Fundamentals of Power Electronics
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Lecture - 49
Buck converter – component selection

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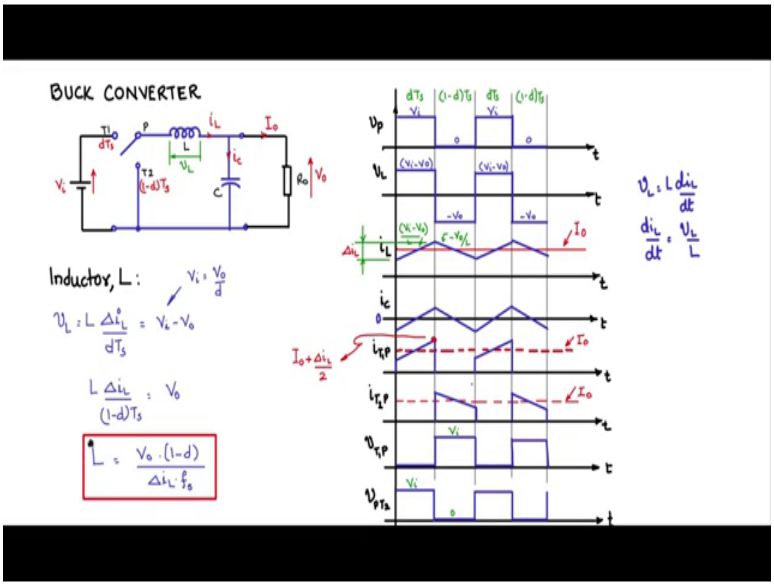

The Buck Converter has 3 important components to be designed or rated, one is the single pole double throw switch the other one is the inductor and the third component is the capacitance. Now let us take one by one let us take the inductor. So inductor L value how to find the value of L? We will use the Faraday equation VL is equal to L delta L by delta T L d iL by d T. Now we see that in the inductor current waveform it is a straight line linear because the rate is constant.

So, therefore, I can take it as delta iL by delta T and delta T is nothing but dTs here or 1 minus dTs depending upon which period you want to take. So, let us say I am talking about dTs period, so in the dTs period the slope is the current traverse through delta iL that is this in a period of dTs in a period of dTs. So, for that the voltage that is seen across inductance is Vi minus V naught which will put it down, other way I can look at the other portion 1 minus dTs portion also. So, L delta iL the current traverses through delta iL in time 1 minus dTs and during that the magnitude of the voltage is V naught, you can put only the magnitude which is V naught because, the traversal is negative you can put negative V naught negative can we removed and you have V naught.

So, either I can use this equation of this equation because let us say for example Vi; Vi can be expressed in terms of V naught as V naught by d substitute here and you will get all in terms of V naught. So, the value of L is V naught into 1 minus d Ts I will bring it down call it fs switching frequency delta iL switching frequency. Now this is the basis for the design equation for L value V naught is a design spec given for you based on the output load side spec d is obtained designed from Vi and V naught both are specs and therefore d is calculatable f s is the switching frequency. The designer chooses whether you want to switch at 20 kilo Hertz 50 kilo Hertz 100 kilo Hertz.

Then delta iL again is a design designer spec and normality is taken as 10 percent of I naught max I naught. So, with this you can get the value of L.

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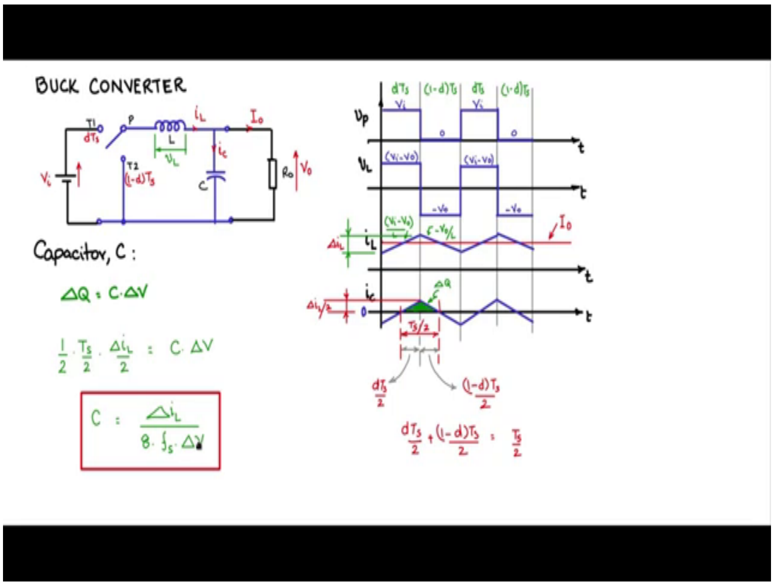

