Pulsewidth Modulation for Power Electronic Converters

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Lecture - 02
DC - DC converters

Welcome back to this lecture series on Pulsewidth Modulation for Power Electronic Converters. So, as we discussed in the last class most of this courses is on pulsewidth modulation; however, the initial few lectures we will be focusing on power electronic converters which is what we are doing presently now.

So, to start with among the various power electronic converters, we will be discussing DC to DC converters which are among the most fundamental of the power electronic converters they take in certain DC input and they provide certain DC output.

So, that is why we call them DC to DC converters and this will help us understand DC to AC converters, which is what we will be primarily be dealing with most part of this course now. So, in this DC to DC before we get onto these DC to DC converters. Let us have a quick recapitulation of what we saw in the previous lectures now.

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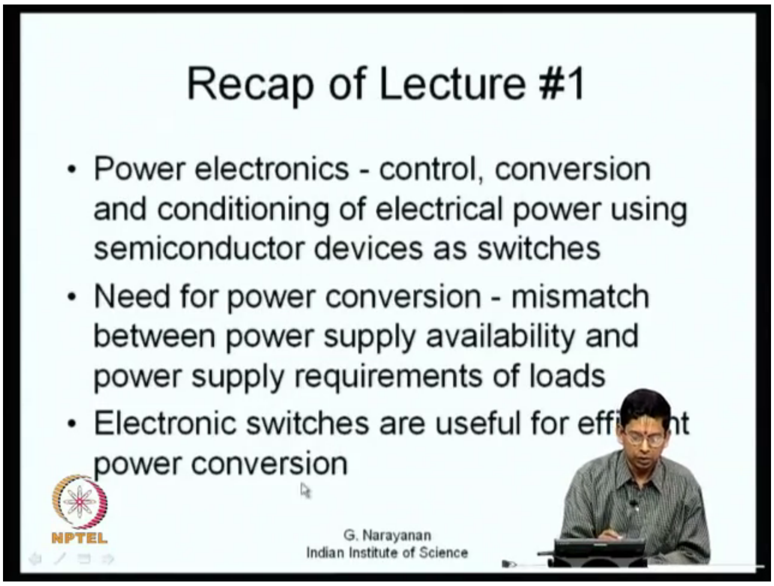

So, here is a quick recap. So, we dealt with power electronics. So, what is power electronics? It involves control conversion and conditioning of electrical power using semiconductor devices as switches.

So, the semiconductor devices here are used as switches right, then why do you need power conversion. So, there is always a mismatch between power supply availability and power supply requirements of loads and regarding loads you know we might have relay coils we might have I c s we might have there are various kinds of loads that we have now. So, there are loads which require AC there are loads which require DC and there are different voltage levels of DC and also sometimes different frequencies and so on and so forth now.

So, the power supply requirements of loads do not always match with what is available for example, we may have 230 volt 50 hertz that is available or a 110 volts 60 hertz that is available or a 400 and volt 3 phase 50 hertz might be available, but that might not directly satisfy the requirements of the load therefore, you need power conversion now. So, we use electronic switches for this power conversion and the electronic switches are particularly efficient. So, because you know a switch does not dissipate any power ideal, when it is on it only conducts it does not drop any voltage across it and when it is off there is no current flowing through that.

So, switches an ideal switch never dissipates power and so, switches are in general useful for efficient power conversion and that is the reason why we use electronic switches and power electronics is about controlling and converting electrical power using switches now.

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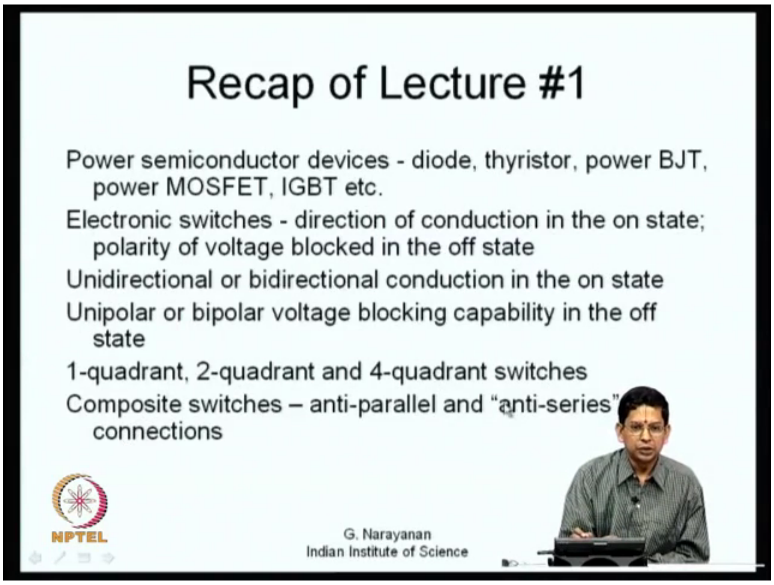

So, let us see more about switches, there are various power semiconductor devices available such as the diode the thyristor or the ac r on, the power BJT power transistor, bipolar junction transistor otherwise called power transistor and we have the power MOSFET, and we have the IGBT and you know IGBT as we saw in the last class it resembles a MOSFET in the when viewed from the gate side or from the viewed from the control side, when viewed from the power side it resembles a transistor now.

So, we have these various kinds of power semiconductor devices that are available now and whenever we say there is an is an electronic switch, an electronic switch is different from a mechanical switch in a number of respects. Let us say we use a mechanical switch to control power supply to our fan or something, you know just to switch on or switch off a domestic fan let us say. So, such switches when they are on you know they conduct in both directions they are basically I mean the element inside is a conducting element where as what we have here is a semiconductor.

So, an electronic switch need not conduct in both directions. So, when it is in the on state it conducts, but it could be only in a specific direction and again when the switch is in the off state, it may not be able to block voltage of either polarity it may be able to block voltage of one polarity or the other polarity. So, that is what we are coming again here. So, when a switch is in the on state, it may be able to conduct sorry when it is in the on state it may be able to conduct in a particular direction. So, its unidirectional conduction or it may be able to conduct in both the directions let us take diode for example.

A diode is not a control switch, but it is a switch nevertheless. So, that a diode conducts in one direction namely from its anode to cathode whereas, if you consider a MOSFET along with its body diode, it may be able to conduct in both directions now. So, thus we have switches which can either conduct in one particular direction or the other direction or in both the directions now. Then again when the switch is in off state it may not able to block voltages of either polarity, taking the example of diode again the diode is off when it is reverse biased and it can only block a potential, you know where its anode is positive with respect to its cathode I mean I am sorry its rather the other way, if you know the cathode is positive with respect to the anode then it can block otherwise diode will start conducting.

So, switch may or may not be able to block voltages of either polarity. So, you have switches which may block a particular polarity or may block both the polarities now. So, these lead us to single quadrant 2-quadrant and 4-quadrant switches. So, we can also have think of composite switches, that is going by anti-parallel or the so called anti-series connections which we will look at.

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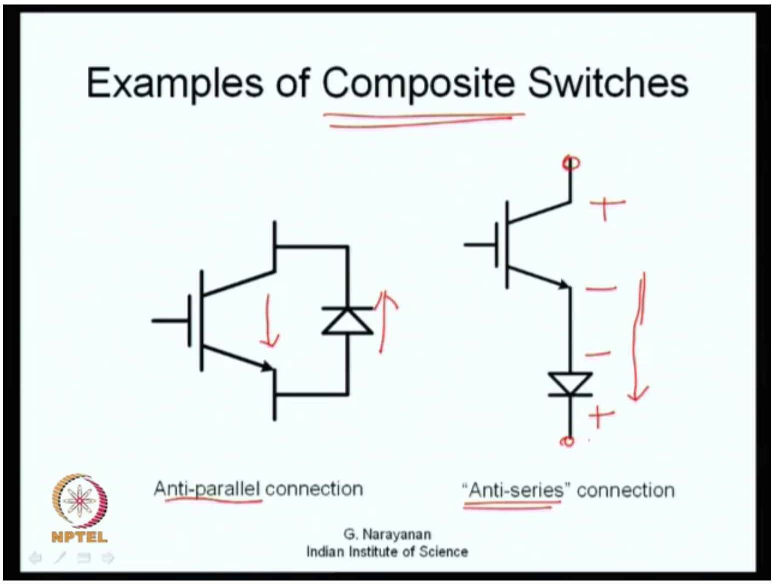

So, now here are some examples of first is an example of what is called as an anti-parallel connection.

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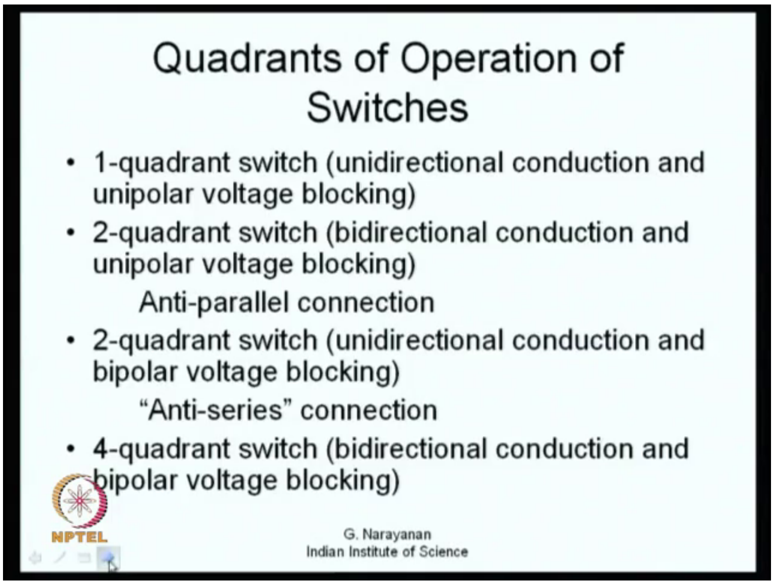

So, in this what we have is we have a transistor which can conduct in this direction, what we have done is we have taken a diode which can conduct in this direction, we have connected them in such a fashion that the transistor conducts in one direction, and the diode conducts in the opposite direction, hence we call this as anti-parallel connection.

Now similarly if let us say in the devices in the off state, you consider this example when this device is in the off state when this transistor is off it will be able to block a potential where the collector is positive with respect to its emitter, but the diode in the off condition may be able to block a potential where its cathode is positive with respect to anode. Now this these have polarities of blocking which are opposite to that of one another; what we are doing is basically we are connecting two elements in series and both the elements conduct in the same direction nevertheless they block voltages of opposite polarities and here we can call this as an anti-series connection. This is not a very commonly used expression. And therefore, you find it within quotes now.

So, these are certain things which we saw last time. So, what we are able to do is we are able to realize composite switches using individual switches that we really have, we can go in for an anti-parallel connection to ensure bidirectional conduction and going for the so called anti series connection to ensure a bipolar voltage blocking capability this switch between these two points, block voltages of either polarity when it is in the off condition now. So, if you are looking at switches, switches can be characterized in a particular fashion depending upon their direction of conduction and their voltage blocking capability. So, we can have a so called single quadrant switch, which will conduct in only one particular direction and which will not conduct in the other direction.

