Fundamentals of Power Electronics

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Lecture – 45
Switched mode DC-DC converter intro

We shall now discuss Switched mode DC-DC converters; I mentioned earlier that DC-DC converters can be executed either using the linear circuits called the linear regulated circuits which we discussed in the last week or using switched method by switching the semiconductor switches.

In the case of the switched mode DC-DC converters all the semiconductor switches that is the diodes, the BJT and the mass feds they are all switched and they are either in the cut off region or in the fully saturated region, which means all the switches are either fully OFF or fully ON. The advantage in such mode of operation is that the switches which are coming in series will either be ON or OFF when they are on the current through them will be flowing through the ON switch, however the voltage across the switch is 0.

When they are OFF the voltage across the switch will be finite and the current through them will be 0 in both the cases the power decapitated across the switches will be 0. Therefore the efficiency will be very high in an ideal case the efficiency will go towards 100 percent, however in a practical case there will be switching transitions while going from ON to OFF or OFF to ON the switch has to transit through the linear region and therefore there will be some dissipation. Due to switching losses and therefore the efficiency will not 100 percent will not be 100 percent but will be slightly lower than that.

So, we will take up now DC-DC converters using the switched mode technique wherein the semiconductor switches will be switched, we will take simple converters and then gradually go to isolated converters and more realistic power supply cases.

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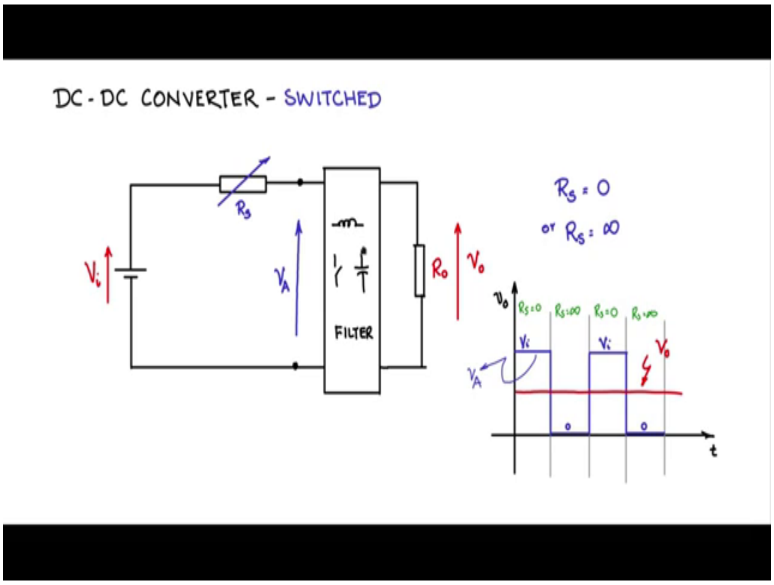

Let us now consider an unregulated DC voltage and this DC voltage suppose to supply power to a load or not, let us say this input unregulated DC voltage is Vi output load is R naught load resistance is R naught and output voltage V naught is demanded is required. Vi and V naught are different values and therefore they cannot be just connected directly with the conductor, so they need to have some series element.

In the linear regulator case what did we do? We put a variable resistance component which could be a resistance or it could be a semiconductor switch operated in the linear region. So, basically this Rs resistance was varied. So, when this Rs is varied accordingly the drop across that varies and therefore we could regulate V naught, but unfortunately there is a voltage drop across this Rs there is a current through Rs and therefore there is a power dissipation V Rs into i naught happening in this resistor Rs and it is not available as useful load, therefore the efficiency is very low.

Now, if we modify the constraint that Rs can take only 2 values it can either take 0 or Rs can be infinite there is open circuit. So, let us say let us put the constraint that Rs is either 0 or infinity, in such a case now let us plot V naught with respect to time what happens.

Let me make time divisions like this let me divide the time in this fashion, now let us say first in this time let us make Rs is equal to 0, so this is 0 Vi comes completely directly to the output and we will see an output like this with Vi. Now in this time region let us make Rs infinity means open this, so when you open this the entire Vi dropper drop drops across this and there is no load current and therefore the voltage V naught across the load is 0 this what we have drawn there.

Now, let us make again Rs is equal to 0 this is a sorted, again Vi comes across V naught and therefore V naught is Vi and Rs infinity again it repeats in this fashion if we take just only this two possible values of Rs. Now if you see here Vi 0 Vi 0 this or the possible outputs voltage states, one thing that you observe from here the output voltage is pulsating not constant fixed at DC.