Let us now obtain the capacitor design equation so capacitor C. So, the capacitor current is the important reform parameter that we are to look at just like in the case of the inductor design we look at the inductor voltage; voltage across inductor here you look at the capacitor current. So, let us remove some parts of the waveform focus on the capacitor current.

Now, let me shade this is the area under the capacitor current curve on the top and this is the change in charge we will call that one as delta Q. So, the change in the charge that is charge up and the area here would be charge down discharge. So, the charge up and the discharge should be equal and should cancel out for amp second to balance. So, delta Q we know is equal to C into delta V change in the voltage across the capacitance.

So, let us try to find what this area is? This area is nothing this is a triangle, therefore half base into height. Let us find out the height; height is the distance between these 2 from 0 to peak of the triangle and that we know is that delta iL by 2, because this height this whole height from here to here is delta iL. So, this is delta iL by 2 and what is the base of the triangle, so that is the distance from here to here. So, what is this distance? So, here if you see that this is from minus delta iL by 2 to plus delta iL by 2.

Now, this is linear therefore this has to be a midpoint, so therefore this must be dTs by 2. So, this is dTs by 2 likewise this is the midpoint in the 1 minus dTs portion, so therefore you have 1 minus dTs by 2. So, together you add up dTs by 2 plus 1 minus dTs by 2 which will Ts by 2. So, this is Ts by 2 irrespective of the value of duty cycle this is Ts by 2 which is the base.

So, now we can calculate the charge this is half base into height, so half base Ts by 2 into height delta iL by 2 and that should be equal to C into delta V. Now C let us calculate C is delta iL divided by Ts I will take it down as fs switching frequency this 2 into 2 into 2 is 8 fs delta V comes down that is the ripple across the output. So, this is the design equation for basis of design equation for C delta iL design parameter while designing VL we took it as 10 percent of the max I naught fs switching we know what switching frequency we are designing for delta V the out voltage ripple due to capacitor action is output spec.

So, we know that so based on that we can calculate what would be the value of C. Of course, in a practical capacitor there will be ESR drop across ESR also will come into the ripple, but anyway we take here the ripple across the capacitor due to that capacitor action which is equal to I is equal to C dvc by dt.

Now, let us look at how we will implement this single pole double throw switch, off course it cannot be implemented by a single semiconductor device it needs at least 2 semiconductor devices and let us see how we select the appropriate semi conductor device for an for appropriate throw.

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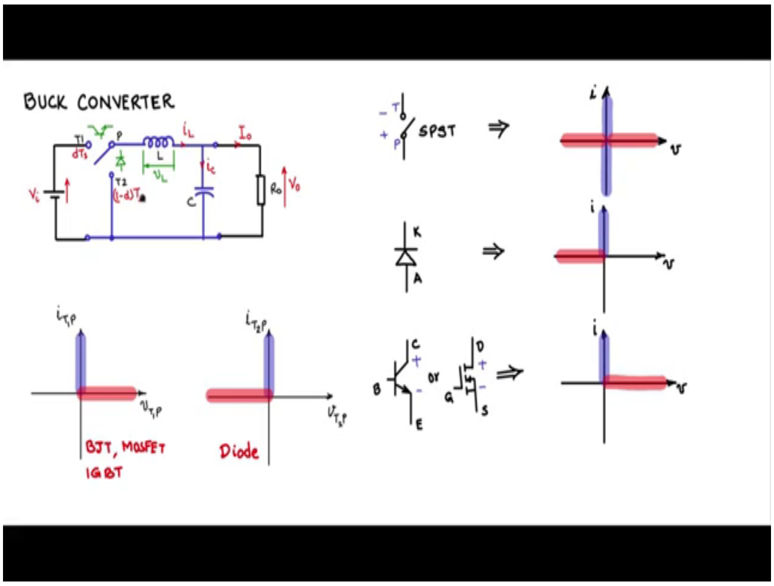