Similarly, when this switch is in the off state, it will block a voltage of only one particular polarity and it will not block any voltage of the other polarity, similarly you have 2-quadrant switches. These 2-quadrant switches because may be because of a bidirectional conduction, some switches will be able to conduct in both the directions, but nevertheless when the switch is off it will be able to block a potential in only one direction. So, this is one kind of a 2-quadrant switch now, you can realize such 2-quadrant switches by going in for an anti-parallel connection of two single quadrant switches.

Now, the other type of 2-quadrant switch is shown here, this is also a 2-quadrant switch how is it different here the conduction is in only one direction its unidirectional conduction, but the voltage blocking capability is different here it is bipolar voltage blocking capability it has got, that is whether the voltage is of one polarity or the other polarity it is capable of blocking now. You can realize such a 2-quadrant switch by going in for the so called anti-series connection of two single quadrant switches. So, this is how you can realize this now, is two of this 2-quadrant switches can be connected let us say such a switch two of them can be connected in the so called anti series fashion or 2-quadrant switches of this nature two of them can be connected in so called anti parallel fashion to realize 4-quadrant switches. These 4-quadrant switches are ac switches they can conduct in either direction when they are on.

Similarly, when they are off they can block a voltage of either polarity. So, we thus we can classify switches based on their directions of conduction and polarity their voltage blocking capability as single quadrant, 2-quadrant and 4-quadrant switches. So, these are certain things which we looked at in the previous lecture now, we move on to DC to DC converters.

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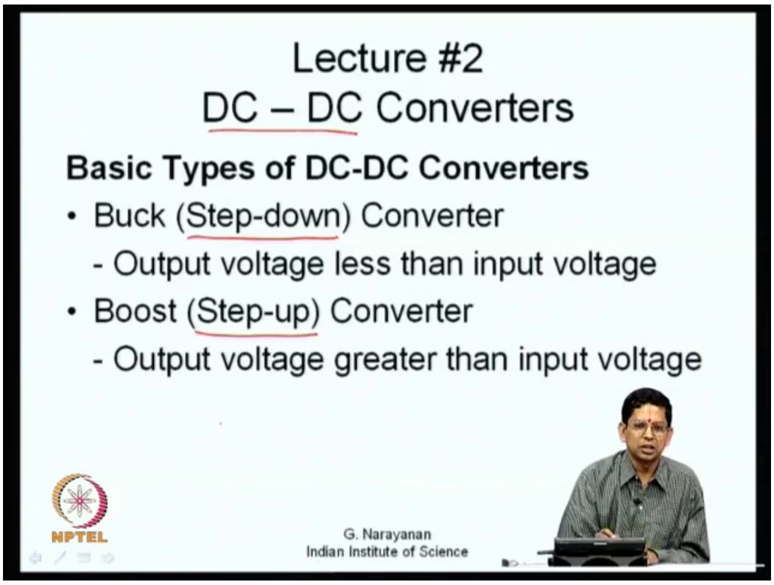

What we are trying to do is we are using switches only for the purpose of DC to DC conversion here, given a DC input voltage we want a DC output voltage, which could be which is different from the input. You might want a step down that is you might you might have a higher DC input voltage say 10 volts and you might want a lower DC output voltage say 5 volts or it could be the other way you might have a 10 volt input and you might desire let us say a 15 volt output now, and that is called step up or boost operation. Thus essentially we have two type basic types of DC to DC converters one is called the buck converter, in which the output voltage is less than the input voltage and the other one is called the boost converter where the output voltage is greater than the input voltage.

So, there are various other kinds of DC to DC converters. DC to DC converters themselves are subject for study you have courses exclusively on DC to DC converters now and there are also converters where you know there is isolation available between the output voltage and the input voltage and so we are not going to be dealing with all of those; here our treatment of DC to DC converters is restricted to just about a single lecture. This is to help us and understand DC to DC converters and so that we can go on to understand DC to AC converters better now.

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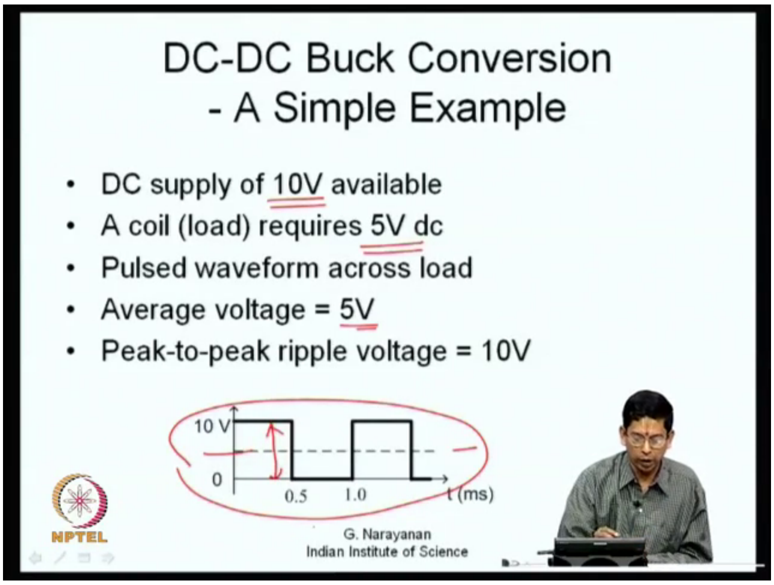

So, let us say we consider a simple example of DC to DC buck conversion. So, what is a simple example? As I said in the previous lecture let us say we have 10 volts supply that is available now, this is a DC supplier that is available, but we have a load which requires 5 volt DC.

So, what can I do you can apply a pulse to voltage reform like this, that is you can apply 10 volts for certain interval of time and you can apply 0 for the remaining interval of time again 10 volts and 0 you can go on doing it in cyclic fashion so that you end up producing certain average voltages indicated here. Here as shown here it is this is high then 10 volt is being applied for 50 percent of the time and 0 is being applied for the remaining 50 percent of the time. So, the average voltage you get is 5 volts. So, you are able to step down that is you are able to apply the 5 volts that is required by the load, but it is not a pure DC that you have, you also have certain ripple on that on top of this you have a ripple and the peak to peak value of the ripple voltage is equal to 10 volts which is equal to the input voltage itself now.

So, what we need to be handling is, if you need buck conversion you need a network of switches which can produce such a pulsating wave form and you also need some kind of filtering, which will ensure that a DC current flows through the load rather than a current DC current with a lot of ripple or a DC current with much reduced ripple flows through the load now.

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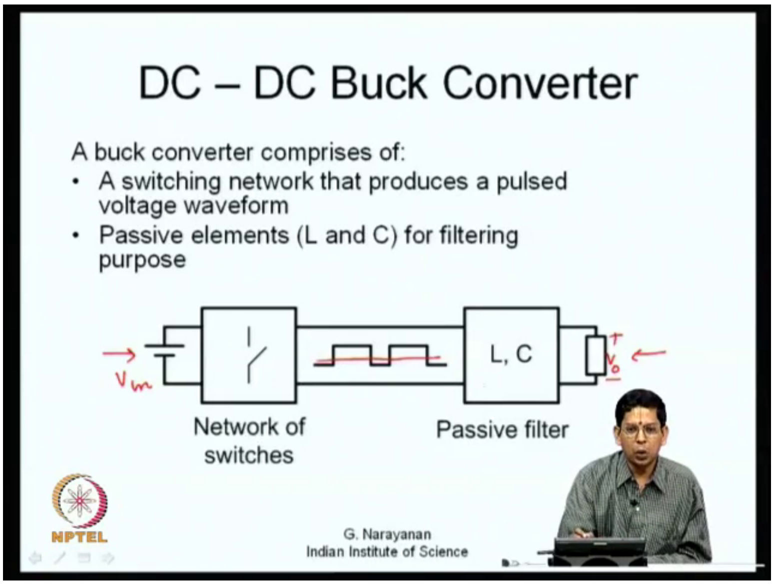

So, a DC what we desire from a DC to DC buck converter something like this, what we have is a DC power supply. And we finally, have a load here and this load needs a voltage this output voltage and this output voltage is much less than the input voltage is as less than the input voltage that s what we are we want now.

So, you can break the step into two stages, one stage comprises of network of switches which can produce such a pulsating waveform, whose average value is the value that you really desire. The average value of this is the value that you really desire now so, but there is there is also ripple on this apart from the average now. So, you might need a filter using some passive elements such as inductance and capacitance.

Thus you can basically you know breakup DC to DC conversion process into these two blocks a network of switches and passive filtering. We will not worry about the network of switches right now, but instead we will start looking at how this filter should look like.

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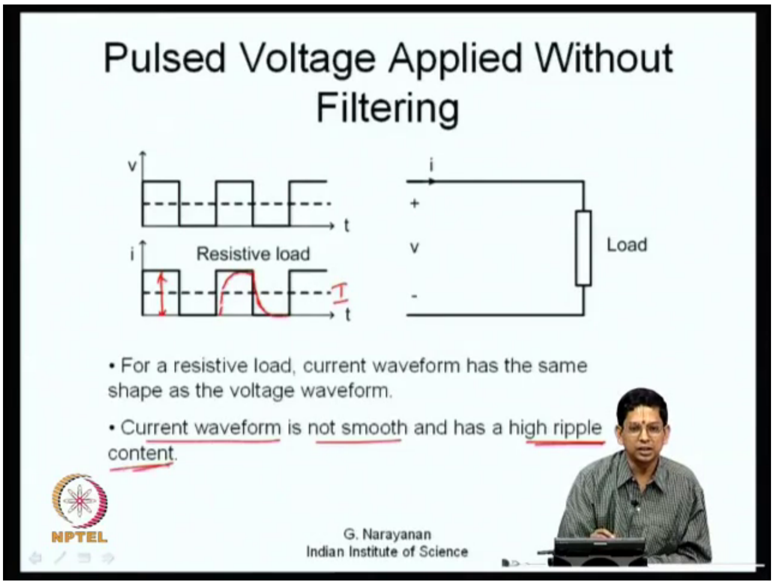

Now, let us say a pulsed voltage is being produced by a network of switches, there is DC source available and there is a network of switches. So, by switching this you are able to produce voltage waveform like this now.

This voltage waveform is being applied to a load, now this load could be resistive. If it is a resistive load then the current waveform has the same wave shape as the DC input voltage now. The current certainly has an average value has its DC component, but the current also has a ripple component. This ripple component as you can see is the peak to peak ripple is twice the average value of the current that will that flows through the load. So, the ripple is pretty high, now the load itself might have certain amount of inductance if the load has certain amount of inductance what happens? This might slightly get smoothened out this might slightly get smoothened out and this current waveform might probably look something like this is probably a nature of waveform that you could expect now.

This is because of the ratio the inductance has the property of smoothening out the current now, the inductance should be higher for the current to be even smoother. So, if we go on to have you know if you simply have without any filtering, if you feed this to the waveform what you are going to have is you are going to have a current waveform which is not at all smooth and it has a high ripple content now. We are trying to see how we can reduce this high ripple current in the current waveform.

