design of the various topologies? This would be the focus of the course let me brief you now about go about the course.

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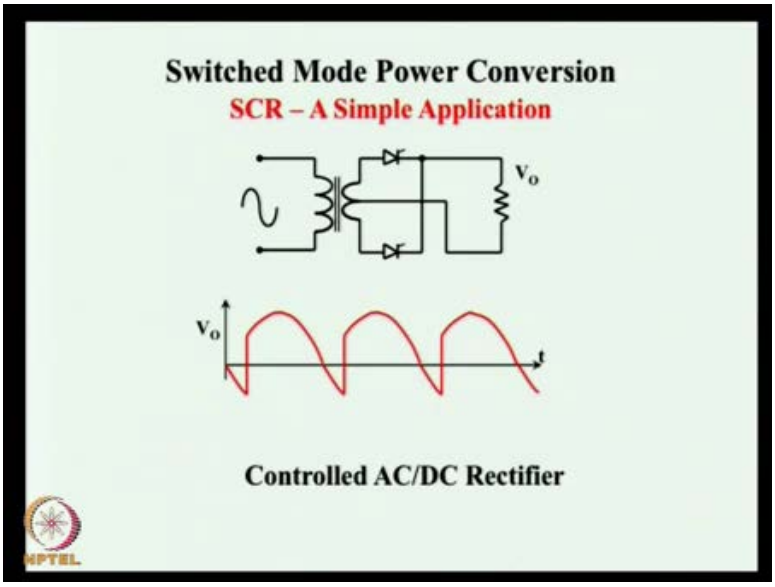

What is the sequences and which we will be discussing, so first the topic of first in the topic of the switch mode power conversion the AC to DC rectifier will be handled, because most of the case you may not have the DC directly available to you. Most of the time, the source is coming from the grid or the means, which is AC. That needs to be converted into DC. Therefore, a c d c rectifier is employed so very briefly the rectifier will be introduced such that you will be able to get the initial DC input voltage in many of the cases simple rectifier based on SCR will be explained.

However, notice that SCR is a switch a power semiconductor switch the diode is a switch a power semi conductor switch the BJT or the bipolar junction transistor the MOSFET field effect transistor the IGBT. They are all power semi conductor switches, even though I am starting here worth am rectifier based on SCR silicon controlled

rectifier. We will not be discussing much about this SCR switch most of the discussion in future classes will be based on controlled switches where you can control the switch on state on to off and off to on, both both the transmission are controllable.

That is the like the BJT the MOSFET and the IGBTs, these are the switches that will dominate in the classes to come. However, the SCR are good devices that can be used for this rectifier application. This is nothing but a simple rectifier circuit, you have a AC input the ac is rectified by the SCR and control rectification and given to the output this will be followed by a discussion on what are the different types of the switches that we would like to employee?

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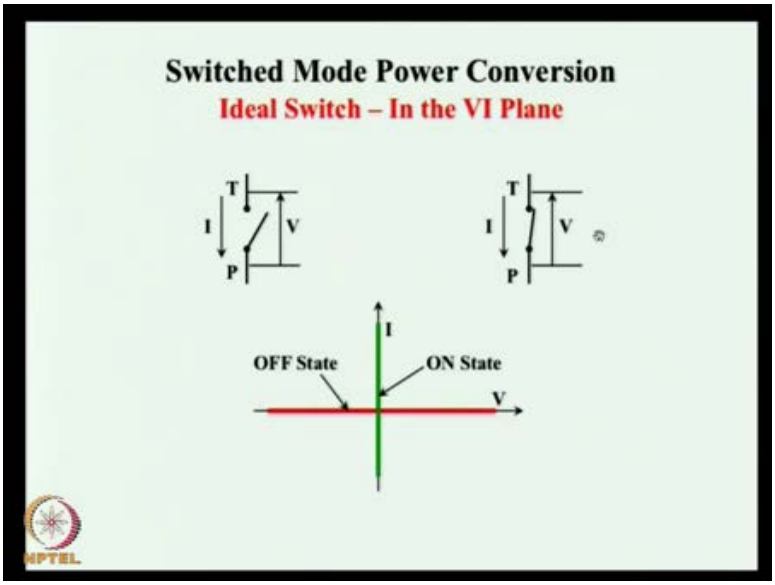

The power semi conductor switches and have a look at what is an ideal switch and do understand about the idealness of the switch and ideal nature of the switch, the requirement that we want it is done with the help of the I V characteristic. This is call the static characteristic, you see here during the off state the switch should be able to with stand voltage both positive are negative and during the on state when the voltage a crosses the switches is 0.

The switch should be able to carry current both positive and negative, but remember that none of the practical switches will be able to have all these four quadrant operation. They are limited to few quadrants, which we will be discussing in the course. But this is one of

the points that we will be trying to touch up on the switch and nature of the switch will be initially discussed.

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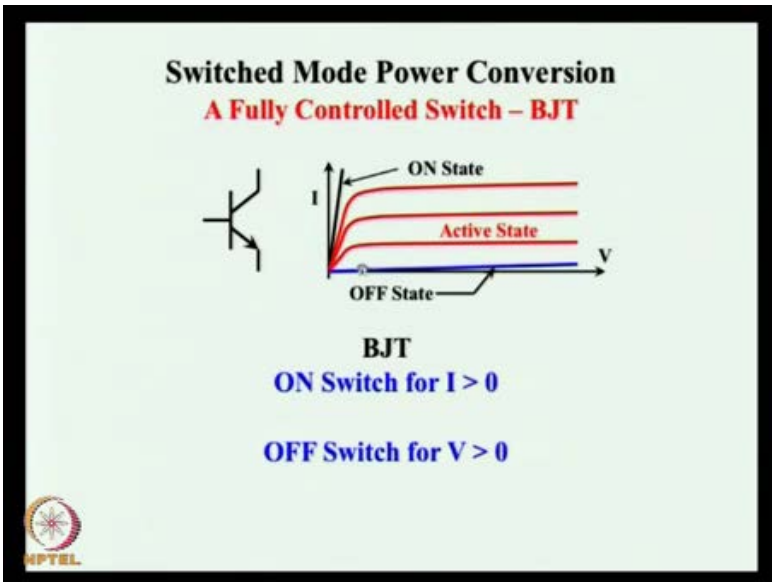

While discussing the switch we will be taking about I V characteristics were the on state in the off state comes where the active region is.

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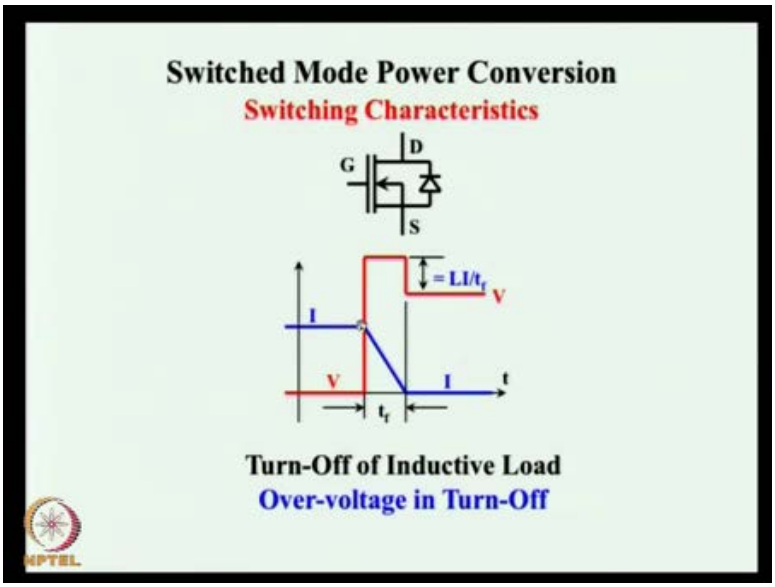

What are the dynamics involved in the switch you see that no switch ideally, we would like that the transition from off state to the on state in the on state to the off state occurs at in 0 time instantaneously. However, now practical's switch will the able to achieve

such instantaneous transitions, they will have finite rise time or finite fall time and we need to discuss these transitions switch transition. They call the switching characteristics this is very important because during the time in that transiting the voltage and the currents, through the switches are not a finite unlike in the fully on condition were the voltages 0.

The fully off condition the current is 0 and the power losses are minimal, but during the transition both the voltage and the current is present, and the losses are non 0. These are called the switching losses, so you need to understand the characteristic off the switch particular switch during switching on and switching off in the present of inductive loads in the present of resistive load or capacitive loads next to that one.

