Indian Institute of Science

Design of Photovoltaic Systems

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NPTEL Online Certification Course

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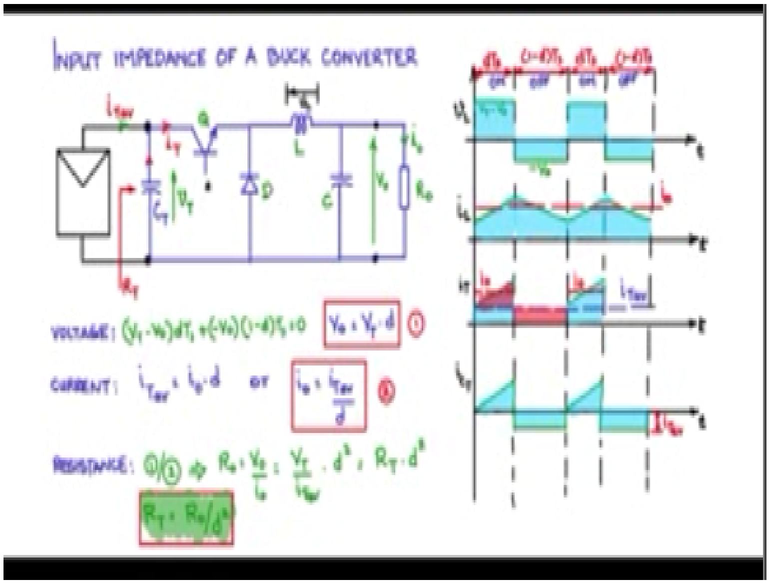

INPUT IMPEDANCE OF A BUCK CONVERTER

VOLTAGE: $(V_T - V_0)dT_s + (-V_0)(1-d)T_s = 0$ $\boxed{V_0 = V_T \cdot d}$ ①

CURRENT: $i_{T_{av}} = i_0 \cdot d$ or $\boxed{i_0 = \frac{i_{T_{av}}}{d}}$ ②

RESISTANCE: ①/② $\Rightarrow R_0 = \frac{V_0}{i_0} = \frac{V_T}{i_{T_{av}}} \cdot d^2 = R_T \cdot d^2$

$\boxed{R_T = R_0/d^2}$

Let us discuss now the input impedance of a buck converter and see how the input impedance of a buck converter can be regulated by duty cycle control consider this PV module and let us interface this PV module of the PV cell to a buck converter the buck converter consists of a BJT switch like this the BJT can be replaced with a MOSFET a MOSFET switch or it can also be replaced with the IGBBT switch and this is followed by a diode connected in shunt like this.

We have an inductor and a capacitor so this would form a buck converter circuit this portion now do that let us connect the load or not so we have the load and that is hot rod the voltage across R_0 is V_0 and the current flowing through or not will be I_0 so let us in have these symbols as indicated this is CLDQ q is the switch and here you have the terminal voltage VT across the panel and the current IT flowing out of the terminals of the path.

So this is the buck regulator circuit connected to the PV module in the boost converter connecting a capacitor across the terminals of the PV panel is not mandatory though it will be helpful but in the case of the buck converter here connecting a capacitance here is mandatory it has to be connected I will connect that later after discussing why for now let us understand the operation of this circuit and try to find the input output voltage relationship input output current relationship and the input output resistance relationship.

Let us have these t of graphs so one axis here the x-axis which is a time and the y-axis VL. VL is the voltage across the inductor and it is measured like this with a common point of the probe on this end of the inductor and the positive end of the probe at this point and we shall also have one axis versus time for the current IL the inductor current these are important variables and parameters that we need to we need to observe which we will use for an illuminator.

Let us mark the time spaces so I will mark the time spaces like this now this portion is the time when Q is on and I will call it as DTS like we did in earlier case for the boost convertor this is 1-TS together this period is TS period, because D <1 now it will repeat for the second TS period also like this now we can use this for drawing the waveforms during the time radius Q is on during 1-DTS Q is off so we will indicate that.