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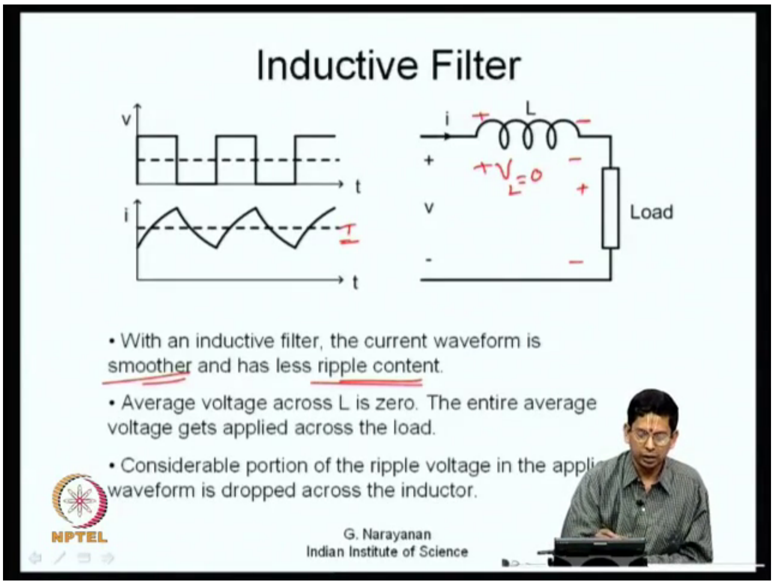

So, the solution is to go for an inductive filter; with an inductive filter what happens it smoothens down now.

So, how smooth it is depends upon the L by r ratio of this load. Now L could actually include this inductance and some inductance that might be part of the load itself and r could be the resistance in the load. If we are talking of an r l load, here if this l by r is very low then we will have a situation as what we saw here it will just get slightly smoothened out like this now. If the l by r ratio is substantially high it is comparable it is higher than the cycle times then you will find it kind of rising and falling and rising and falling and it goes on like this now. So, this is the kind of current waveform that you really see.

Now, you can see with an inductive filter, the current waveform is smoother certainly. It is not yet this d c, but you can see that it is much closer to the d c value. The peak to peak ripple is now much less than the previous value in the previous case we had a peak to peak ripple that is equal to almost twice the average current for a resistive load here it is much less than that now, this the current waveform has a much reduced ripple current now. So, what happens to the averaged voltage we are applying certain averaged voltage here. So, this averaged voltage the averaged voltage across the inductance is 0, let me write it as capital V L that is the averaged voltage across the inductance that is 0.

So, when I view it over a cycle where a switching cycle, the average value is 0 and so, the entire average voltage gets supplied across the load. So, now, you have certain amount of ripple voltage, this pulsed waveform can be broken up into the average value and its ripple value. The entire average value goes across is gets supplied across the load what happens to the ripple? A substantial part of the ripple is dropped across the inductance here and it is only the remaining ripple that gets applied across the load thus the load voltage is also now better. So, you have some improvement in doing that.

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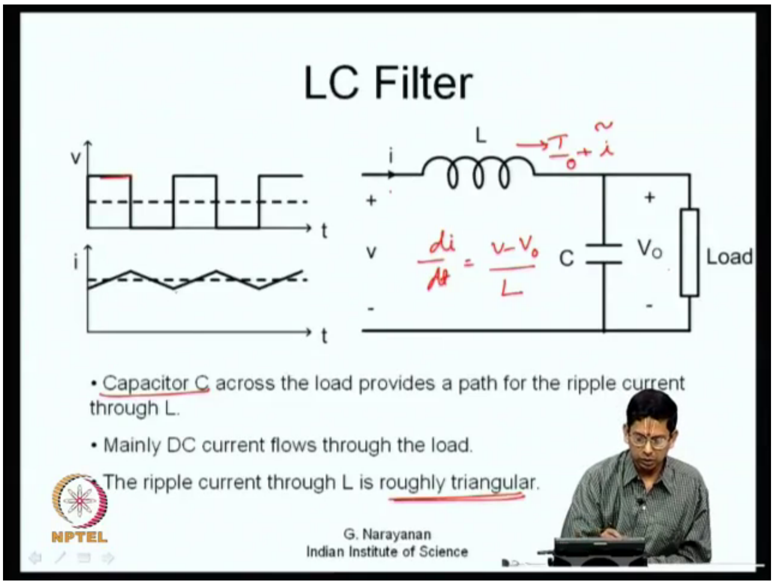

A further improvement is possible if you go in for an LC filter, now you still have the same pulsed voltage waveform applied, you have an inductance here in addition to that you also have a capacitance now.

So, this inductance has DC current flowing through that and also a considerable amount of ripple flowing through that what we can do is we can connect a capacitance c across this load. So, this will provide a path for the ripple that is flowing through this now, that is I will say this current has something like I o which is the average part and something as I tilda which is the ripple part. Now what we are trying to do now is we are trying to provide a path for the ripple current to flow through this capacitor now. So, good part of the ripple flows through this now. So, what happens only ripple can flow through the capacitor and no average current can flow through this.

So, the entire average current flows through the load only and most of the ripple current flows through this capacitance. So, you have a much better waveform here and now how does the current waveform really look like the voltage waveform is now much better and it is closer to DC you may have a small ripple on that, but it is kind of closer to DC now. If it is really a DC voltage now when you have this the applied voltage is equal to the input voltage some capital V is applied here. So, this is some v and this is some V naught; so v minus V naught equals l di by d t. So, you have v di by dt is v minus V naught times v minus V naught divided by L.

So, if v is constant and v naught the ripple in V naught can be ignored. So, v minus V naught is almost a constant. So, what do you get di by dt is a is a constant and therefore, you find the current increasing with almost a constant slope. Similarly when this input v is equal to 0 in the other interval in one of this interval it is equal to some 10 volts or so, in the other interval it is equal to 0 in that case di by dt simply minus V naught by L. So, the slope is negative and therefore, the current comes down and if V naught is practically a d c.

So, it is going to come down with a constant slope. So, you see that the current waveform is roughly triangular in nature now, if this is a much improved waveform. You what you are we are slowly moving towards what is really the ideal condition its almost direct current that flows through the load and the voltage across the load is also almost DC.

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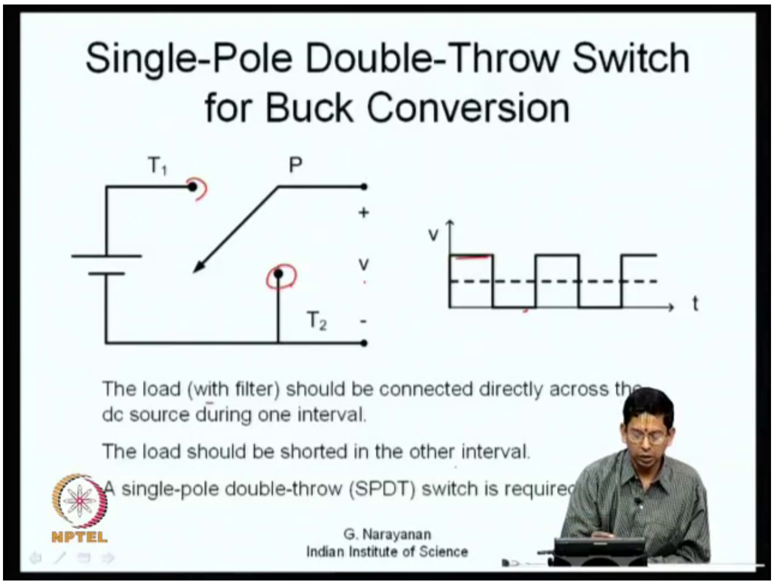

So, the filter is able to do this now. So, now, let us move on to the other portion the buck converter and buck converter we looked at two parts, one is a network of switches and the other one is filtering. So, what kind of network should we have? So, as to produce such a pulsed waveform now; what we need is such a waveform like this, where this output voltage is equal to the input voltage during one interval of the time and the output voltage is equal to 0. So, now, the load should be connected directly across the DC source, if you want this v to be equal to the input voltage what we need to do is we need to connect the load directly across this, and if we want this voltage to be 0 then the load should be shorted.

So, the kind of switch that you need is a single pole double throw switch as indicated here. This is a pole P this is connected either to the throw T 1 or the throw T 2 as I have indicated here. So, now, what happens now? You have you have a single pole double throw switch; if you have a single pole double throw switch you can realize such a pulsed waveform. So, we can put the two together a switching network and a filter.

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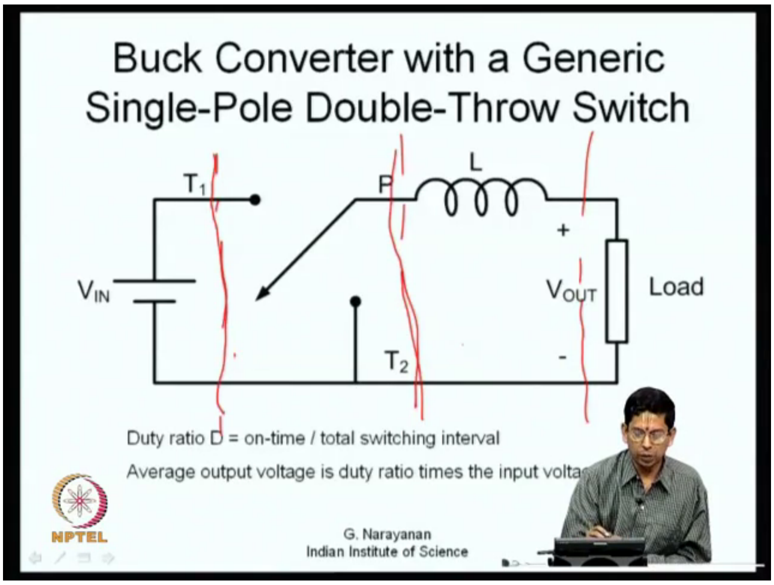

So, this is the switching network we are looking at and this part is the filter of course, in the filter I have ignored the capacitance c which you know may or may not be there. In application such as power supplies it is typical that the capacitance is there, where as in certain applications such as DC drive you might not need a capacitance here now.

So, what you have is this part this part is the so called switching network, we actually have a single pole double throw switch and the next part is the so called filtering unit that I said before. So, we put these two together to get a single you know to get a buck converter, here we have indicated this buck converter with a single pole double throw switch we actually have to realize this switch little later electronically. Now what is the output voltage here it depends on the duty ratio d. Let us say this pole P is connected to throw T 1, for some on time sometime that is called beyond time and it is connected to T 2 for the remaining time that is called off time now.

So, the duty ratio d is on time divided by the total switching interval now, and whatever average output voltage you have is the duty ratio times the input voltage. The product of duty ratio and the input voltage that will be your average output voltage now.