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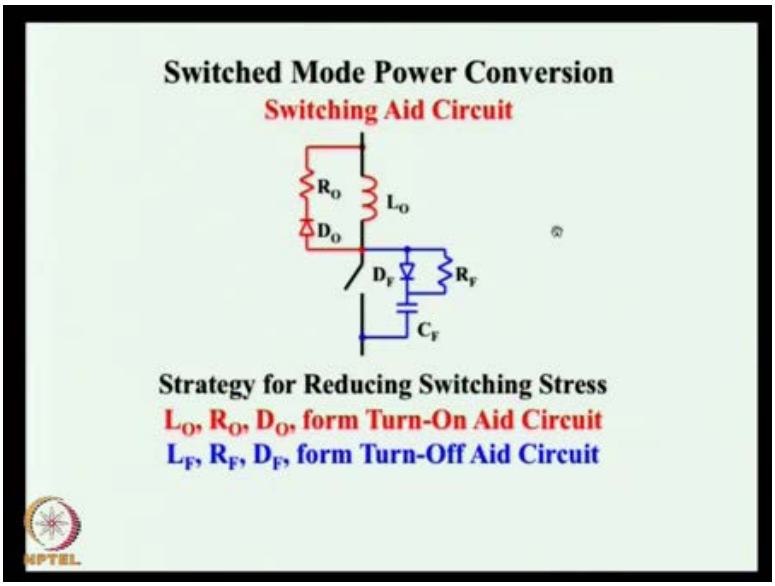

Then while discussing on the switch is in order to address the issue of switching transitions turn on and turn off the stress on the devices maximum during the turn on and turn off, because we see that there is loss during that time. Not only that there are the electrical stresses during turn off the voltage stress across the switch. If there is inductor present the there will be a huge voltage kick which can stress the device.

During turn on there could be parasitic capacitance across the device, which will try to have huge current through the device. So, you need to d stress the device using turn on and turn off aid circuits call the snubber circuit, it is snubs the stresses. So, these are

called the switching aid circuits, they will be discuss the turn on snubbers turn off snubbers.

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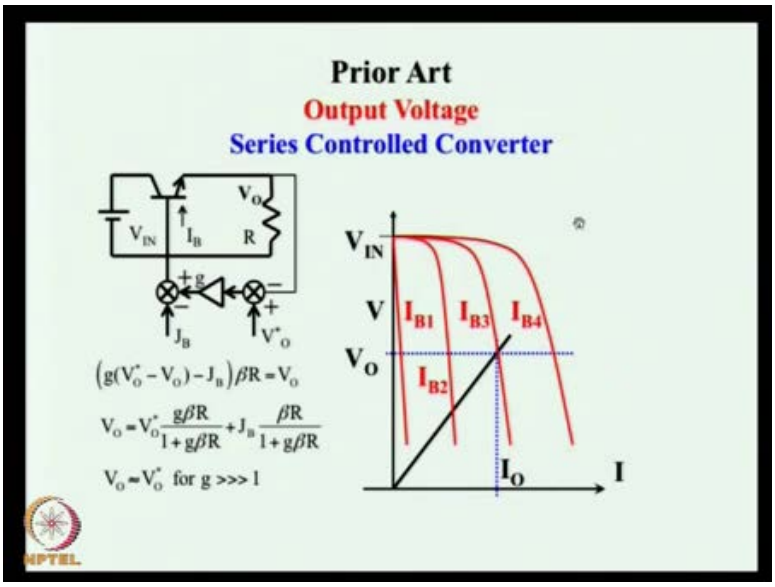

This is one aspect that will be discussed in the course of the in the course of the discussion on switch mode converters then after discussing about the switches. Before we actually go to the converters a brief discussion will be held on prior art what people were doing to interface the source and the load. Before the advent of the switch mode power converters, so people were using linear regulators were the linear power interfaces. We shall briefly study about this, such that we will able to appreciate the advantages of the switch mode converters over the linear converters.

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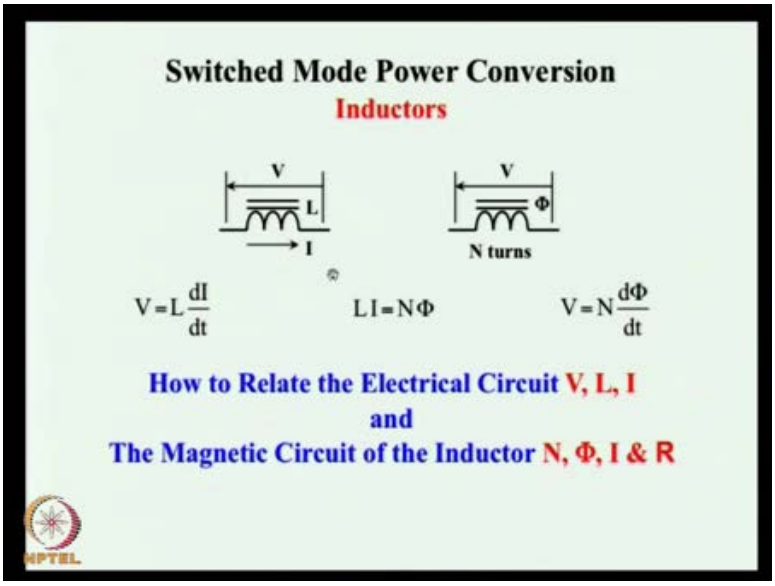

We then come to the discussion on inductors the passive component inductors in the capacitors, so will take up the or ah inductor fast try to understand understand it first from the paradise principle V is equal l d I by d t V is equal to n d pi by d t. Then try to go a bit inside the inductor and see look at it from the magnetic properties and how the magnetic and the electrical properties are inter related? This is very crucial because the inductor will have to be designed by you and they will have to be owned by you on a score specific application. They are not available of the shelf, so it is crucial to the design of the whole switched mode power conversion.

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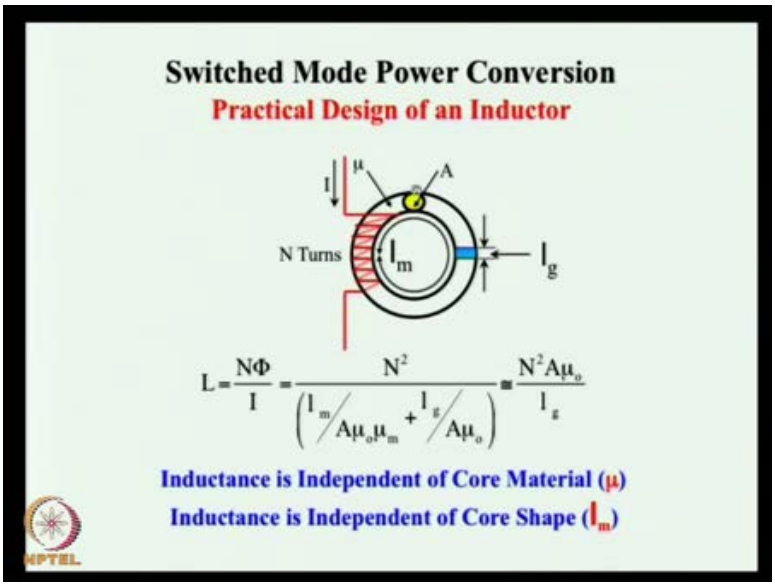

So, the various magnetic a cores that are available and how we will go about doing the design using the area product? Approach all these will be addressed when we are discussing on the inductors and ultimately to go to words practical design and implementation. So, this is one major important topic that you need to understand not only the inductors while we attaching uponing the magnetic later on.

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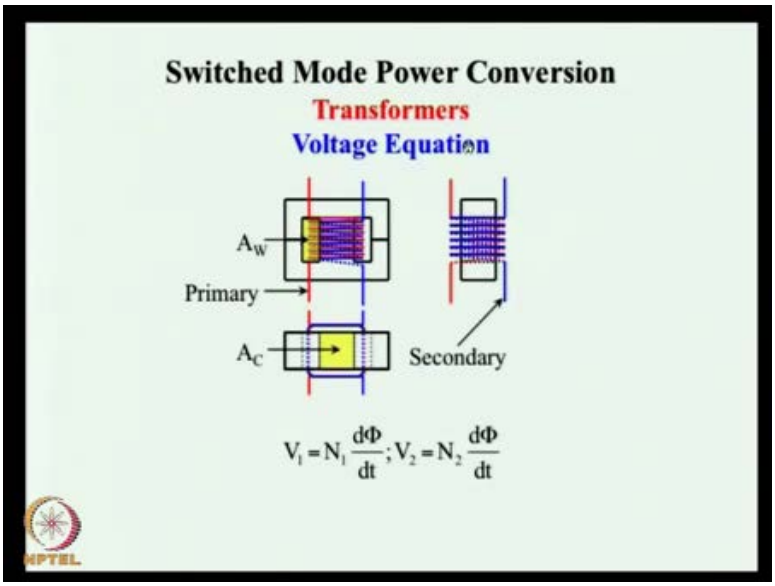

We would also initially we will talk an inductors and later on for the down in the course we will also talk on the transformers and how we would use this transformers and switch mode converters high frequency transformers in a way which will which will give additional degrees of freedom in making the input and output more compactable. They also will be based on the paradise loss V is equal to N by N d pi by d t the fundamental paradise a principles.