This is on time of time in the next cycle again on time of time and so on so when Q is gone what happens we will have the current flow in this fashion Q is on so this node is connected this node potential is the same as this node potential so this is VT this is positive diode is reverse bias it is out of the picture Q is on so you have the current flowing like this through the inductor part of it goes into the capacitance to another part goes through the load I_0 and comes back.

So this is the current flow through the circuit when Q is on so when Q is on during the DTS portion so during this time period let us see how the waveforms look like the voltage across V and just this node of the inductor is at potential VT because Q is on diode is off this and this will have the same potential so that will be VT this potential is connected to the output therefore this is at V_0 so the voltage across the inductance VL will be VT-V term $V_{0.}$

So that is what we will have here VD-V0 so let us share that and the current through the inductor is flowing in this fashion I said this is more positive than this as shown in this graph the current will rise up linearly VG-V0 is constant and because we L=L D, L/DT IL is an integral IL arises up with a slope VT- V0/L so it will be like this and I will add one more axis like this and that is to see what is the terminal current like.

So this is terminal current IT and because this is coming that in series with the inductance at this point because that is out of the picture the inductor current is same as Q current same as I T and therefore IT and the inductor current will look same during 1-DTS period Q is off so when Q is off there is no current flowing out of the terminal of the P V and the current through the inductor cannot stop.

It has to continue and part of it goes into the capacitor part into the load with appropriate directions and then you see that it freewheels in this fashion through the type diode is now on so under this operating mode let us see how the waveforms develop the voltage across the inductor during this mode of operation is -V0 that is because this node is connected to the ground so this potential is 0 this node is at V0 potential so 0-V0 will become $–V_{0.}$ So you will have a negative voltage across the inductor $–V_0$ this again is expected because we want the positive voltage a negative voltage to balance within the cycle such that the average voltage across the inductor should be 0 in the steady state and the inductor current so the voltage across the inductor is $–V_0$ and therefore, the inductor current is now discharging falling down with a negative slope of -V0/L because VL=LDR/ DT the slope DIL / DT will have a fallings lope of –V0/L.

So this would be the inductor current within the cycle IT because Q is off there is no current flow from the terminal off the PV panel so this remains 0 so this repeats the cycle also so you will see that the voltage will be a repetition cycle by cycle so on the inductor current and the terminal current of the PV panel will look like this now if you take the average of the inductor current so the outage of the inductor current the DC equivalent of the inductor current is flowing through or not that will be pure DT V0/R

So that is equal to I_0 the ripple portion which is having an average about this DC as 0 will flow through the capacitor because the capacitor should have a 0 average so the AC part the ripple part having a 0 averaged flows through the capacitance and the DC part flows through or not so therefore we know that this value here right through the metal would be having a value or not I not in the wave form of IT there is a terminal correct observe the terminal current is not continuous it is switched broken up okay.

So if it is switched and broken up when IT is flowing the power is some finite value when IT is 0 during this time IT is 0 which means the power drawn from the panel is 0 which means you are under utilizing the panel for the panel will be delivering peak power we need IT to flow continuously so now what is the continuous equivalent of IT here so this would be the average value of this.

So let us say the average value of IT I will call that as I T average is the DC value or the average value of this switched with current waveform and this average value has a value like this ID average is equal to I_0 x DI not introduce the average value like this now this average value has to flow here always continuously then only the PV panel will behave in a way where you can you can draw or maximum power from it.

In order to make buck converter operation for maximum power point tracking meaningful we need to have the terminal current rolling order the PV module is continuous so that peak power point can be tracked at every instant of time so which means that through the terminals we would like to have IT average amount of current flowing continuously from the PV module how do we do that so let me do some modification here. Let me erase this and also that and here.

