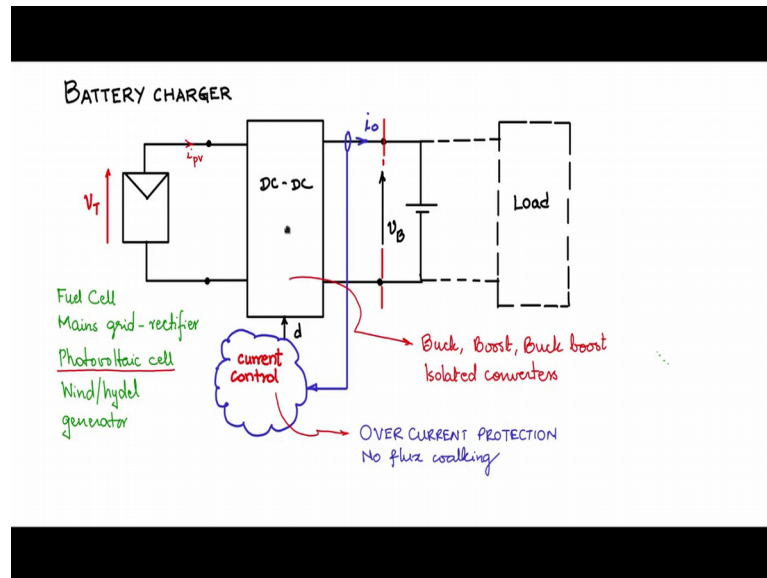


Fundamentals of Power Electronics
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Lecture – 93
Current control for battery charger application

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A very common and popular application of DC-DC converters is an battery charging, battery chargers are made of switched mode DC-DC converters. So, you see that here is the battery which needs to be charged, that battery of course will be used to drive some load. Now this battery is interfaced through a DC-DC converter with some DC source. Now that DC source could be a fuel cell or it could be a mains grid followed by a rectifier or it could be photovoltaic cells, very popular photovoltaic cells charging the battery or wind hydro system connected to an alternator or a generator followed by a rectifier which is used for charging the battery.

So, there are very many sources which can be used as the input source which can be used to charge the battery. And as far as the DC-DC converter is concerned, you could use any DC-DC converter. It could be the buck, the boost, the buck boost converter and we have discussed the isolated converters like the forward converter, the dual switch forward converter, push pull converter, half bridge converter, full bridge converter, fly back

converter all these converters are possible candidates to be used for the DC-DC converter to charge the battery.

We have seen that in a DC-DC converter, the output voltage the voltage which is across the output of the DC-DC converter can be regulated, and we also saw how to do the closed loop operation. In this application; the battery charging application we need to control the charge current that you are pumping into the battery. So, it is a slightly different nature of control where you are controlling the current the output current in naught of course, in the case the DC-DC converter if it is the buck converter which is used, the output current and the inductor current of the same.

When many cases the inductor current that is the state is controlled and which will indirectly control the output current. If you are using a boost converter, the inductor current which is the input current will be controlled. In the case the buck boost, the inductor current is controlled. Generally for battery charging, the recharging current which is being pumped into the battery needs to be profiled. So, it is properly profiled then the chemistry in the battery will work properly to extract as much life out of the battery as possible.

However, what we will be discussing is not just output current control. We will be discussing the inductor current control that is controlling in the inductor state, using any one of the converters the buck, boost, buck boost converters.

The concept of current control is similar whichever be the converters, I will initially explain with the buck converter using let us say photovoltaic cell input as the source here, being the one of the most popular and growing application areas. You can use it with either the boost or the buck boost or any other converter also. So, let us discuss the DC-DC converter operation with current control, controlling the inductor current. So, in the case the buck converter that I will be discussing the inductor current control and the output current control will become same.