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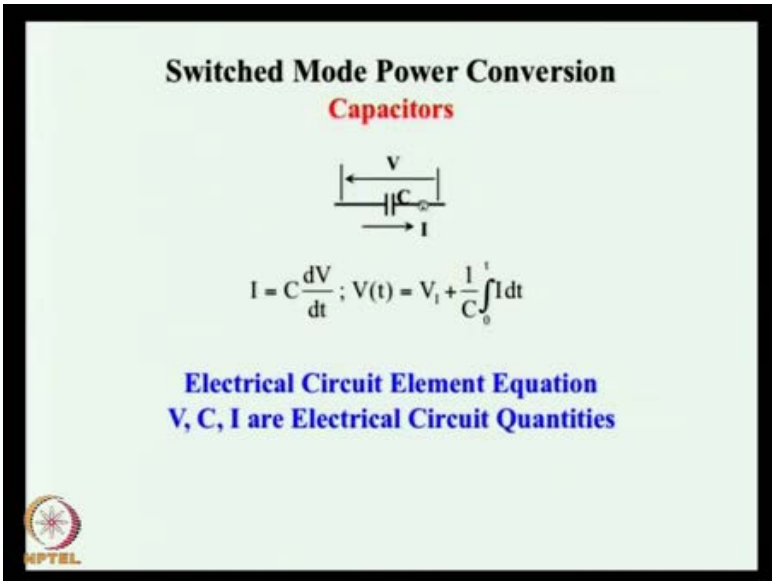

How this will be followed by a discussion on capacitors? The capacitors are energy storage elements like the inductors, while the inductor stores the kinetic energy that is in terms of the flow the current of lies squares. So, the current the flow of the current by virtue of it, by virtue of it flow hey the energy. That is stored is called the kinetic energy and that is where the inductors come to the picture and the capacitors store the potential energy of C V square a by virtue of storing the charges a across dielectric elements.

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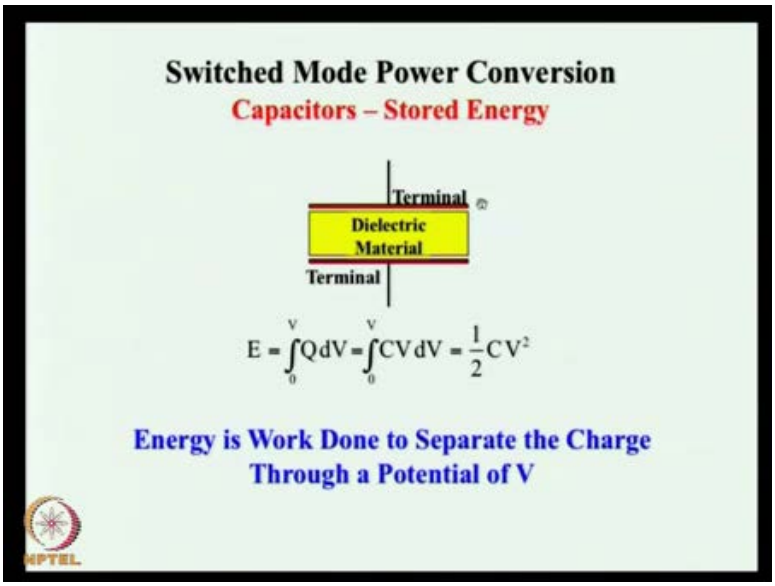

The storage in the capacitors are discussed and the various properties of and non idealities in the capacitors or also discussed in the course.

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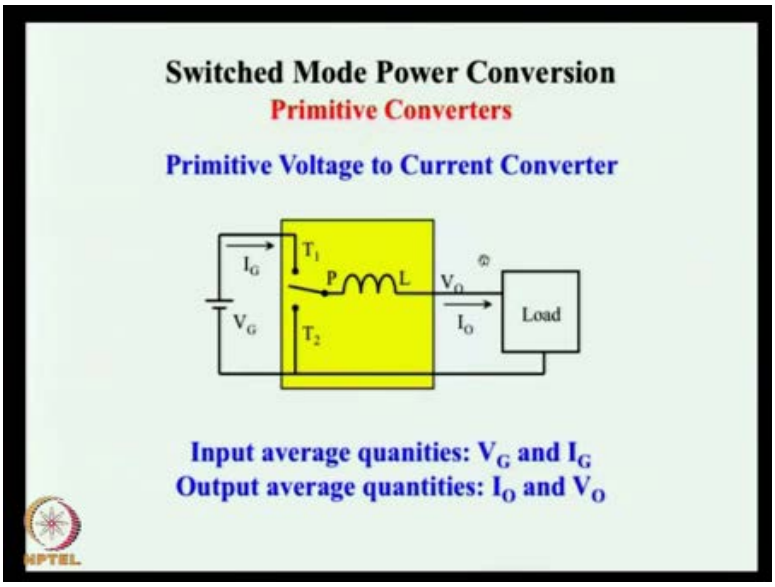

This is one's, we have discussed all the components of the switch mode converters, the component meaning the switches the power semi conductor switches like the b j t is the moss crate the IGBTs and diodes it is static characteristics and the dynamic at the switching characteristics. Then the passive passive components like the inductor and the capacitors and of course, the transformers we are ready to start discussing on the topologies of the converters. So, we starts we begin by discussing primitive simple converters DC DC converters a primitive voltage converter voltage to current converter will be discussed. This, less the crowned work for the more practical advanced converters to come up.

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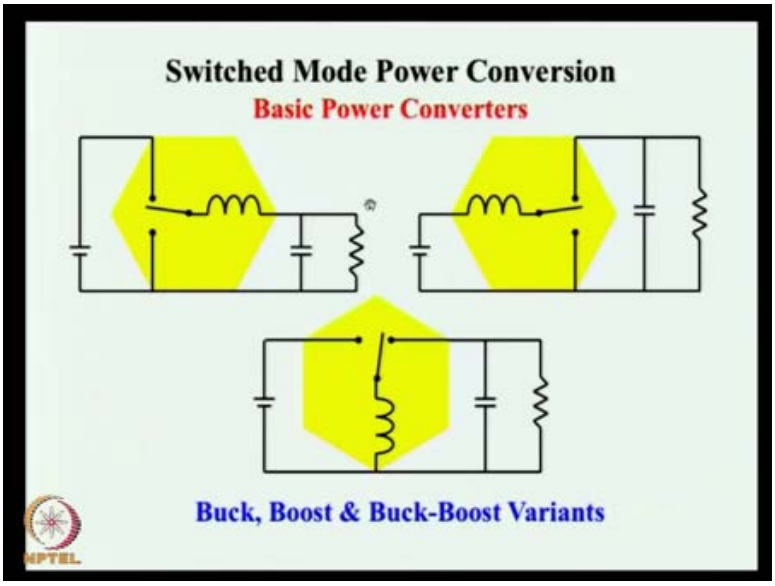

The primitive converters will lead to three fundamental converters, the basic power converters; that is what we call them. You have the buck converter, you have here are the step down converter, the input voltage will be step down to a lower value, a lower output voltage. This is a one basic topology, the second topology here is the boost converter, the input voltage is boost adopt to higher voltage here. So, this is the boost converter see that this is this is called a primitive converter topology. A single poled double through switch along with the inductor in the pole the primitive converter.

Another a configuration is the buck boost converters input voltage can be either step down or stepped up in this converter, by adjusting the time set, which the pole is at this through are at this through. So, these three converters are called the three basic converter, the buck boost the buck boost variants and based on this three you have many derived varieties and very derived converters both non isolated and isolated.