I will place a capacitor so let me place a capacitor here CT the current that is flowing here I will name it as IT as it was originally IT which was flowing into the Q when the capacitor is not there and this current I will rename that as IT average and I am going to draw another waveform section here and I will call it what is the current through CT now note that the current through the capacitance will have 0 average just like the voltage across the inductor is 0 average voltage within the cycle in the steady state.

So in the steady state the current through the capacitance will be 0 now IT waveform is like this the shaded one blue shaded we want IT average to be what is marked here IT average continuous DC so if IT average is flowing continuous DC during this time actually no current is being demanded from IT because Q is off so what would happen during this time this portion of the energy should be dumped into the capacitance.

So that is what is happening that portion of the energy gets into the capacitance and during this portion IT average is coming out from the PV panel and the excess portion is coming from the capacitance so the capacitance current we can draw like this so this portion this is the excess portion above IT average so during the time when Q is on when Q is on high D average is contributing up to this line blue line and above that the stored charge in the capacitor is contributing this.

So these two had up to give you IT and during the 1-TS period IT average is continuing to flow out of the panel but as Q is off it is going entirely to charge the capacitance CT so it is flowing into CT of course this area should balance out the area and it repeats likewise so this portion of the area corresponds to the area here above the IT average line and this area corresponds to this area below the average line.

So if you take IT average line as the 0 line above and below the wave shape is exactly what would flow through CT and it repeats for the cycle this height down will be same as this height and that is IT average so if you connect the capacitor in this fashion then you can ensure that a current equivalent to IDL ID average is continuously flowing a DC current is flowing here such that peak power is being drawn from the PV module at all times and when IT does not flow and Q is off.

It is being dumped into the capacitance and the capacitor is acting as an energy bar so this placement of the capacitance here is very important in the case of the converter in the case of the boost converter this problem did not arise because the inductance was on the input side and there was a continuous current flowing through the inductor however one can put a capacitance of the terminals of the PV module it will improve the ripple and it will it will make the input voltage much more stable and to stabilize the voltage.

However it is not mandatory for the boost converter for but for the buck converter placing the capacitance is maggoty is compulsory let me mark the voltage across the CT as VT it is the terminal voltage and we are interested in finding the input impedance from the PV panel side so as seen from the PV panel from here would be the resistance of interest RT and we would like to find the relationship between the resistances RT N R_0.

So let us first find the voltage input output voltage relationship so it is given by taking the average voltage across the inductor a zero cycle by cycle in the steady state so we know from the waveform VT-V0 x DTS will be this area minus V0x1 -DTS will be this area so we will just put that down because this area should balance out this area so we will say VT minus V0 into DT S+ minus V0x1-DTS should be equal to 0 this implies that V_0 = VT x D will mark this as equation1.

The current relationship and we found that from this waveform I T average is nothing but I_0 x D would give you IT average height average is I_0 x D or can write I_0 = 80 average by D and this we will name it as relationship to we are interested in finding the resistance relationship input output resistance relationship so1/2 we will give you R_0 which is V0/I_0 which is equal to VD/ VT/IT average VT x D/DH/D which will give you VT/ T average x D^2 xD^2.

We know VT / IT average the voltage across the terminal divided by the continuous current that is flowing through the terminal is T average is the input impedance RT has seen from the PV panel so that is RT into d square so rewriting you can write it RT is equal to R_0/D^2 so this is the important relations relationship between R_0 and RT that we have been looking for in the BA converter so RT is a function of R_0 and D which is the control input to the buck converter so D is coming as a control input by controlling the on good cycle of this Q here.