Some of the advantage of current control is that there is inherent over current protection. So, cycle by cycle instantaneous over current protection can be achieved with current control. Another nice advantage spinoff benefit that you would get from current control is that no flux walking will happen, you do not need flux walking capacitor. And that is a

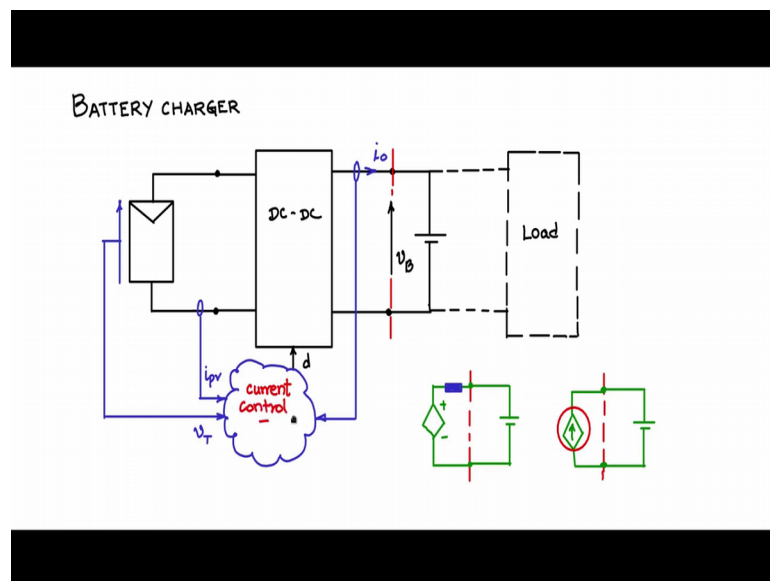
significant benefit because as you start going for higher and higher powers, the capacitor can become significantly costly in order to prevent flux walking.

So, let me consider a photovoltaic cell as the source because it is very popular source. Now rooftop solar pv cells becoming more and more popular and many applications related to photovoltaic cells are involved in charging the batteries. So, I will replace the generic source with a photovoltaic cell. You may use any of the voltage sources, but I am just using a photovoltaic source. It may as well be mains grid rectifier which we have dealt with earlier in the course.

So, this photovoltaic cell is used to charge the battery through this DC-DC converter, and the DC-DC converter will be a buck converter that I will be using. You can use any primary converter and we will be sensing the output current which will be the inductor current and you that to control the current of the inductor. So, let me mark this is the terminal voltage of the source, v_{pv} is the current input current to the DC-DC converter.

So, now let us see how this battery charger is built. Let us try to understand the principle of operation and then let me go into the circuit and give you the schematic for controlling the DC-DC converter for current control and later I will be explaining some problems that we will also later address by providing slope compensation.

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Let us now discuss the battery charge a circuit where MPPT is integrated inbuilt into the charger scenario. So, let us consider this pv module or pvra. And this pvra is connected to a DC-DC converter and then the output the DC-DC converter is connected to a battery that needs to be charged. So, you will say this is the DC-DC converter. It has a control input d , the duty cycle input. The voltage across the terminals of the DC-DC converter output is connected to the battery and therefore, the output of the DC-DC converter the voltage is fixed by the battery because the battery is a source. Across the battery you may have a load connected like this. So, you have a load connected like this.

Now, how do we charge the battery? The terminal voltage is v_B and this voltage is defined then and what would be the charge current. So, let us say we want to put the peak power from the panel into the battery. Now let us say p_m is the peak power, p_m by v_B will give you the i_b the peak power that is going out of the DC-DC converter.