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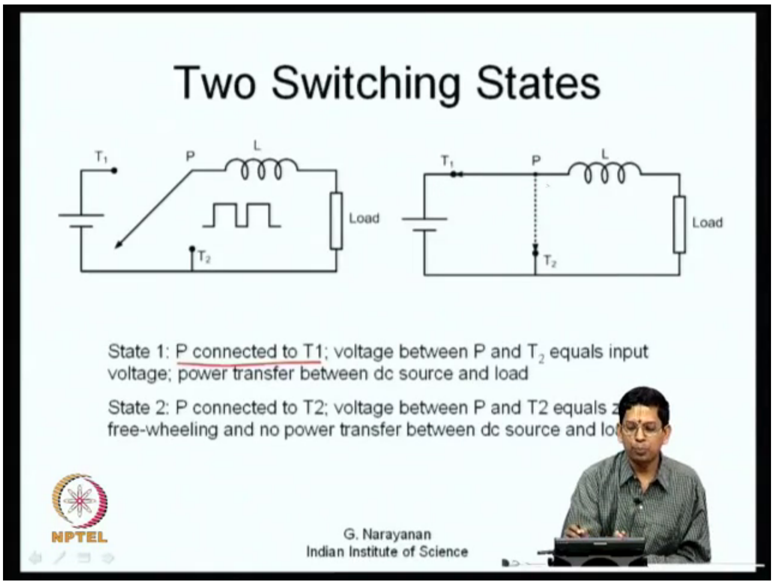

So, we have to realize the single pole double throw switch electronically. So, let us try and understand the different switching stage now. So, there is a single pole double throw switch the pole can be connected either to throw T 1 or throw T 2 there are. So, that basically means there are two states, in one state the pole P is connected to throw T 1 pole is connected to throw T 1, in this case what happens the voltage between P and T 2 equals the input voltage and this is the situation where there is some power is being transferred now, the load is connected directly across the source there is some power transfer between the source and the load now.

You need to go a little farther from here, that is we need to look at the other state also and the other state is what has been indicated by a dashed line here P2 T2. So, when P and T 2 are connected what happens? There is no power transfer between the source and the load and whatever is there in the load energy is stored a current continuous to flow it is so called freewheeling mode now. So, these are the two states pole P either I mean the pole P being connected to T 1 let us call that as state one then pole P connected to T 2 let us call that as state 2 now.

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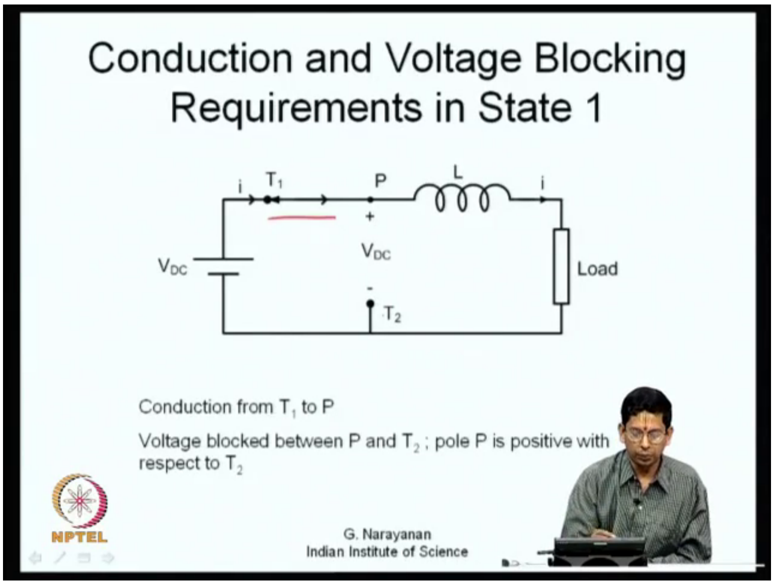

So, we move on we take a look at the state T 1 now. So, what do we need in state T 1 pole P is connected to T 1 it. So, you have certain requirement for conduction, whatever switch you may use between T and P 1, it should be capable of conducting in this direction from T 1 to P the direction of conduction required is from T 1 to P, when P is connected to T 1 there is no connection between P and T 2.

So, whatever switch comes in between here between P and T 2 is now blocking certain voltage now. So, we are looking at two individual switches one switch which is conducting which is between P and T 1 that is conducting and we are looking at another switch between P and T 2 which is blocking and the blocking polarity is as shown here now. This is what we have in one of the states now and the blocking polarity is such that P is positive with respect to T 2.

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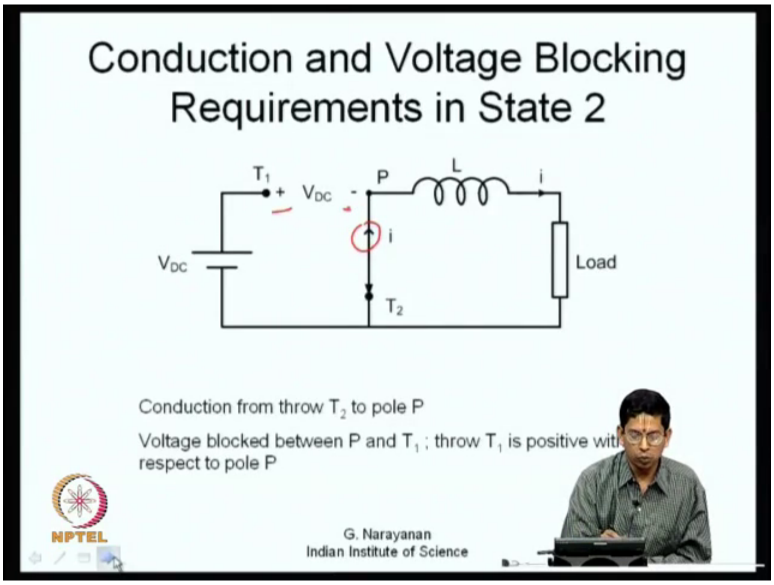

If you look at the state 2 it is slightly different, pole is connected to throw T 2. Now the direction of conduction is as indicated here, it conducts from T 2 to P the other switch which comes between P and T 1 is actually half now, and this blocks a voltage and this voltage is you know T 1 is positive with respect to P, the entire V DC comes across T 1 and P.

So, T 1 is positive with respect to P. So, that is the requirement we need to find out come up with a switch which will conduct in this direction. And here we need to come up with another switch which will block as indicated here now what we do is we move on we look at both.

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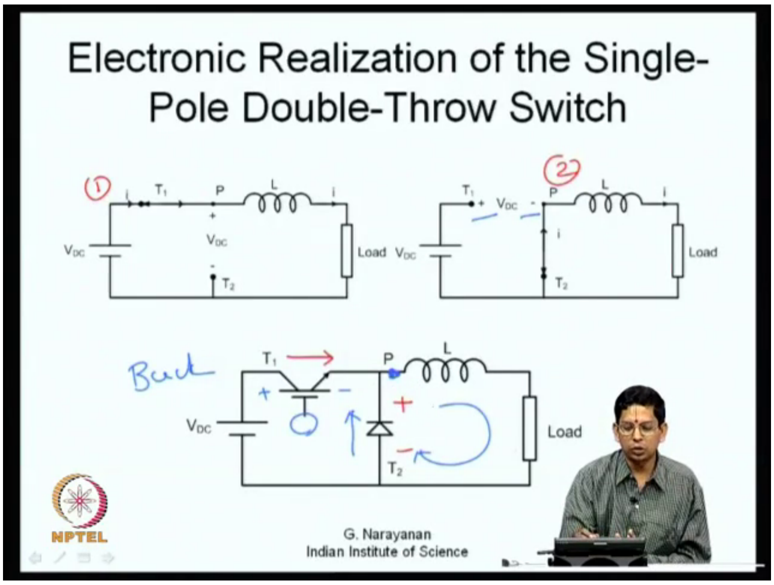

So, here this is the so called state 1 this is the so called state 2, we have a picture of both these presented here now. So, what are we going to do look at both now what is the kind of switch that you will really need? Now let us say in state one you need conduction in this direction right and you need a voltage blocking capability as indicated here. So, if you go to state 2 what we need in state two is conduction in this direction and voltage blocking here.

So, for a conduction from left to right here and voltage blocking polarity as indicated here, a transistor is a very good option a bi power BJT or a power transistor or equivalently an IGBT insulated gate bipolar transistor is a very good option, you can use an IGBT here it will serve the purpose between P and T 1 what should you be connecting between P and T 2? You can connect a diode that simply serves the purpose now; it can really be an uncontrolled switch. So, let us say the diode is conducting. The moment you turn on this transistor the diode will get reverse biased therefore, the diode will turn off and once again let us say the transistor is turned off then the diode will come into conduction because of the stored energy in this, there will be freewheeling action now.

So, this switch between P and T 2 need not have to be a control switch, it could be an uncontrolled switch namely a diode. So, this kind of what we have here is a buck converter. So, this part the single pole double throw switch is capable of giving you certain average voltage, the average voltage at P is lower than V DC and this average voltage here is basically duty ratio times the input voltage. And now the voltage at P not only has an average it also has certain ripple and that is what actually gets filtered out using either an inductive filter or you know you use either an inductance or use an L c and that can be effectively filtered now.

So, this overall is a buck converter now.

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So, that is how you realize a buck converter I mean you will be given a higher DC voltage and if you want to lower a DC voltage, you use a buck converter. Now if you have a lower DC voltage and you want a higher DC voltage. So, what do you do? So, you need a boost converter now.

So, the question is how do you realize a boost converter? Buck converter the idea was fairly simple now, you need a voltage lower than the input voltage what you are trying to do is you have a source you have a load you are connecting the load directly across the source and you are shorting it for some time, directly connecting and shorting it for sometime this is how you are doing. So, the idea is fairly simple, but now how do you realize a boost converter. Let us try to understand a boost converter starting from a buck converter. Let us start from buck converter which we have discussed till now and see how we could possibly have boost conversion.

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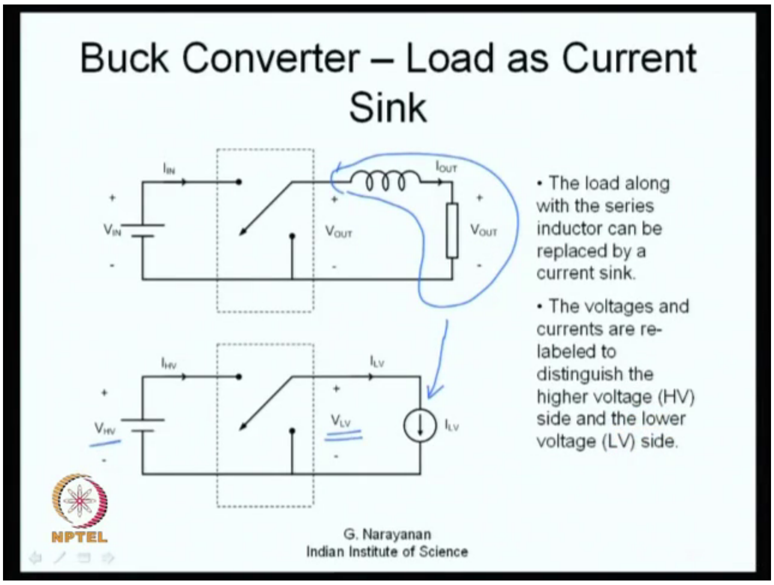

Now,. So, let us say this is the buck converter, we saw I have shown this using a single pole double throw switch rather than using a transistor and a diode now. So, you have a single pole double throw switch and you have some inductance or there could be even a see here. So, now, what you can do is, this inductance together with this load out this inductance together with this load out can be replaced using a current source current sink you can model this simply as a current sink now. Then the input voltage and the output voltage let us slightly change the where they are labeled let us call the input voltages the higher voltage. So, we call it as V HV and the output side voltage is lower let us call it V LV.