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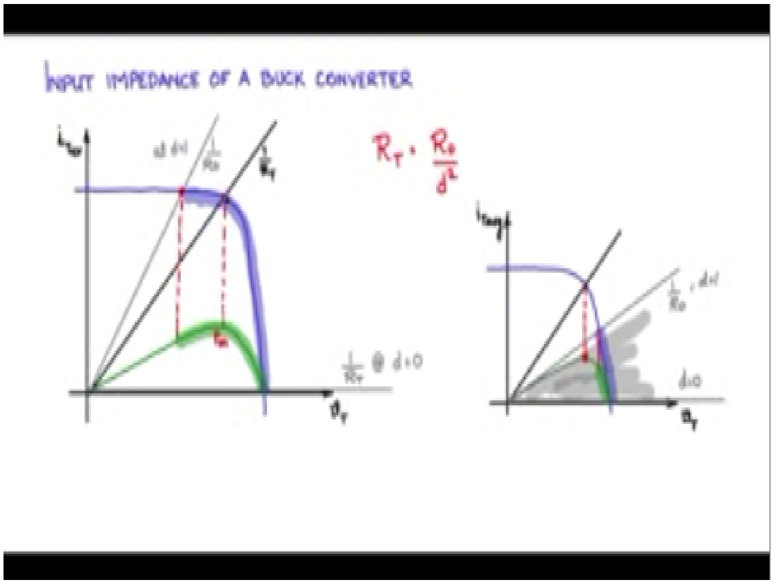

Let us now understand the effect of the input-output relationship of the buck converter on the IV characteristic of the PV panel so I will put VD on the x-axis or on the y-axis for the buck converter case it is ID average because you have to take the equivalent continuous current that is flowing out of the PV path so let me draw a sample IV curve and also a PV curve or versus voltage curve.

And let me take a load line like this is 1 /RT apparently this RT is adjusted such that it is at an operating point which is the peak power we would like the PV panel to operate at this operating point or at this load line so for the buck converter we have seen that RT is equal to R_0/D^2 D is the control input R_0 is the output resistance of the load resistance which is not under your control so if D is made 0 whatever may be the value of R_0 RT will be in finite infinite mini open circuit.

And therefore, the load line will align itself along the x-axis so if we draw that this load line is RT at D=0 likewise if we make D = 1 then RT =R_0 so it will result in a load line with a slope 1 /R_0 at T =1 so you see for the buck converter all these highlighted zone is the range of the buck converter all these are reachable points with different values of D varying from 0 to 1 you can have different slope load lines from 1/ RT with slope of 0 to 1/ RT = 1 /R_0 with RT=R_0 at D=1.

Now here in this case in this figure you see that this line which results in the peak power the peak power operating point lies in the zone of operation of the buck converter which means this point this peak power operating point is reachable by the buck converter oh did I mark the extreme operating point at 1/R_0 and drop a vertical you see that these are the powers that can be drawn from the PV panel at various operating points and you see that the peak power operating point is within the range.

Therefore in this picture the converter is a meaningful design however again like in the boost converter I am going to raise a caution let me draw another VT versus IT average graph so you have this typical IV and the power curve and this is supposed to be the optimal load line for peak power point and I have here the load line corresponding to D= 0 which is where RT in finite open circuit and let us say I have another load line 1/R_0 so this is the other limiting instead of being here R naught value is such that the slope results like this.

So this is what you would get a D=1 so for the buck converter apparently all load lines will fall only within these two limiting cases and this would be the range the reachable operating points and from the 16 point if I drop a vertical and I will see that only these are the powers that can be outputted from the PV module but the peak power operating point is somewhere here and the peak power falls here which is outside the zone of operation of the Backend therefore this scenario would lead to a situation where the buck converter operation is not meaningful.

Whatever maybe the duty cycles the controlling input the buck converter will not provide a road line which will give a peak power operating point so you have to be very careful when you design the converters whether it be boost buck or any other converter the load line analysis has to be done first to ascertain whether that particular converter can really provide maximum power point operation you should for the buck converter how a scenario like this where the extreme $1/R_0$ slope line.

That is a load line slope is such that the range of operating points should allow for a possibility of peak power point operation such so that the peak power point the peak power can be drawn from the DV panel which means the power point operating point should be a reachable point for the buck converter zone of operation.