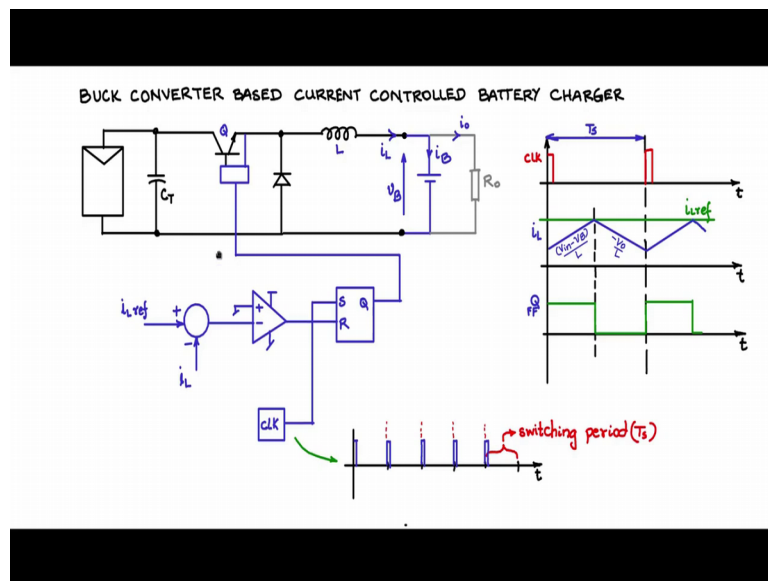
So, i_b can be controlled by controlling the duty cycle because v_B is fixed and therefore, power can be controlled by controlling the duty cycle as v_B is fixed. So, that is the strategy that we want to adopt. Sense this current i_b which is flowing out of the terminals of a DC-DC converter and you start as the feedback you also provide the pv current i_{pv} and also the terminal voltage of the pv v_T which will be used for sensing the power that is being drawn from the pv module.

Now, what is the control algorithm that you need to put in here? Let us consider this boundary here the terminals of the DC-DC converter to which the battery is connected. Now, normally if you consider these terminals and the battery is connected here, all those portion pv source DC-DC converter can be considered as a controlled source. Now let us say if it is the controlled voltage source plus and minus like this. If you have a controlled voltage source, you cannot parallel to voltage sources because there is no impedance in between and there can be huge circulating currents which can blow up something in the control voltage source.

So, whenever you are having a control voltage source, you need to have a series impedance which will limit the current. So, if you are having a controlled voltage source have a series impedance, this is one possibility. But you do not want to control the voltage because battery voltage is fixed you can directly control the current. In fact, a controlled voltage source with the series impedance and if the impedance is inductive

non-dissipative that will form a controlled current source itself. So what can be also done is across this boundary here you have the battery, you have a controlled source and that controlled source you make it as a controlled current source. It has the inbuilt impedance, necessary impedance inbuilt within it, so that there will always be a current limit, current source and the voltage sources can be connected in parallel. So, we will follow this model and that is what we will introduce into this control algorithm which is a current controller.

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Let me draw and discuss the schematic for a buck converter based current controlled battery charger. Now, what it basically means that the pv module or the pv array is interfaced with a buck converter which will charge the battery. So, let us draw the circuit schematic. So, you have the pv module, pv panel connected to a buffer capacitor C_T at the terminals and this was followed by a buck converter. So, I have a BJT switch. Now this BJT switch can be replaced with a MOSFET switch or an IGBT switch or semiconductor switch followed by a diode and I have an inductor and following the inductor I am not going to place a capacitor. Instead of the capacitor I will connect a battery in this fashion.

And across the battery you may have the load R naught like this. So, because the battery here fixes the potential across the output terminals of the DC-DC converter, the current i naught R naught is decoupled from the rest of the circuit operation. So, the current i naught

through R_{naught} is B battery by R_{naught} . Now here you have the battery voltage v_B , we will call that as v_B . The current through the inductor is as shown here, this will be the current through the battery i_B and this current will be i_{naught} which is flowing through the external load.

Now, our point of interest is this current, the current that is going to the battery load combine should be such that maximum power is drawn from the pvra or the pv module. So, let us draw the control schema. I have a comparator here plus minus so, it compares the feedback signal with reference signal I will call the feedback signal as i_L . So, what happened feedback is the current? Recall our discussion voltage v_B being constant because of the voltage source connected across the terminal, it is sufficient to feedback just the current and you start one to control the power and here you will have a i_L reference, i_L reference for this.