Another thing is we have restricted Rs to only these 2 possible values and when Rs is 0 the voltage drop across Rs is 0 and therefore there is no dissipation across Rs when Rs is infinite the current through Rs is 0 and therefore there is no dissipation across Rs. In both these conditions the power dissipation across Rs is 0 has no power dissipation, so the entire power goes only to the load the only drawback is that the output voltage is pulsating and not regulated DC. So, one thing that we have achieved by doing this is to remove the power dissipation and improve the efficiency.

Now, to take care of this pulsating or chopped DC that is coming across the output we need to put a filters, so we will put a filter which is not dissipative so we have to put a L C filter, so that is what we will do to obtain a DC again at the output. Let us now introduce a block where which is suppose to do a filtering, so let us say that there are these components the filter consists of 3 important components one is the L or the inductor which is the kinetic storage C or the potential storage capacitance and there can be switch elements like diodes and other semiconductor switches. Now the filter comprises of these components.

Now, if I take before the filter VA consider it as VA now that will be chopped like that and after the filter the chopped waveform will be smooth and out and that will be the smooth DC which will be applied to the load R naught. So, therefore, in a DC-DC converter switched mode DC-DC converter you have an input Vi unregulated and output V naught regulated different value. Now in between there is a switch which chops the waveform there are filters which will do the job of smoothening the chopped waveform to obtain filtered DC, so these are the main components of a DC-DC converter. Now, let us take the simplest DC-DC converter with 1 switch 1 inductor and 1 capacitance.

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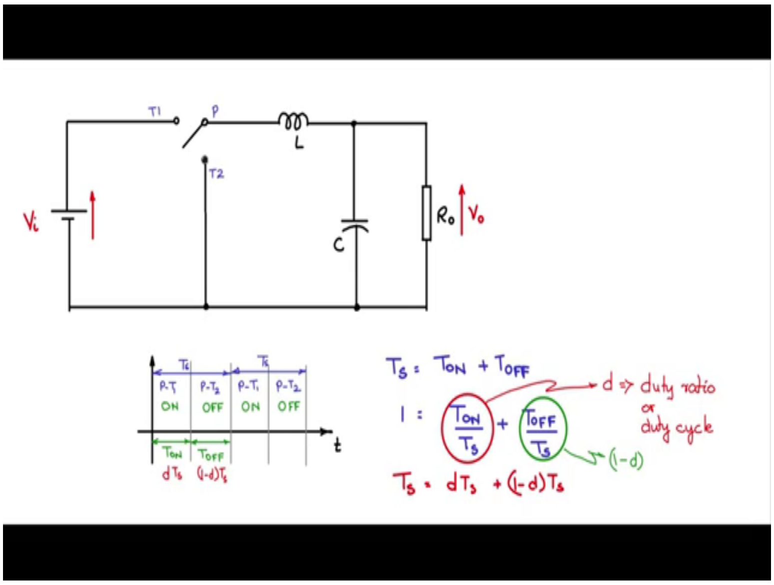

Let us now draw the circuit of a DC-DC converter with 1 switch 1 inductor and 1 capacitance this is the load and this is the input unregulated input L C R naught, we have Vi unregulated and this is V naught ok. Now this is as single pole double throw switch because this is a pole p this is throw 1 this is throw 2 double throw. So, the most fundamental switch would be having a single pole and 2 throws if 1 throw is not connected then we call it as a single pole single throw, but more fundamental is a double throw switch.

So, let us also make the connection for this throw T 2 and let me connect this 2 ground. So, which means throw T 1 is connected to Vi throw T 2 is connected to ground and the pole P will alternately connect to T 1 and T 2 ok. So, this is a full fledged DC-DC converter it has a single pole double throw switch and inductor L capacitor C, so this portion will be a switched mode power converter.

Let us now have some clarity on when the pole will be connected to T 1 and at what times the pole will be connected to T 2. So, let us make some definitions and clarifications on that. So, for that let us shift make some space and I am going to have graph of time verses amplitude here. But I am not going to use the y axis in the time axis alone I want to split it up into different periods of time. So, let me make these kind of divisions in time and let us see how this time divisions or defines split and define. So, let us say this period this is called Ts switching period and this is called again the next switching period Ts.

So, this width period time period is switching, now the time period and switching period is divided into 2 parts this switching period is also divided into 2 parts. So, in one in part 1 let us say pole is connected to T 1 and in part 2 here pole is connected to T 2, likewise the next switching cycle pole is connected to T 1 during this period and during this period pole is connected to T 2.