So, the input side is now being called the higher voltage side and the output side is now being called the lower voltage side. So, we have just simply changed its essentially still a buck converter, but the load has been modeled as a current sink and there has been some change in the way we are labeling the voltages and currents instead of calling them input voltage and input current we are now calling it as v high voltage and I high voltage and so on. So, next step what we need is we need a reversal in the power flow.

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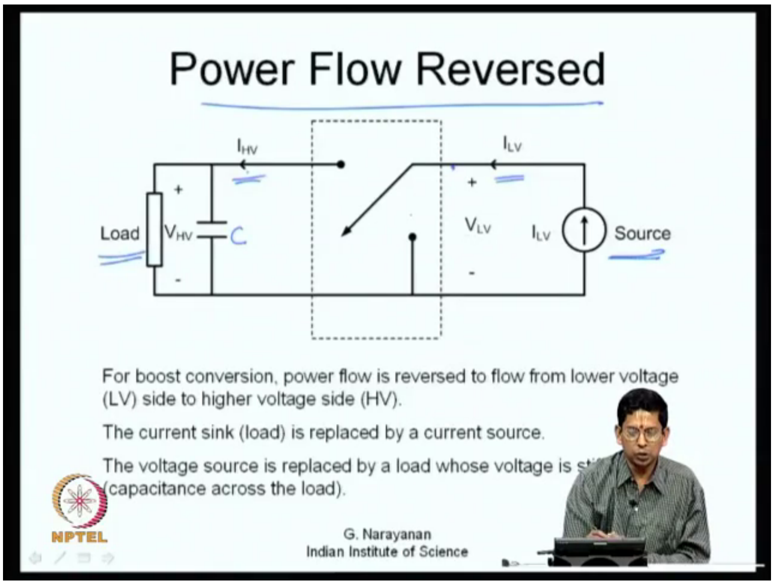

We want the power flow to be reverse how do you reverse this power flow? What we had here when it was load is basically a current sink now, let us change this current sink to a current source.

So, the direction of current changes here also the direction of current changes, the direction of current changes now. So, this is this will change the power flow, but the polarity of the voltages are still the same, but only the direction of current has been changed now. So, the input side what we had originally on the higher voltage side we had a DC supply, we now replace this by a load. A load whose voltage is stiff the voltage across the load should be stiff. So, what we do is a load with a parallel capacitance we use c. So, this presents itself like a stiff voltage source I mean this. So, you can see that the conditions have not been modified. So, what you really had originally is a stiff voltage between these two terminals and a stiff current at the pole.

So, now what do you still have is a stiff current here and a stiff voltage between these two terminals now. So, now, we have reversed the power flow and the sink has been replaced by a current source and the voltage source has been replaced by a voltage stiff load and the direction of power flow is now reverse now, let us go one step further.

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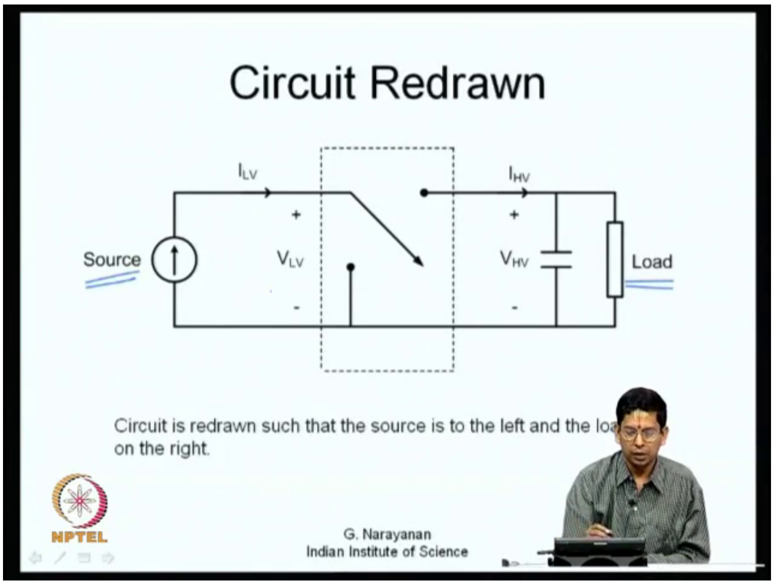

This is just nothing this is just a question of convenience; we usually want to see the source store left and load to the right. So, that is what many of us would probably want, therefore I have just simply redrawn this now. So, this source and this load there is a single pole double throw switch coming in between here now. So, let us move on further.

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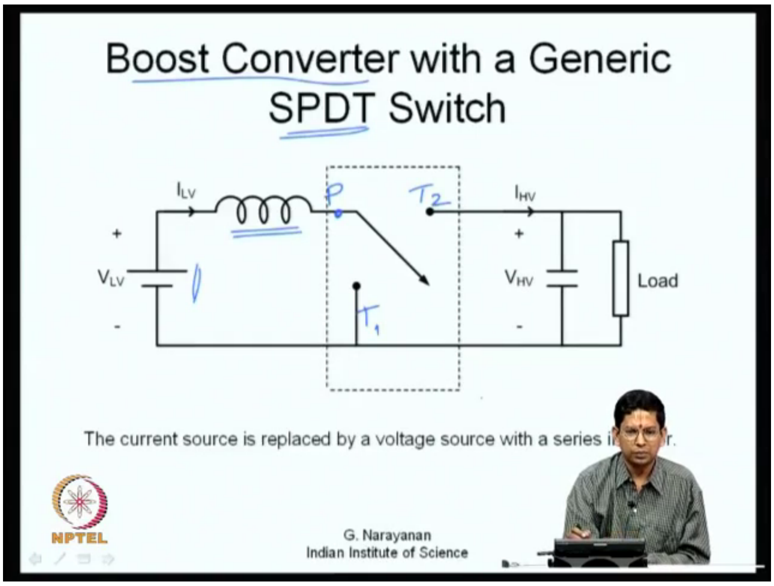

So, what is that what we have here is a current source, what we can do we can replace the current source by a voltage source, in series with an inductor as shown here that is the only change that I have done now.

So, this essentially is boost converter, except that we have not shown the exact electronic switches that are used we have still showing it as with a generic single pole double throw switch. So, what you now have is a voltage source with a series inductance and there is a single pole double throw switch and the single pole double throw switch its pole is connected here and the throws are here you have the throw let us call this as T 1 and let us call this through as T 2, you have a single pole double throw switch and across the two throws you have a capacitance and the load connected here now. So, this is basically a boost converter now.

So, I hope you know we have reached this is how it is going to look like.

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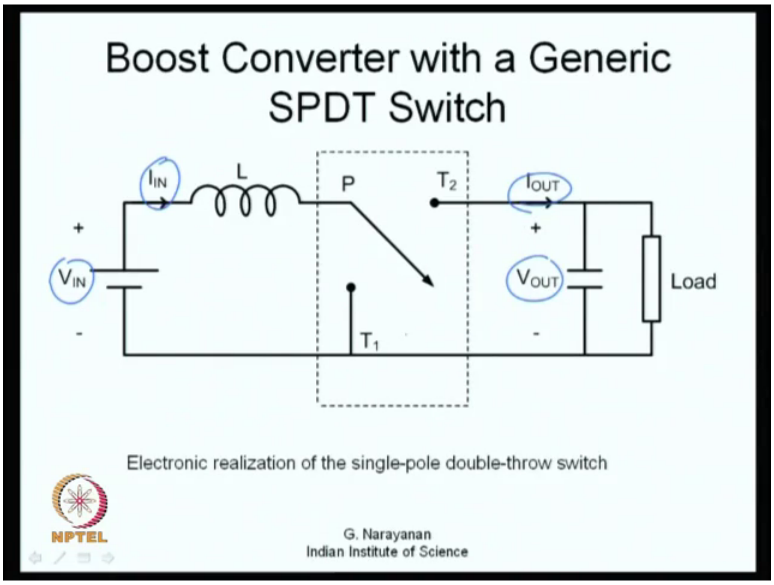

If you just want to be sure you know we will let us try an alternative approach to reach a boost converter now.

So, this from the previous figure to here only the notations have been changed, it is now back to an input voltage this is the input current. So, this is the output voltage and this is the output current now. So, the output voltage will now be greater than the input voltage. So, we need to realize this single pole double throw switch electronically, which we will do in a short while from now.

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So, what we do is we just go on look at how to realize a boost converter, now within we will use an alternative approach. Here what we did earlier was certainly a valid approach. So, what we did? We basically had had the load replaced by a current sink, then we reversed the direction of power flow we reversed the direction of power flow by changing the current sink into a source and the source into a voltage stiff load.

Then we simply redrew the circuit change little left to right change the orientation and the current source was replaced by a DC voltage source, in series with an inductance now. So, here we are going to try an alternative approach.

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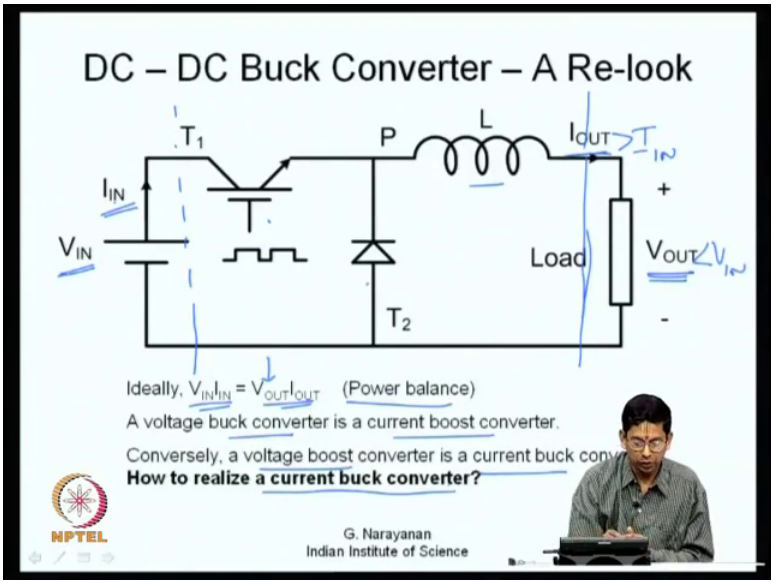

That is once again let us look at a buck converter what does it do? You have certain input voltage and you have certain output voltage. The output voltage is less than the input voltage. So, let us take off the load separately. So, this part is basically the converter that is the switches together with the filtering elements now. If you look at this product V IN multiplied by I IN that is the power that flows into the circuit and what is the power that is fed to the load? It is this product V out multiplied by I out this is that. Ideally that is if all these devices are ideal they do not dissipate any power and if the inductance is also ideal or all your filtering elements are ideal there is no dissipation.