So, let us make some space here, now consider for example, a single pole single throw switch single pole a single pole single throw switch like this like that of a relay contacts how is it is iv static characteristics so draw the v versus i. So, v is the voltage across the SPST switch and is the current through the switch. So now let us say that this is throw and this is the pole and let say that positive direction is current flow from throw to pole. Now does this switch allow positive direction current flow yes.

So therefore, we will mark this like this, will it allow current to flow from pole to throw this PST switch like the relay contact will definitely allow. So, which means this is also a potential operating point. Now coming to voltage can throw to pole support a voltage the throw as positive and pole as negative, when the switch is off can the voltage that needs to be supported by the switch be positive like this throw positive pole negative yes in this case this is possible therefore, you can say that these are possible operating points. Likewise we can also find out whether the switch can with stand sustain voltage in the negative direction yes, so this also become an operating point.

So, for the SPST switch static iv characteristic though entire y axis current axis an entire voltage axis or operating points, which means the switch can support positive voltage during off condition it can support negative voltage during the off condition and doing on condition it can support positive direction current flow it can support negative direction current flow.

Now take for example, another switch a diode; diode is a switch with an anode cathode like this, so is it static iv characteristic as a switch. So now, let us consider does this device allow current flow from anode to cathode yes, so that if we call as positive direction then we say this is the set of operating points. Will it allow negative direction of current flow that is from cathode to anode no that will not be allowed buy this device therefore, there are no operating point the negative access of i.

Will the device the diode support voltage from cathode to anode yes, but cathode to anode is negative voltage yes can you support positive voltage and anode to cathode during which time before it bias no, therefore there is no operating point in positive direction of the voltage axis. So, this means that diode can have operating points on these marked segments, where it can support negative voltage when it is off and when it is on it can support positive current to flow through it which is an anode to cathode. Take for example, another semiconductors switch like the BJT or a MOSFET.

So, you have collector base emitter gate drain and source. So, how do the iv static characteristics or switch appear like if these 2 are operating as switches. So, when they are on does these device allow current to flow from collector to emitter if you consider that as positive direction drain to source consider that as positive direction then yes all these are operating points. Does it allow emitter to collector current flow or source to drain current flow no, so therefore, the negative portions negative portion of the i axis is are not operating points.

Likewise, now for the voltage can a positive voltage connector to emitter be supported by BJT during off condition or drain to source voltage positive drain to source voltage is supported by the master during the off condition yes it can do that, therefore all these are potential operating points. On the other hand negative voltage for both BJT and MOSFET cannot be supported by this and therefore the negative axis cannot be operating points.

This indicates that doing off condition this device can support only positive voltage and during on condition it can support only positive current. Now with this background let us get back to our buck converter single pole double throw switch, now there are 2 throws

T1 and T2 PT1 is one semiconductors switch PT 2 is another semiconductor switch. So, let us take one static characteristic for PT 1, so we call this voltage T 1 P I am taking T1 as the first note T as the second note i T 1 P.

So, the positive direction of current flow is T 1 2 P and positive for the voltage support is P more positive than P. Likewise for T 2 P I am taking V T 2 P throw to pole and i throw to pole. Now let us see how they how this characteristics get filled up and then we will map up them to the available device, now take for example, PT 1; in the case PT 1 you can see the; you can see the current through T 1 P the current through T 1 P is positive only positive there are no negative direction currents.

So, all the current that flow through d T 1 P is positive and if we go back to this page you will see that the positive axis of current are all possible operating points, because the current in this pole throw switch is always positive. Likewise the current through the pole throw to pole T 2 to P is always positive, observe that T 2 to P; T 2 to P the current flow is always positive. So, here to you will see that the possible potential operating points lie on positive current axis, likewise when you talk of the voltage supporting when PT1 is off T 1 is more positive than P because when T 1 is of P is connected to ground, so T 1 is more positive then P.