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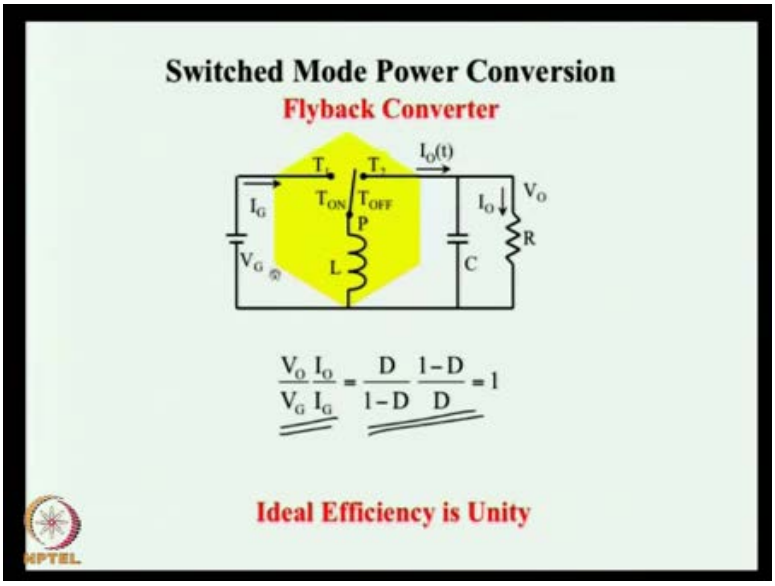

The buck boost converter also called as the fly back converter is a very popular converter which we will discuss much later many converters are derived from this topology. Fly back converter isolated fly back converter is one such and it has a pretty good efficiency to, so this is one of the topics at will be discussed.

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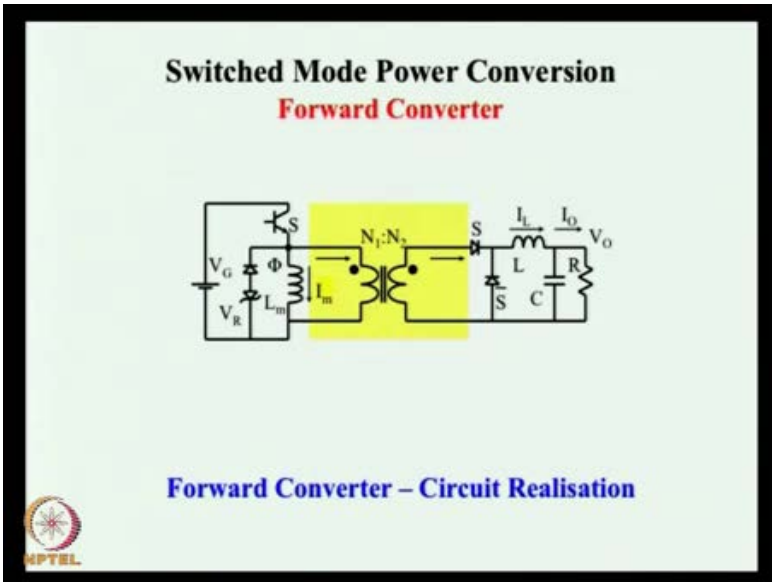

You also have other topics other topologies of the converters the forward converter where in the output side the is filtered, so the switching the EMI and EMC at the output side will be reduced, much reduced switching component or switching ripple on the

output will be smaller. Also have isolation galvanic isolation between output and the input, so this is one type of topology. Many derivatives out of rate, which we will be dealing with forward converter the push pull converter.

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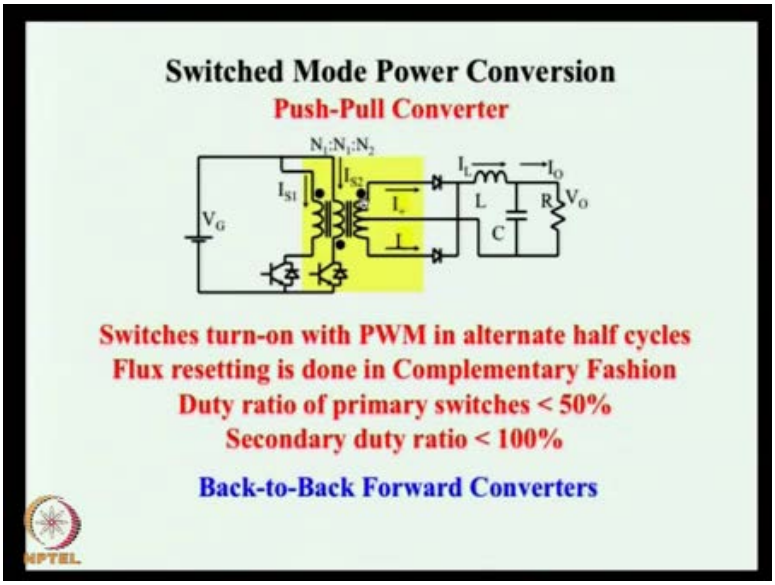

Again for push pull, push pull converter is another derived version of the forward converter or the buck converter the push pull converter is then leads to the half bridge converter, which again other derived version of the forward converter which is another derived version of a buck converter.

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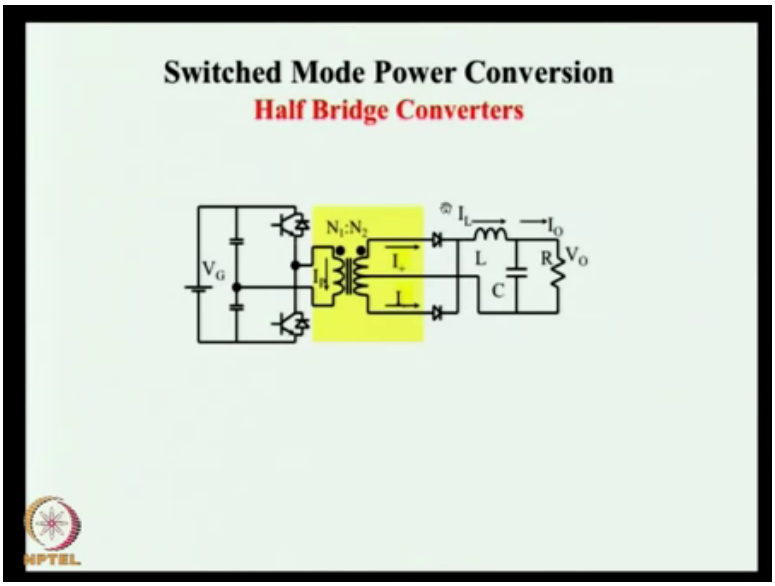

The basic converter and then you have the full bridge converter were in you have a many other advantages as we will be discussing in the class.

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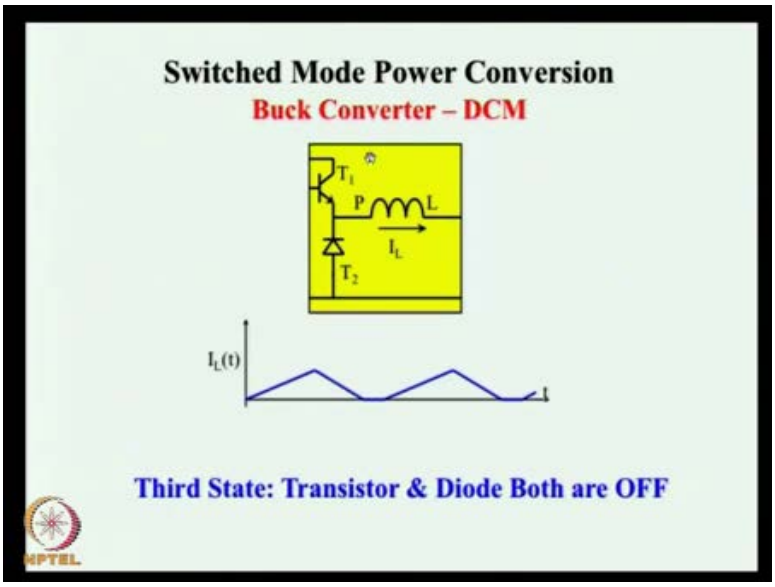

So, these variants of the basic converters will definitely the the practical variant will be a delta with in detail both in analyzing modeling and design. The next topic would be on interesting part which is called the discontinuous mode operation, so the inductor current so inductor we said was a storage element, which stores energy the kinetic energy by virtue of the current flowing throw it as half l i square. So, if if the in every cycle the entire energy in the inductor is removed and transfer to the load. Then you you, the current here will go down to 0 like this. The current become discontinuous, then such a state is called discontinues conduction mode, when only part of the energy is remove.

Then the current does not reach to 0, it is over above 0 and the current flow in the inductors continues, then that is called continues conduction mode. So, initially we will be discussing mainly the continues conduction mode operation, which will be the later. Now, followed by discontinues conduction mode operation. There are many advantages in the discontinues conduction mode operation to especially many practical circuits. We do employ the DCM mode of operation. So, this will be discussed in some detail later on in the course.