So, ideally your input power is equal to output power and this is what is called as power balance right you may have some losses a little bit of in a practical case input power will be equal to output power plus certain small amount of losses we can ignore that losses does not matter now. Let us say when input power is equal to output power and what we have here is a voltage buck converter, we have an output voltage which is less than the input voltage.

So, what does it mean what should the output current be? It should be greater than the input current because V in I in is equals V out I out you say when V out is greater than V in or I am sorry V out is less than V in I out has to be greater than I in. In this situation you have V out is less than V in and therefore, you have I out greater than I in. So, it is a voltage buck converter, but it is practically a current boost converter. A voltage buck converter is actually a current boost converter.

Now what we want is a voltage boost converter. So, what is a voltage boost converter? It is a current buck converter, if you can realize a converter whose average output current is less than the average input current that s a current buck converter or that is what will be the voltage boost converter which we want now. The question is how do we realize a current buck converter. So, we have changed the problem from realizing the voltage boost converter we are trying to realize a current buck converter now.

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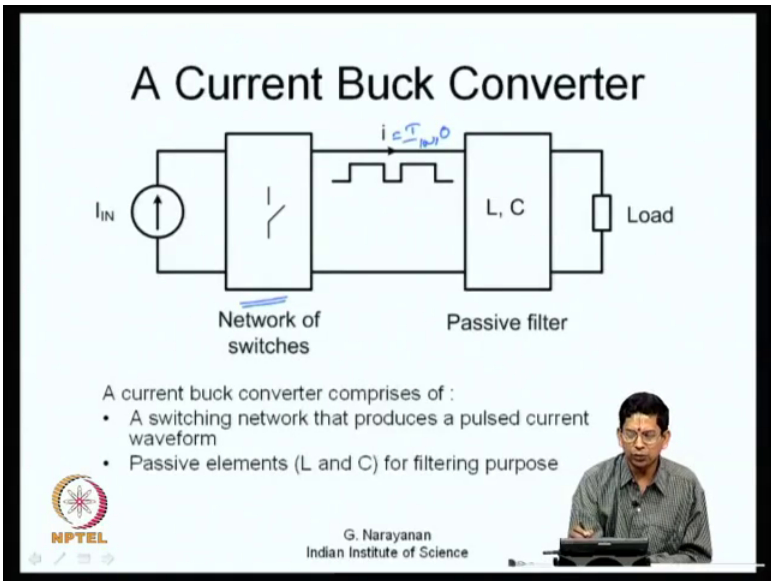

So, let us see how you can realize a current buck converter. The approach is fairly fairly you know similar to what we did before.

Let us say you have a current source and you have a network of switch, which can inject certain amount of current through this load with certain amount of filtering now. So, let us say this network of switch is capable of injecting this current I is equal to I in or 0 this is equal to I in at times or it is equal to 0 at certain other instants of time, you can it can inject such kind of current pulses into load circuit and once again you have certain kind of passive filtering. So, that you know these pulsed currents are there, they have ripple too. So, to filter out this ripple you have some passive filtering now. Just like what we used in a voltage buck converter, we can think of these two things here.

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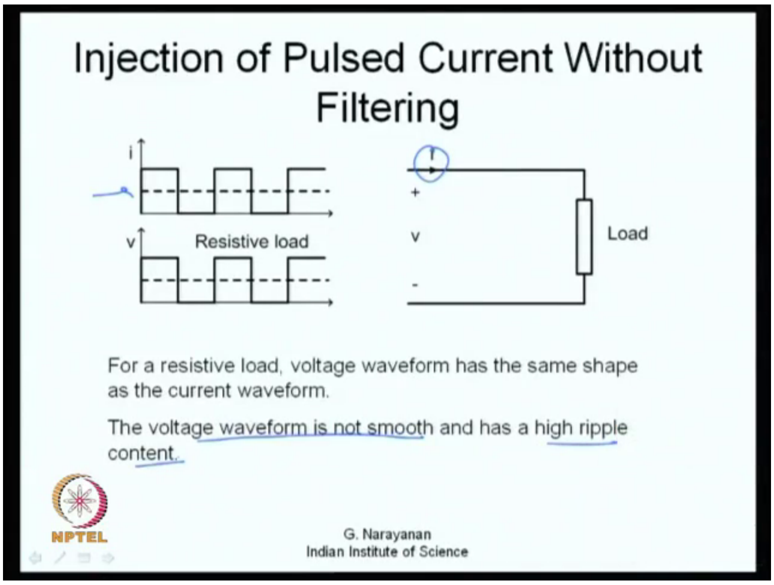

once again let us focus on the passive filter first now let us say you have current pulses being fed what you have here is you have certain current pulses being fed as shown here, this is the kind of current pulses that you feed now.

If your load were resistive, the voltage waveform will have a similar shape as that of the current waveform. So, the current waveform is a square wave and therefore, the voltage waveform will also be a square wave. So, do you have a DC voltage applied here yes you have a DC voltage, but on top of it you also have a ripple voltage and the peak to peak ripple voltage is almost twice the average output voltage now. So, you have an output voltage that you want I mean it is whose average values what you want, but which has a high ripple content now. So, the voltage waveform is not smooth and it has a high ripple current and. So, we want to address this issue we want the voltage waveform to be smoother and should have lower amount of ripple content so, what do we do?

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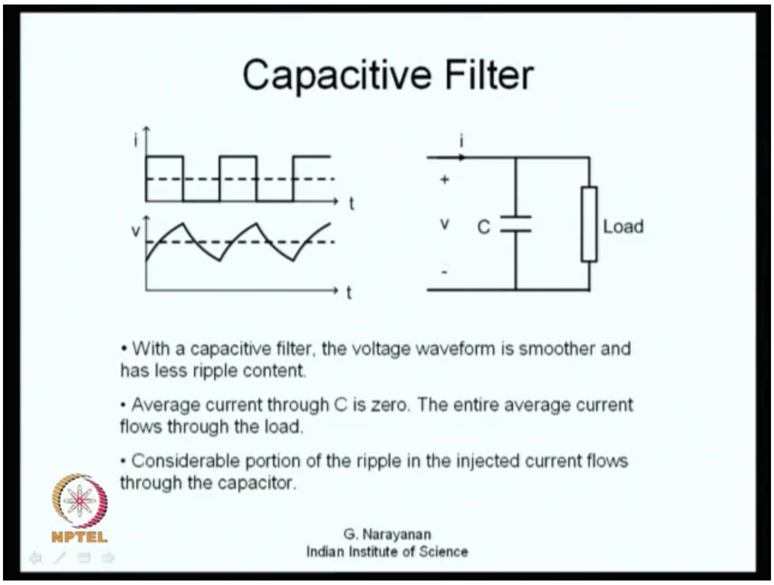

In an earlier in the earlier scenario when we applied voltage pulses here and wanted a smooth current we had an inductive filter here. Now what we have we are injecting current pulses here and we want the voltage to be smoother. Therefore, what we are trying to do is we are connecting a capacitor across that.

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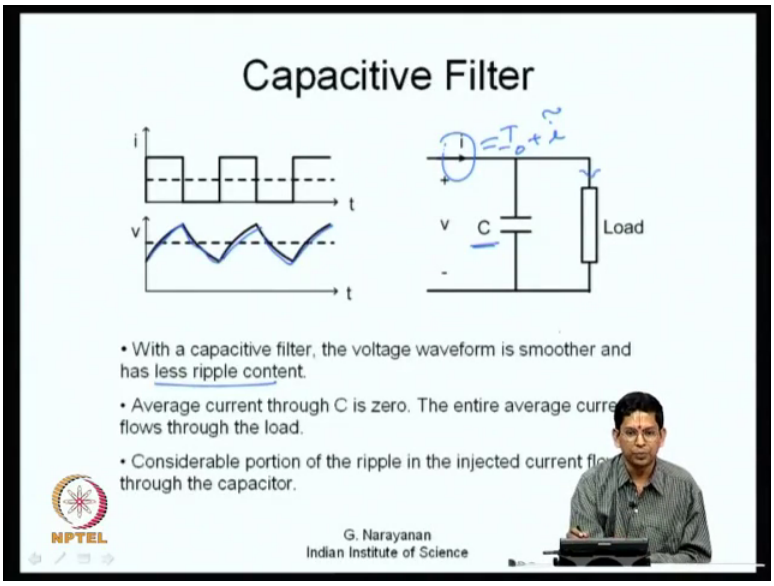

So, what happens with a capacitive filter the voltage waveform is now much smoother as shown here this is a typical first order response if you take it as a resistive load here this is what you are going to get now. So, it is much smoother than what it was you still have ripple, but now this ripple is much less than what it was earlier. Now whatever is the average component of this current I nothing of it flows through the capacitance c through capacitance, it takes only the ripple average current cannot flow through that so at steady state.

So, what happens is all the average component the entire average component of this current flows through the load that is I can divide this current as certain i naught plus i ripple and the entire i naught flows through the load and a good part of this i ripple flows through the capacitive element. So, the ripple current that flows through the load is also now much less reduced and you are your waveform quality is now much better than what it used to be. You can also use inductors as in come up with a more complex figure as I mentioned in my previous lecture this design of this inductors is an involved subject and you know there are certainly other lectures in the area of power electronics, where designing of filters are dealt with in good details. So, I would leave those things to you.

So, what we need essentially is a capacitive filter that is the basic filter that we need in such as case.

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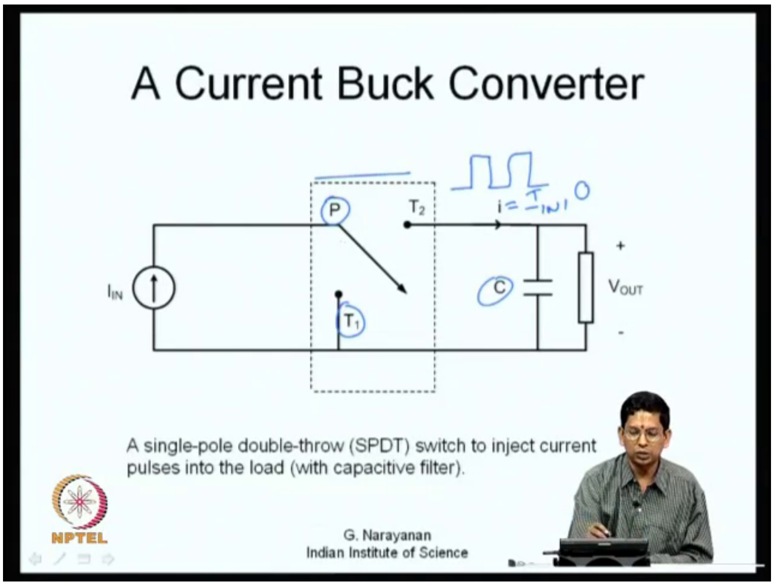

So, let us move on to how a current buck converter should look like, what we need is we have a load and with capacitive filtering we have a load and there is a capacitive filtering here and we can have such kind of a single pole double throw switch. The current source one of its terminals can be connected to the throw P, its other terminal I mean the pole P the other terminal can be connected to throw T 1 when P is connected to T 1 the current source is simply shorted no current flows through the load. When pole P is connected to throw T 2 then this i is equal to I in otherwise when P is connected to T 2 I is equal to 0.