So, only the positive side of the voltage axis are potential operating points for PT 1 and in case of PT 2 P is more positive than T 2 is grounded 0 potential P is either 0 or V i. So, when P 2 is of P is connected to Vi positive potential, therefore VT 2 P is negative. So, only the negative portion of the axis are possible operating points. So, from this set of requirements of these switch i v we can say that this matches with the BJT or MOSFET or IGBT type of iv switch characteristics.

So, we can choose a BJT or MOSFET for P T 1 switch or even an IGBT and this matches with the characteristic of a diode. So therefore, we can say diode is the best suited for T 2 P, so we can place a diode somewhere like this here and we can place a BJT or a MOSFET or an IGBT in the T 1 P place and these 2 together will form the single pole double throw switch the equivalent function.

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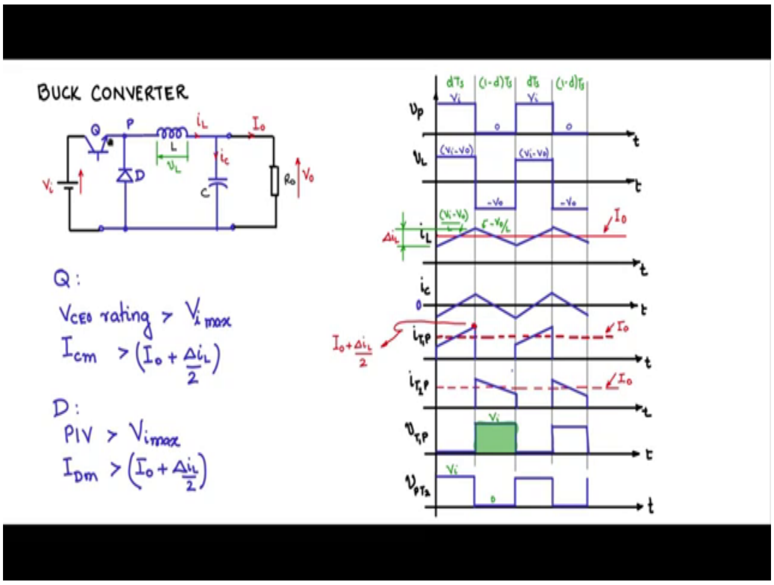

So, let us place these components in place of single pole double throw switch and see how the circuit will look like. So, let us erase those portion we will place the BJT here in this direction T 1 to P this is the pole diode in this direction this is the pole this Q and this is the. So this is the buck converter circuit with semiconductor switches in place. So, when this Q 1 is made on you will see that current flows in the direction charges of the inductor and then back, when you switch off Q1 the inductor current will pass through this and this and free wheel throw the diode automatically and the energy will start discharging and therefore the following slope in the current.

So, this is how the switches are selected for a converter for any general converter. Now let us look at the waveform let us see how you will rate Q and D. Now Q is T1P so T 1 P the voltage V T 1 P look at this when this Q is on it carries current i T 1 P is one and when the Q is off the voltage is withstanding capability should be at least Vi comes across this. So therefore, if we take Q 1 the V CEO rating for Q 1 should be greater than V i. So, it should be greater than this height and Vi max because unregulated this can swing from Vi main to Vi max it should be able to withstand Vi max.

The current rating current max rating flowing through this BJT or MOSFET should be capable of withstanding this much. So, it should be greater than I naught plus delta iL by 2, likewise for the diode the peak inverse voltage rating for the diode the negative voltage that diode should be able to with stand is P T 2 and this is Vi and therefore it should be greater than Vi max hand the current IDm max current that flows through the diode is here shown here T 2 P and this again is i naught plus delta iL by 2, therefore IDm should be greater than i naught plus delta iL by 2.

Other currents like average and RMS currents can be easily calculated from this wave shape and there be we get the ratings of the 2 semiconductor switches. So, now we know how to calculate value of the L, how to calculate the value of C how to choose the semiconductor switch and the semiconductor switch ratings Q and D for the buck converter.