So, let us say when pole is connected to T 1 we will call that one as the ON time. So, I will say on when pole is connected to T 2 T 1 is off so I will call that one as OFF time pole is connected to T 1 we will call that one as the ON time, when pole is connected to T 2 T 1 is off therefore we say that is the off time for T 1. So, with reference to T 1 I am saying this is the ON time OFF time ON time OFF time or symbolically we can say this is T ON period this is T off period.

So, look at this and this and this T s can be written as T ON plus T off. So, let us divided by T s we have 1 equal to T ON by T s plus T off by T s. So now, this T ON by T s we will define it as d which is the duty ratio or duty cycle it is called the duty ratio or the duty cycle and this T off by T s we will call it as 1 minus d just 1 minus d, because the some should be equal to d there are only 2 states p can be connected either here or here no in between states.

So, T ON by s is d so therefore T s can be written d T s plus 1 minus d T s. So, we have now converter this time into an equation based on d that is the duty ratio, so duty ratio is the value that varies from 0 to 1. So, this portion here will be d T s this is d T s and this portion will be 1 minus d T s.

So, what we have now achieved is that when we can say for a period d T s time p pole is connected to T 1 for a period 1 minus d T s time pole is connected to T 2. So, this is the way we will be describing the switch ON OFF without confusion and d is an important variable called the duty cycle or the duty ratio please carefully understand this particular variable.

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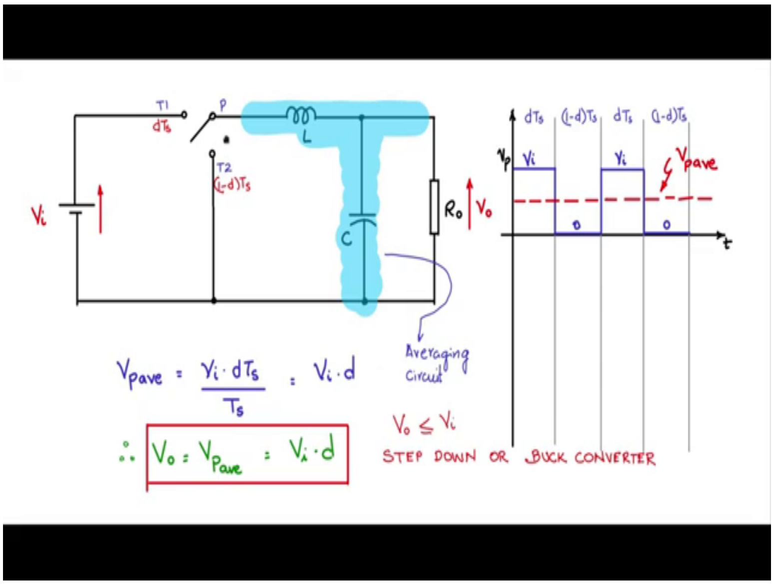

Let us now mark the period for which P T 1 will be ON as d T s and the period for which P T 2 will be ON will be 1 minus d T s or is the period for which T 1 will be OFF. So, now with this definition of operation of this single pole double throw switch let us look at some waveform. So, let me now divide the time in this fashion this is d T s period this is 1 minus d T s period this is neck cycle d T s period and this is 1 minus d T s period so on its keeps going, so this 1 period d T s plus 1 minus d T s is 1 period T s.

So, during this time let us see what is the pole voltage with respect to the ground so let us plot V p. So, during the time when during the time d T s P is connected to T 1 so it has to be Vi. So, Vi comes in there now during the time 1 minus d T s p is connected T 2 and T 2 is connected to ground 0, so that is that point then d T s period again Vi and 0.

So, this is the voltage that you will see the chopped voltage that you will see at the pole of the switch. Now what is the average value of this particular wave shape we will call that one as v p average and from this relationship waveform we can find v p average is this is Vi in a cycle Vi into d T s and here it is 0. Therefore, 0 into 1 minus d T s divided by the entire time period T s so you have Vi into d this is the average value.

Now, what is the function of this L C; L C is a filter which is nothing, but an averaging network. So, this is an averaging network or averaging circuit and therefore V naught is the average of V p and therefore V naught is equal to Vp average which is equal to Vi into d.

So, the relationship between V naught and Vi is Vi into duty cycle duty ratio and note that d is a value. But in 0 and 1 and therefore V naught is always less than Vi for the circuit topology, therefore it is called a step down or up buck converter. So, this is the first primitive DC-DC converter circuit that we have seen.