Now, this error goes through a comparator. So, I will connect this to the minus terminal to the plus terminal I connect ground 0. Of course, there is power supplies for the comparator. The output of the comparator goes to an SR latch. So, I am going to connect the out of the comparator to the R reset pin of the SR latch. There is set pin also and there is a cube the output pin of the SR latch. The output of the pin of the SR latch is going to get connected to this get drive circuit or this drive circuit in this fashion.

So, output of the SR latch Q gets connected to the base drive circuit which will drive this on or off. So, how does this operate? Now, before that there is something we need to connect to the set pin also. So, let me how clock block. So, the clock output is connected to the set pin of the SR latch. How does this clock look like? So, let me have the time. So, I will buck these sticks. Each of the stick space is this switching time period T_S , ok.

So, the clock is in this fashion at the beginning of every switching time period, you will have a very narrow, very small duty cycle pulse coming like that at the same period the period being defined by this clock. So, this moment is small duty cycle pulse comes to the set pin; it comes and sets the output of the latch on the rising edge. So, you have the rising edge. So, at the rising edge we will see that Q gets set and at every start of the period Q is set and then switches on the transistor.

Now, let us look at the various waveform to understand how this operates. So, I will draw the various access time access basically and I will divide this into two portions.

This is the first cycle TS and this is the later cycle. So, at the start of the cycle you have a small duty cycle pulse and that is this clock pulse and it happens at every starting of the period. Now, the moment this clock pulse is given, it sets this SR latch Q is high. Moment Q is high there is base drive for the BJT or gear drive for the MOSFET and this is on and V T gets connected and the inductor is charging up the inductor current is growing.

Now, let me give some reference here. Let me for the moment set a reference which is a constant, clock then I will set a reference which is constant i_L reference. So, when Q is high, it is providing the base drive or gear drive to this for semiconductor switch and there by the inductor current is integrating and having a positive slope and that positive slope is v in minus v_B ; v battery divided by L . So, it keeps increasing in the fashion.

i_L ref is higher than i_L . This is i_L ref which is higher than i_L . So, when i_L ref is higher than i_L , the output of this algebraic sum R will be positive, but that is connected to the negative of the comparator then the output will be low, the reset pin will be low and no change on Q. So, it keeps increasing till the point when i_L reaches and crosses over i_L ref. So, the output of the algebraic sum R becomes negative and this becomes positive, reset becomes positive and therefore, Q will reset and go low. Moment Q goes low, there is no drive for this power semiconductor switch. It will switch off and the inductor will start freewheeling and start falling; current will start falling.

So, if you take this portion of the operation you will see that if you look at the output of the Q of the flip flop, it would have been high till this point and then it resets. So, during this period when this is low inductor is freewheeling, you know the buck converter operation it is freewheeling. This is connected to 0 because it is freewheeling like this and what is connected to the inductor is minus v naught by L or minus v naught in this case is v_B minus v_B by L .

And then again at the new cycle there is a clock coming in. This will trigger the SR latch the Q goes high the cycle repeats. So, you will have the inductor current rising and then at the point when i_L reaches i_L ref, there is a change in the slope so, it keeps happening in this fashion. So, observe that whatever current value you are setting i_L ref i_L ref, the inductor current the current that is going to the battery load combined never exceeds the i_L ref. So, it is always below the i_L ref and gets controlled in this fashion and this is

called current control. It is as though every cycle there is a check for the current and the moment there is a over current within a cycle, it is switched off. And then again the power semiconductor switch is switched on, the next cycle when it is on till the point when the current exceeds the reference current and again it switches off. So, it keeps doing and cycle by cycle there is current limiting and therefore, this is a very safe and fast method of doing battery charging through current controlled mechanism.