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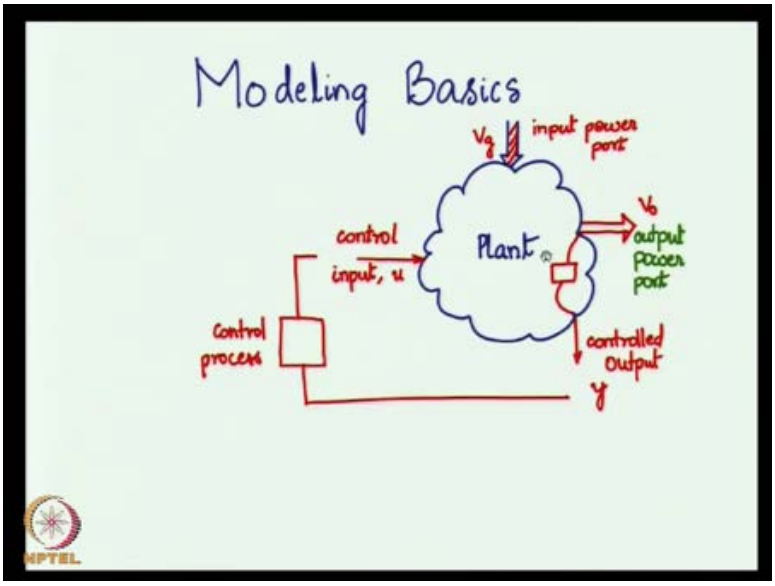

This will be followed by another important topic that is modeling, see after understanding the operation of the converters, one should then understand, how to go about modeling, the converters, the reason that you need to model the converter is that a mathematical representation. The converter will lead to better control controller design you need to clues the loop and a controller needs to be design such that the output voltage is controlled.

So, the plant which is the DC DC converter will be modeled and mathematical representation of it will be brought out and then using that mathematical representation, the controller will be designed and used for controlling the some variable either it will be the output voltage or input current in the unity power factor type converter cases beings like that.

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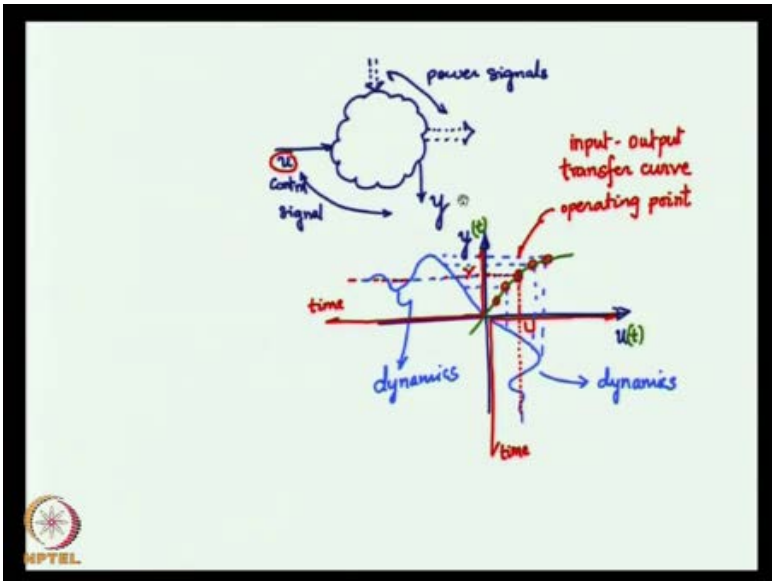

So, briefly we will be discussing about the non linearity's applied. It is non linear and what is the operating point and the operating point swings and the non linear way. How we go about linear rising grid? What are the principles used the linear rising? Then trying extract the linear rising the mathematical representation of the DC DC converters.

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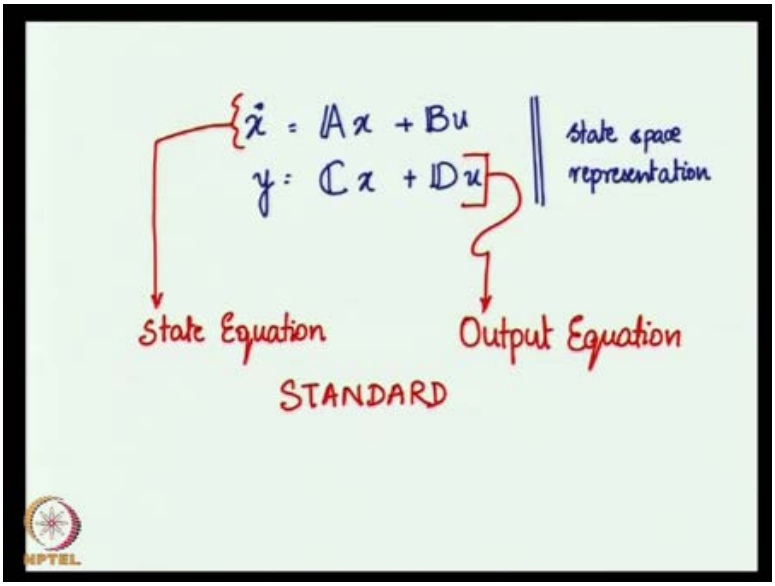

So, these issues will be delta with and we will try to also discuss about the state space representation. Try to bring the a plant, which is the DC DC converter in a standard form in this state space form x dot is equal to A x plus B u y is equal to C x plus D u form

called the state space representation, such that it becomes amenable for the controller design portion of the system.

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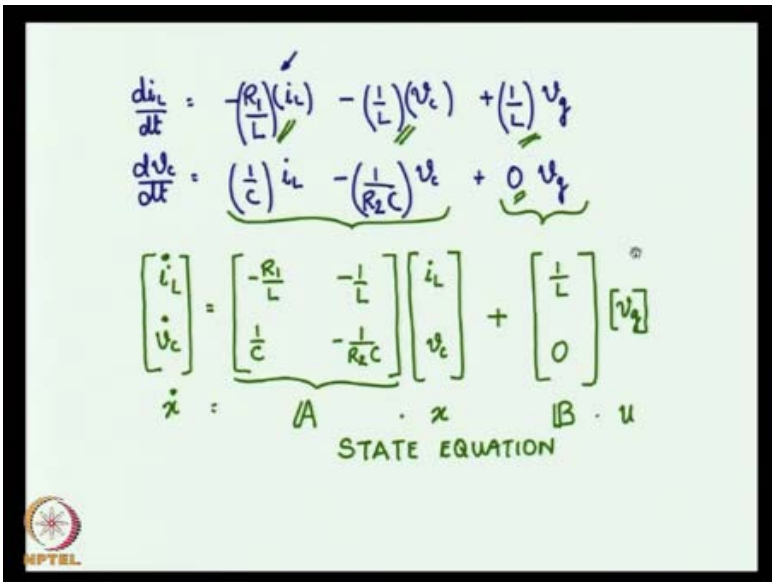

Not to get worried here, we shall go in a step by step approach on how to identify the state? How to obtain the state equation, the dynamic equation and from the dynamic equation how to go about the obtaining the state equation? All these things we will try to discuss in a systematic and step by step way and try to obtain the mathematical model of the converter of any converter for that matter.

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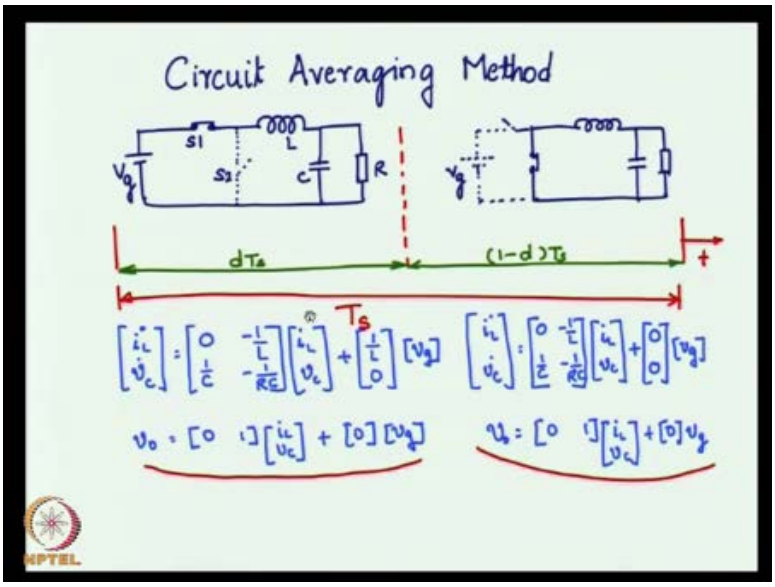

So, you should be able to achieve get the mathematical model of any given converter by up by taking the generic approach, that we will discuss in the in this lectures. Now, circuit averaging method is a important technique that we will be employing for switched mode converter circuits, were the switch mode converter circuit you will see that the circuit can be split into two or three modes.