So, it can take basically two instantaneous values, the instantaneous value of this current could be either this I in or could be equal to 0 and you really have a pulsed current flowing through this point this I is going to be a pulsed current flowing through this now. So, this is getting filtered here you have this capacitive load and therefore, you get what you want now this is a as a current buck converter now.

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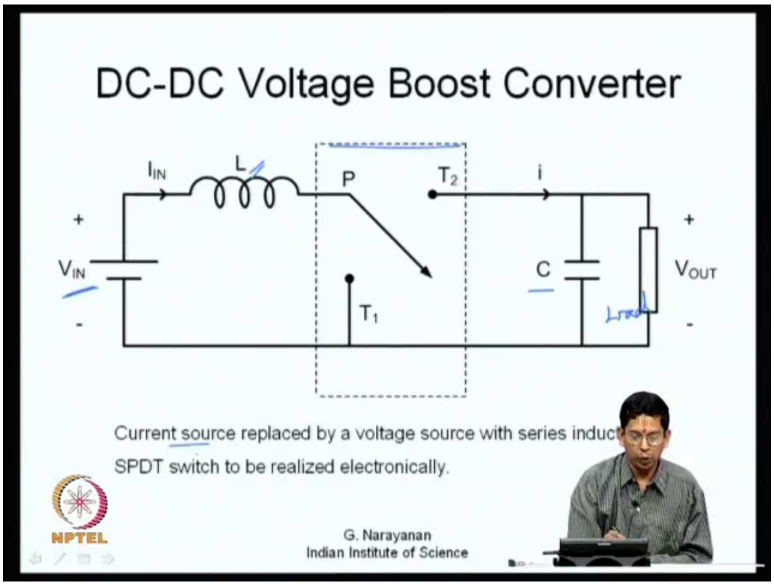

So, what we are doing is, this current source as before we can replace it by a voltage source with a series inductance. As a same single pole double throw switch here and there is a capacitance and load is here this is the load. So, you have what is called as a DC to DC voltage boost converter now.

The current source has been replaced by a voltage source with series inductor. So, you have to realize this single pole double throw switch electronically, how do you realize that is the next question.

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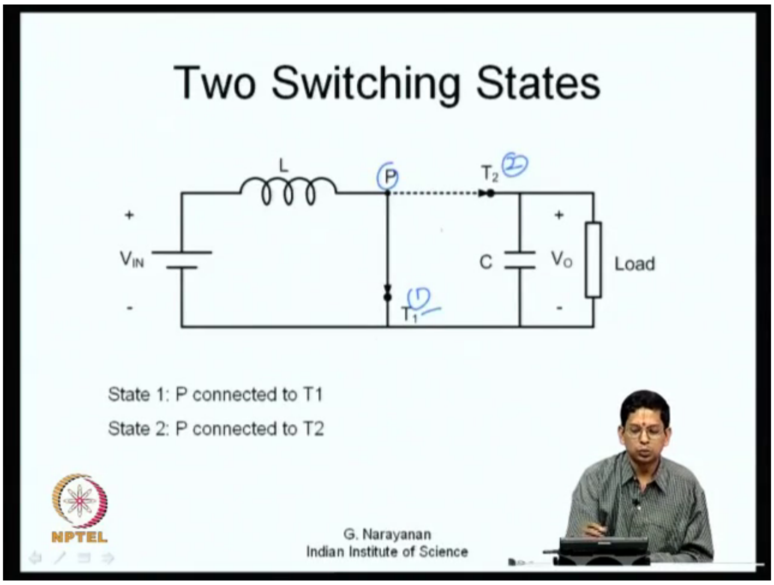

Let us look at the two states the converter in the converter there is only one single pole double throw switch, the pole P is connected to throw T 1 that is state 1 or the pole can be connected to throw T 2 that we can call as state 2. So, these are the two states now.

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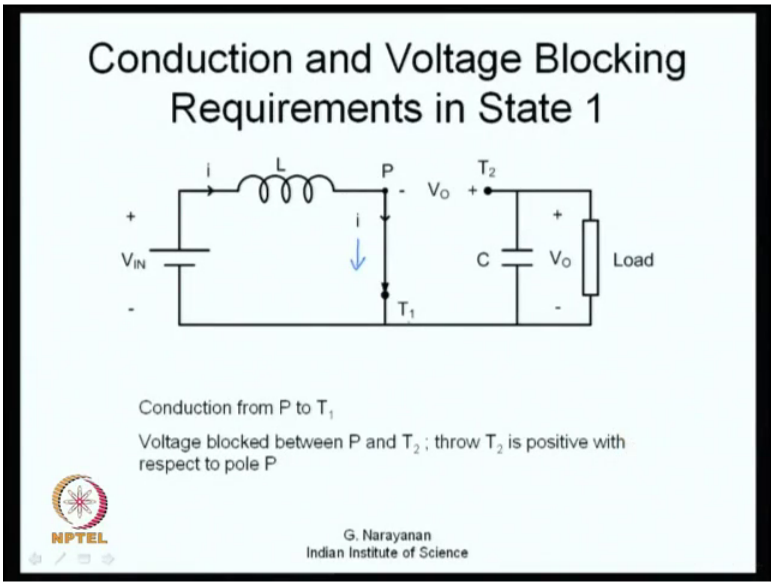

Let us look at the individual states one by one, if you look at the state 1 pole is connected to throw T 1 what is the direction of current? The direction of current is like this the current has to flow from P to T 1, and between P and T 2 whatever switch is connected that switch is in the off state. So, what do you have? You have a polarity where T 2 is positive with respect to P what comes between P and T 2 is the load voltage V naught.

So, T 2 is as a part of potential v naught higher than p. So, here you need a switch which can block a voltage of polarity as indicated here T 2 positive with respect to P now.

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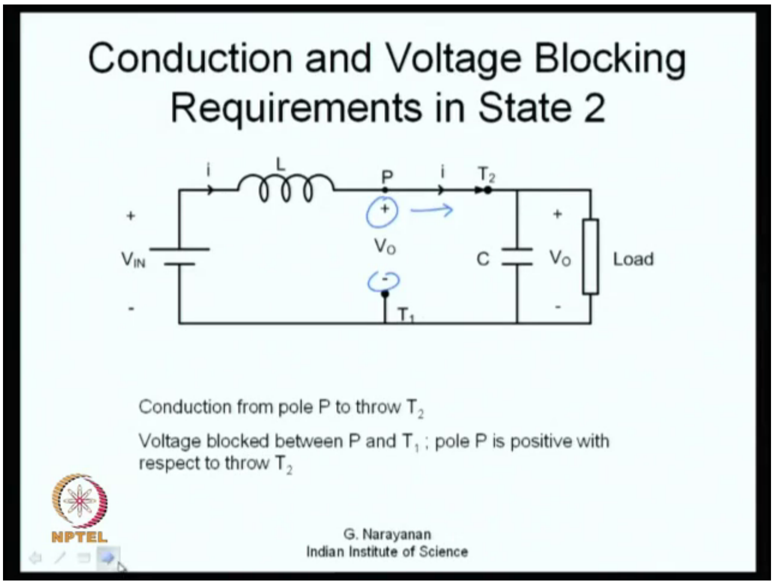

So, if you look at the other state, now P and T 2 are connected. So, the conduction is like this. So, the voltage blocking is between P and T 1 voltage needs to be blocked. So, this potential is positive and with respect to this potential which is negative now. So, these are the conduction and voltage blocking excuse me requirements in the two states now.

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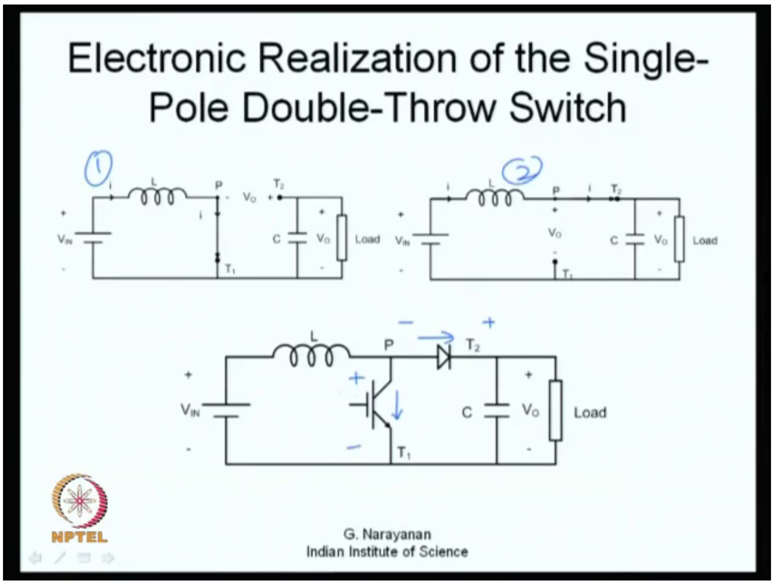

From this let us say we move on to an electronic realization of the single pole double throw switch what I have done is this is the state one this is state two both have been indicated here what you need between P and T 1 you need something that can conduct in this direction. So, you can use a transistor which conducts from its collector to emitter and which has to block a potential plus minus as indicated here.

A transistor can block this potential plus and minus with polarity plus and minus as indicated here, then it is in the off state and again what do you need here? You need a device which can conduct in this direction in this so called state 2 and when it is off it has to block potential like this this is exactly what a diode does. So, transistor fits the bill here and a diode fits the bill here. So, what we need once again we can have a power transistor and a diode or IGBT and a diode as indicated here and this is a boost converter.

So, what we are trying to do is essentially we are having a single pole double throw switch and we are looking at the states of the single pole double throw switch. For every one of the state we are trying to drop the conduction and the voltage blocking requirements that the switches need to satisfy, this is for state one and this is for state two and then we are trying to come identify appropriate switches that would do this now.

So, here is what you have a boost voltage boost converter now.