When the switch is connected to one of the through on the pole is connected to one of the through, the circuit is in one form. When the pole is connected to another through and circuit is in a different form, so it is a different circuits. So, the states equation model for both the modes is taken. Then the state is average and that is called the circuit averaging method. How we go about doing this and we will be discussing in quiets some details as as we go through the classes.

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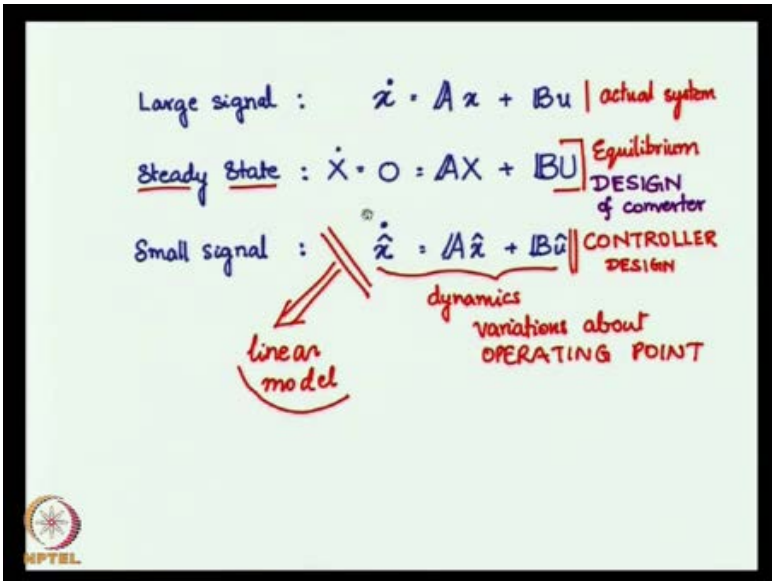

We shall obtain many different types of models we call the large signal model, which is the model where the operating co point and can swing throughout the range it could be non linear also, need not necessarily the linear. We have the steady state model were during steady state, when there are no dynamics, there are no the all the deviations with respect to time become 0. What is the steady state model very much used for design purposes design of the converter to rate the switches, rate the components.

Then you have the small signal model, which is used primarily for controller design because the small signal model gives ideas about, what happens when the operating

points swings in the neighbor wood of the nominal operating point? What are the dynamic involved? The small signal model is essentially a linear model we linear rise them and therefore, this is amenable for controller design. We will be designed the controller based on the small signal model. So, how do we obtained these various models from the mathematical model using circuit averaging in technique, will be a significant topic, that will be discussed in the course of this course.

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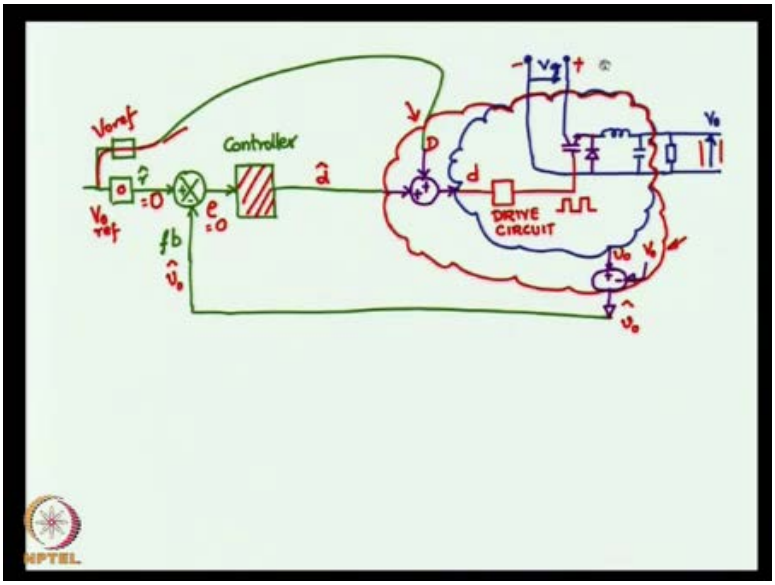

Once we have attained the magnetic module the mathematical model of the DC DC converter, we shall go on to discuss the controller structure diagram, the controller block diagram and how we go about designing the controller for a given switch mode converter system.

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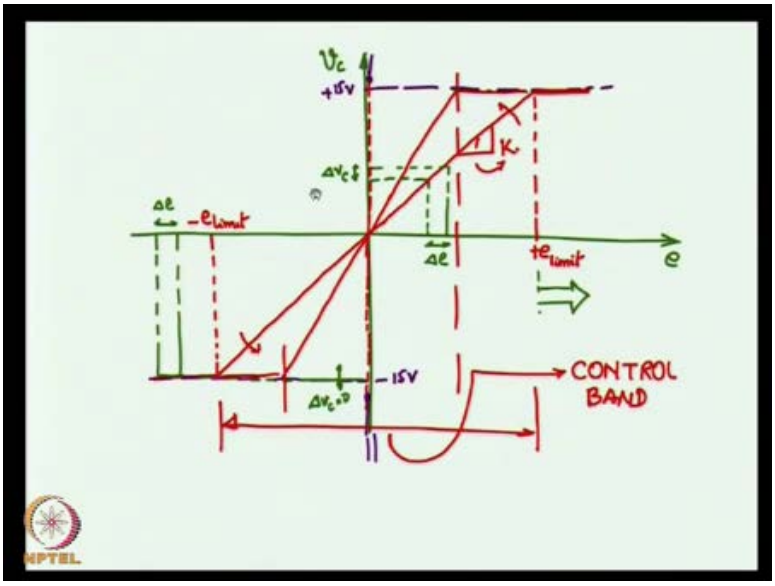

This is discussed in quite some detail the controller aspect; we discuss about what is the controller band, what are such saturation phenomena? At what point saturation occurs? What is the saturation limit? How do we set that, how do we set control band? These are some of the issue that needs to be addressed in detail and these will be discussed in in the course of the 40 hour lecture.

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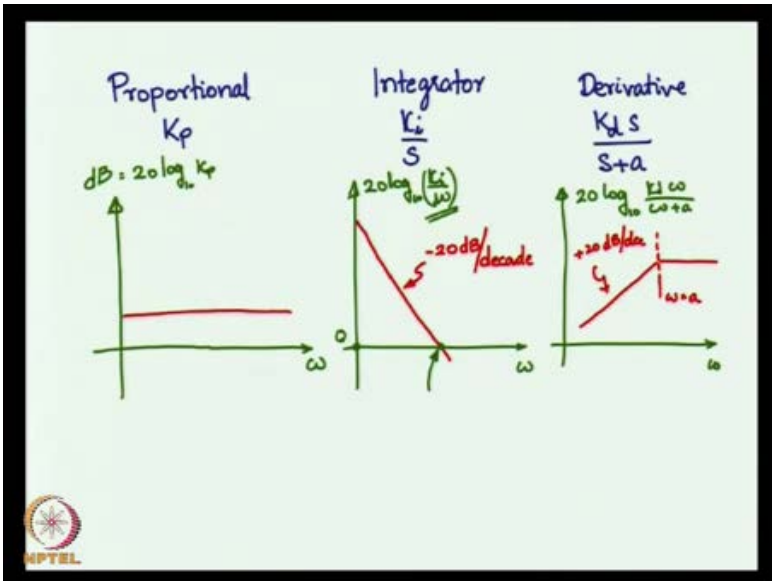

One of the more popular controllers; that is the proportional integrator derivative PID controller will be discussed in quite some detail. How we try a trying to understand the

way significance of the proportional part, integrator part, the derivative part and how we go about analyzing the system in the presence of these standard PID converters? How we go about designing the PID are controller for the converters?

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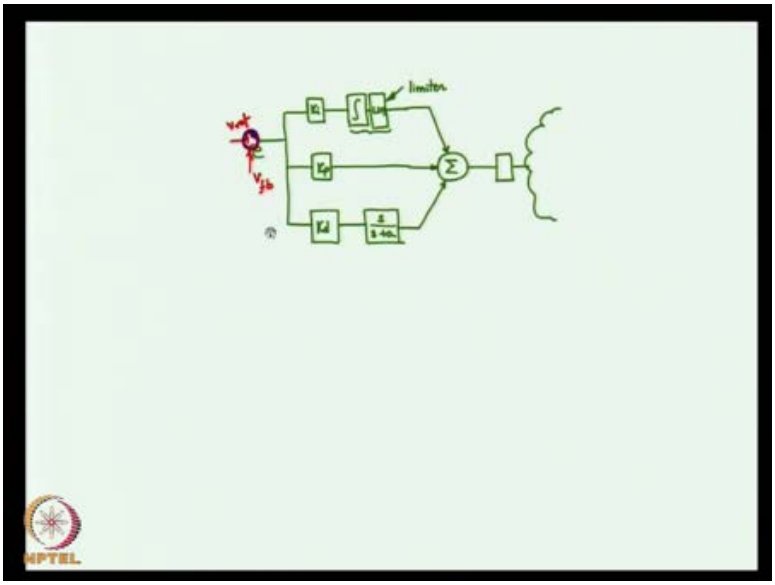

The topology of the PID converter will be discussed along with…

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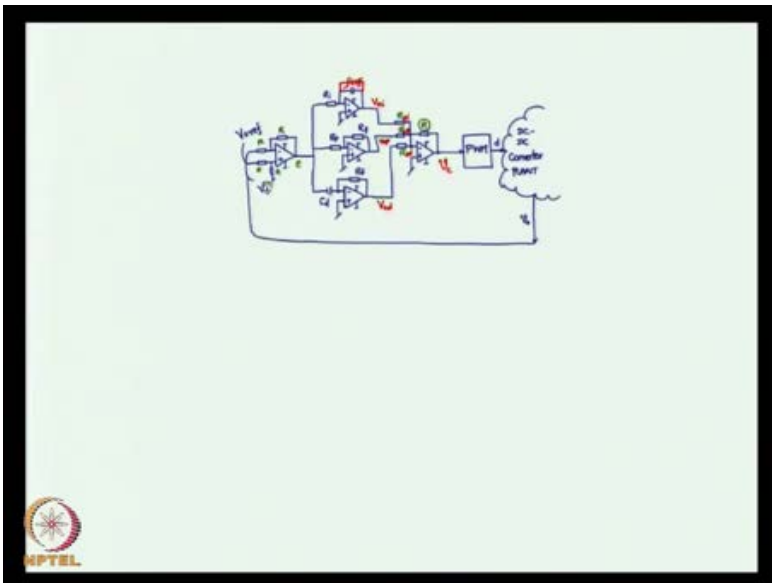

How we go about implementing them with op-amps? Then also probably in the discrete domain the algorithms, these will be discussed.

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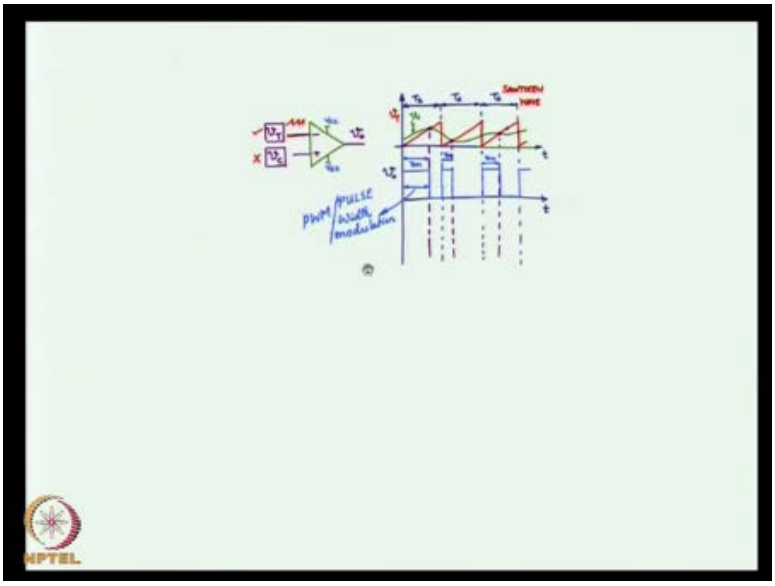

This will be followed by a discussion, I want about discussion on the pulse with modulation. How we obtain the pulse with modulated wave form which will actually be the basics pulses are the gate or the dry pulses, which will turn on the switch turn off the switch the information signal, which needs to be given to them. How do we generate this? How do we go about integrating it along with the controller to give the specific a gate pulse to the various power semi conductor switches?

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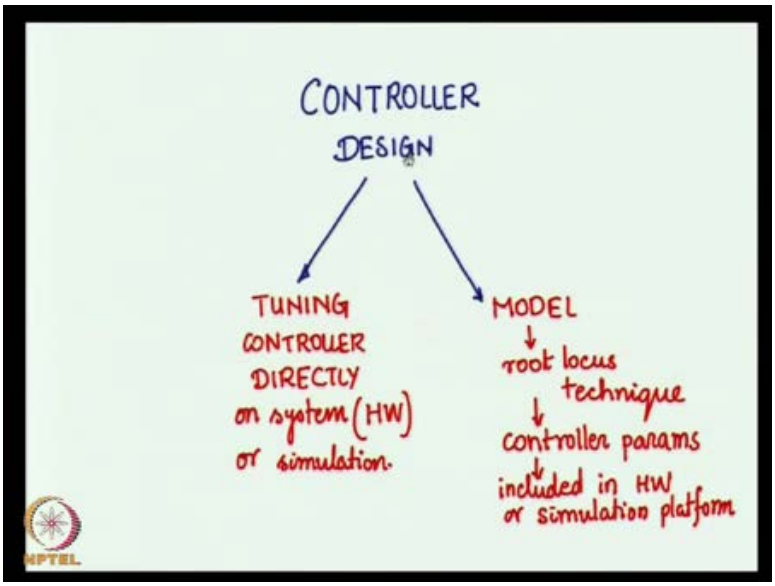

This will be followed by a detailed discussion on how on the design of the controller excel. So, there are two basics methods; the tuning the controller directly on the system. This is by turn error and how we go about systematizing systematizing this turn error approach, directly on the hardware this is address first. Then the model based we have gone about studying the manner and which, we can obtain the mathematical representation of the switched mode converter. Using that model, how do we use the first root locus technique to design the controller? Then how do we use the a state space method to design the controller and how to include this controller parameters into our modeled?

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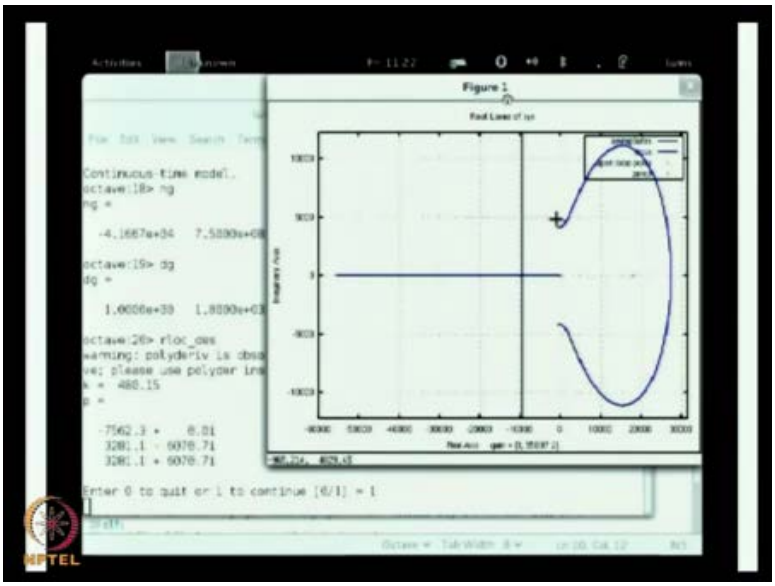

We shall also a try to learn abate about simulation simulating the model and trying to design the controller iteratively by using simulation tools, either MATLAB or octave can be used and we will try to demonstrate that as we go long.