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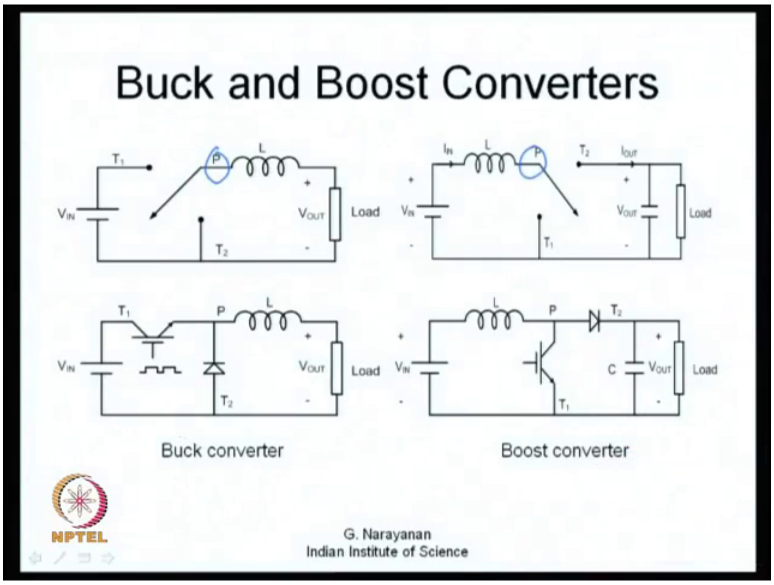

So, in this picture I am trying to show the buck and boost converters together. So, what do you want to do here this is a buck converter what do you have a single pole double throw switch, what do you have here boost this is a boost converter, here also you have a single pole double throw switch now where is the pole connected? The pole P is connected in series with the inductor why? The inductor current should never be snapped open an inductive circuit should not be opened. So, this switch will provide a path for the inductive current to flow either through this throw T 1 or T 2. So, an inductance are a current source is always connected in series with the pole.

Now, what do you have across throw T 1 and T 2 here you have the input voltage here you have the capacitive load. So, the capacitance or any capacitance or a voltage source is connected across the two throws because a capacitance should never be shorted and inductance should not be opened or a current source should not be opened. Therefore, a current source or an inductance is always in series with a pole, but a capacitance or a voltage source should never be shorted. And therefore, what we have you have them connected between the two throws here. So, this is these are basic rules in connecting switches now, a good part of power electronics is actually understanding switches and understanding how to connect switches and how not to connect switches to realize your power conversion now.

So, what we have been trying to do from here is, from this particular point of and this single pole double throw switch we are trying to realize now how are we trying to realize? Pole to throw T 1 and pole to throw T 2 we are looking at the two states and we are looking at the conduction and blocking requirements between P and T 1 and between P and T 2 the same story here and we are realizing whatever switches are necessary. So, for those of you who are already familiar with DC to DC converters, this is just a review of what they are, but those of you who might not know would probably be benefited here. One primary purpose of you know explaining these things is there are and unfortunately there are students, who are able to draw such a circuit, but really do not understand why it is so, I mean we are trying to understand why a buck converter looks the way it does and why a boost converter looks the way it does. So, that is one part of our exercise now.

Let us straightly take a closer look at the various average voltages that that we will have here, that we have come to you know the circuits you can draw them using single pole double throw switches and you can replace the single pole double throw switches using actual electronic switches now. Once we have done this, let us look at the average voltages in this circuit now.

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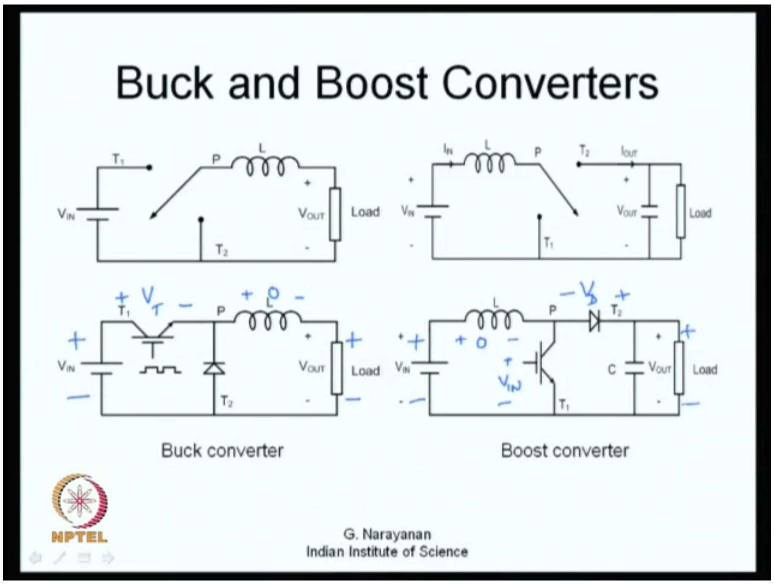

So, you have a source V in it has you have an averaged voltage and the instantaneous voltage and the averaged voltage are just equal here what you have is V in now. Then across the load you have an averaged voltage V out like this with this polarity and V out is less than V in. So, therefore, certain amount of averaged voltage is dropped somewhere.

Now, the averaged voltage across the inductor is 0. So, where do you have the averaged voltage dropping the averaged voltage drops across this transistor? So, whenever the transistor conducts ideally the drop is 0 whenever the transistor is blocking the potential is as indicated here, I mean the polarity of voltages as indicated here the collector is positive with respect to the emitter and therefore, the averaged voltage also has the same polarity. So, you have certain amount of polarity that gets dropped let us call this as V transistor. So, what you really have is this V transistor is the averaged voltage across the transistor and that gets subtracted from the averaged input voltage or simply the input voltage to produce your averaged output voltage. What happens in a boost converter? You have this polarities plus and minus as indicated here already we have this plus and minus this is the input voltage that is available.

Now, the average voltage across the inductor is 0 therefore, what you have here is you have certain averaged voltage across the transistor plus minus and that is equal to the input voltage V in this is what you have now. So, here you have an average output voltage as indicated here plus and minus now. So, this output voltage is actually greater than the input voltage. So, you the difference should be something like this, when the diode conducts there is no drop ideally and when it is blocking it blocks such that its cathode is positive with respect to the anode as indicated here in this figure now. So, the averaged voltage across the diode also has the same polarity as indicated here let us call this as V D.

So, what you have now is this V in plus V D is equal to V out, the diode voltage the average voltage across the diode gets added up to the input voltage to produce your higher output voltage. In this case in the case of a buck converter the averaged transistor voltage gets subtracted whereas, in the case of this the averaged voltage gets added. So, you are able to realize a buck and a boost conversion what we are interested subsequently is actually DC to AC conversion now. So, what we want to really see is understand the basic rules by which we have come here now.

Let us take a look at you know how we really came up to this DC to DC converter now. We look at how exactly we came to DC to DC converter we first realized this converter as you know what we need to do is what kind of switch is necessary is one of the questions we understood that.

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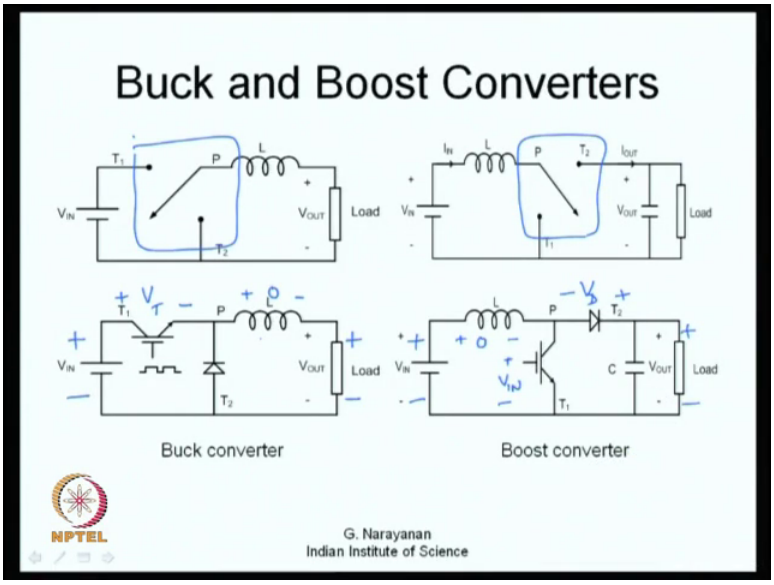

We need a particular kind of a single pole double throw switch that is one part of it and the enxt part of it is to understand how a particular single pole double throw switch can be realized.

So, in the first part, you can say that all the power electronic converters they comprise of certain switches and these switches are like for every pole there will be multiple throws and so on and the pole as I mentioned before is always in series with a current source or an inductor. An inductive circuit or a current source should never be opened. And therefore, the pole will always be in series with that and again the voltage source any voltage source or capacitance should never be shorted and therefore, capacitances or voltage sources will always be connected across the two throws. These are two basic rules in the way we connect switches with poles I mean with inductors and capacitors, this is how we should go about connecting now this is one fundamental rule that we need to keep in mind as we go on to our DC to AC converter.

So, we will build up on this, in the next lecture we are going to be doing a DC to AC converter and we will see what kind of a switching arrangement it needs and then you will see what kind of switch realization that you really will need now. So, this will be. So, this DC to DC converter is kind of the first step in our overall understanding of what are various power electronic converters.

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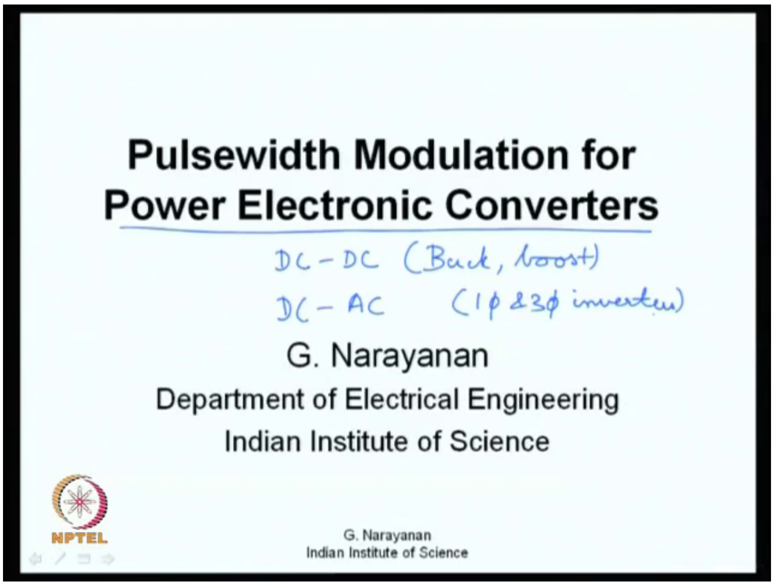

In this various power electronic converters, today what we have done is we have tried to understand a DC to DC converter. Again we have not gone through the entire DC to DC I mean all possible or various possible DC to DC converters, we have confined ourselves to simply buck and boost converters. We have various other combinations also such as the buck boost or boost buck and so on and you have many other topologies to and you have lot of isolated DC to DC converters, we have not looked at all those now we have looked at buck and boost which are the most fundamental among the DC to DC converters now and from this we are planning to move on to DC to AC converters.

So, in the next lecture we will be trying to see how DC to AC converters look like or how to realize them. So, we will be looking at what are called as voltage source invertors you will look at single face and three face invertors. So, this is something that we will be doing in the next lecture. I hope you enjoyed this lecture and I thank you for your time and your patience and your interest. And I will see you again in the next lecture.

Thank you very much.