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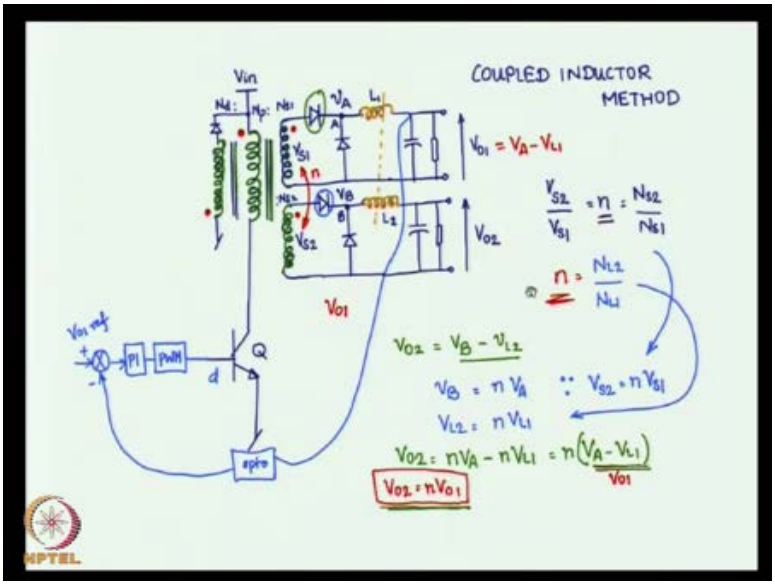

Then we shall come to some design challenges and examples, how do we the control control the output? How do we control multiple outputs in a switch mode converter? These are issues challenges that need to be addressed and we will be discussing them significantly the coupled inductor approach.

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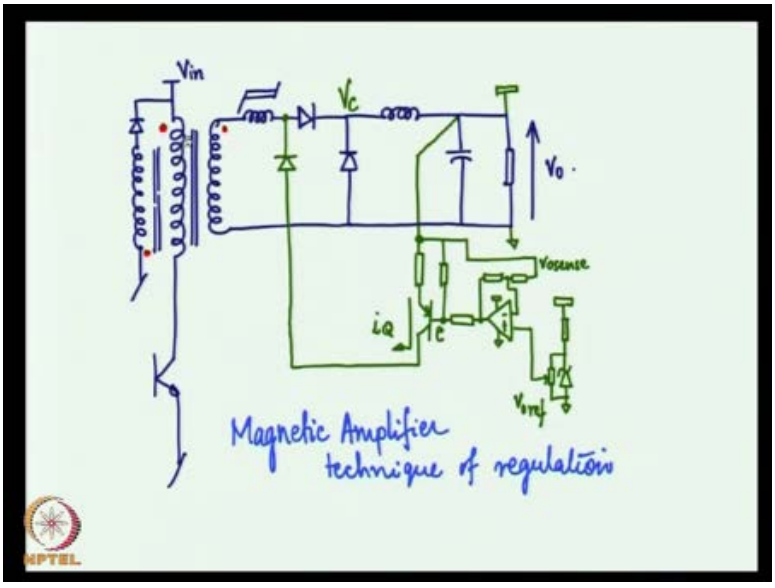

We will also be discussing in the magnetic amplifier approach to control multiple output.

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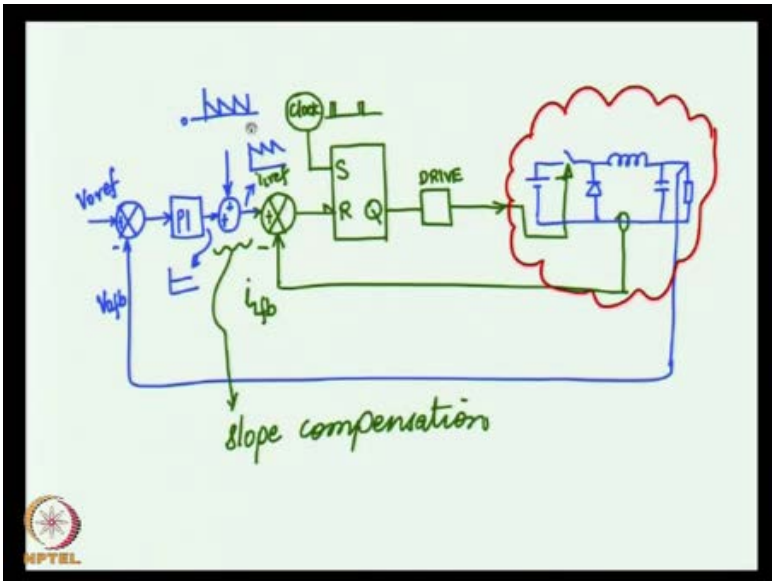

We will also, we discussing method to control the current. You see most of the lecturers previously we would have discussed, how to control the output voltage? We also will discuss methods control the current in the inductor current control slope compensation the issues of slope compensation.

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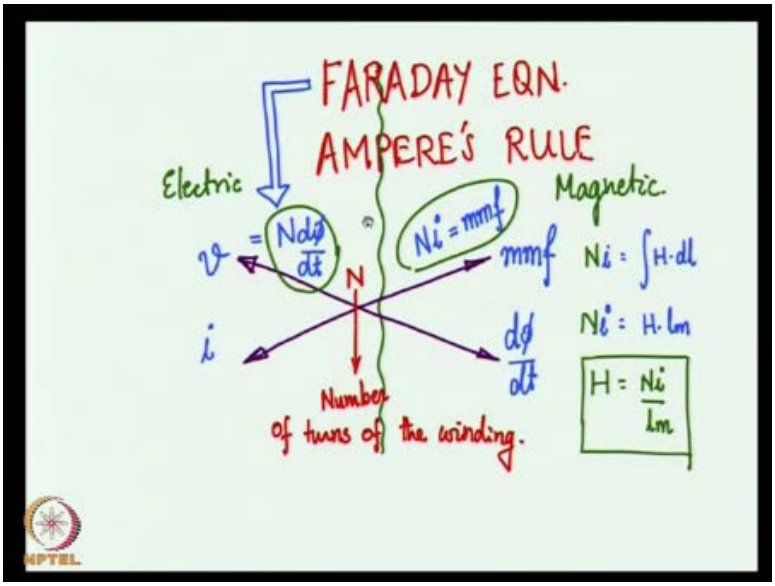

How to also control the current for a unity power factor application? Then we will come to the topic of magnetic realizing the magnetic in a practical way, how do we go about

making the magnetic components again. We will be re visiting the Faraday Faradays eon amperes rule and try to understand them.

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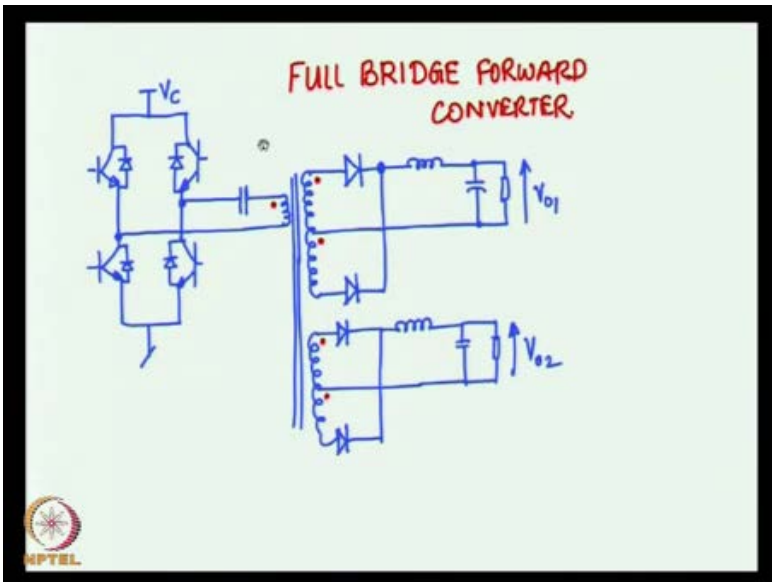

Try to implement it implement both the inductor and the transformer for a practical specification. Then finally, we will try to design few converters for a given specification design the various components. How we go about designing them? How do we try to incorporate these designs in a systematic way into either octave or MATLAB, as design program files, such that you can keep iterating it for various specification, till you achieve at a optimal design? So, we shall, so we shall discuss this design with the the example of a full bridge forward converter this is a full bridge forward converter multiple output.

Then later for a fly back converter are to so in this way we shall try to cover the topics write from the basics. That is the components to the various topology understanding the topologies followed by analyzing modeling them. Trying to extract the mathematical representation of any converter should be able to generic method. You should be generic method that we present you have be able to extract the model for any given a converter. Then apply the control controller design principles and basic that we discuss in this course to design the controller PID controller are even other wise of or the various the converters.

Then we will be able to design the inductors on the transformer magnetics such that you can use them in a practical converter, so this will be the topics that will be covered in the entire range of 40 hours. So, this is the first hour of the 40 hour, you have 39 more hours that will be are coming up. I hope the knowledge knowledge that will be discuss a in the next 39 hours will be not only interesting, but also useful to you the next lecture. Will be given be professor V Ramanarayanan and he will start of with the basic of power conversions.

Thank you.