Selecting the right DC/DC converter for maximum battery life

Milos Acanski

ABSTRACT

Choosing the best topology for a battery powered application such as IoT sensor, smart lock or IP camera might not always be straightforward, based on the available and required voltages alone. When it comes to battery life, some topologies might have advantages over others, depending on the battery discharge profile and the type of load. This application report shows how battery life can be maximized by selecting the most suitable topology for the given conditions.

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1 Introduction

Choosing the right converter topology for a power supply usually starts by considering input and output voltages. If the input voltage is always higher than the required output voltage, a buck converter is the first choice, and if the input voltage is always lower than the required output voltage, a boost converter is the best bet. With battery powered devices this is not always so easy. A typical lithium-ion (Li-ion) battery voltage, for example, can change from 4.35 V down to 2.5 V during the discharge cycle. If we need to generate a fixed voltage within this range, the first solution that comes to mind is a non-inverting buck-boost converter. But is this always the best choice? Like in many engineering problems, the answer is – it depends. One has to consider which design goals are most important. When it comes to battery life, which is often one of the most important design goals, depending on the design parameters, all three basic converter topologies may have advantages over the others.

Rechargeable Li-ion batteries are often used in personal electronic devices as the power supply source. One possible discharge curve of a Li-ion battery is shown in Figure 1. For this particular battery it can be seen that the voltage changes in a relatively large range from 4.2 V down to 2.8 V after which the output voltage rapidly drops, the internal resistance rises, and the battery is depleted. It is important to stress that this profile depends strongly on the load profile, temperature, and aging due to number of charge and discharge cycles.

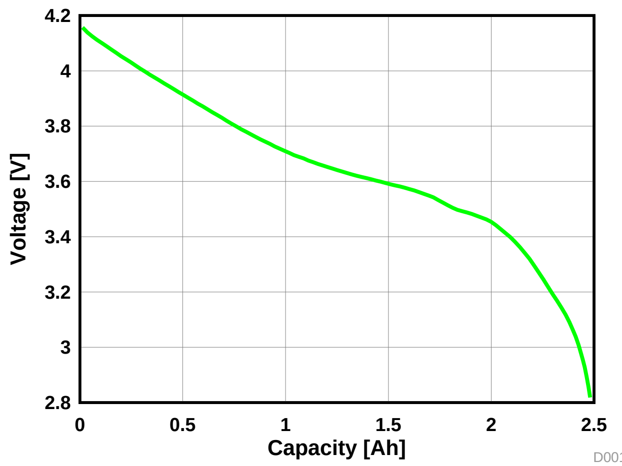

Figure 1. Discharge Profile of a Li-ion Battery at 1 A

2 Converter Topologies for Battery Supply

A fixed 3.6 V supply from a Li-ion battery with a discharge profile shown in Figure 1. Since this voltage is within the voltage range of the battery, we can consider three basic topologies: boost, buck, and buck-boost topology.

2.1 Boost Converter

A boost converter is used to step up the input voltage. If the input voltage is higher than the required output voltage, the input is normally fed through to the output. In this case, an internal switch that can bypass the power stage can be implemented in order to increase the efficiency. Once the input voltage goes below the required output voltage, the boost converter starts switching until the battery is depleted. Figure 2 shows the output voltage of the boost converter versus the battery state of charge, assuming the same discharge profile as in Figure 1.

It is important to note that in bypass mode the output voltage is the same as the input voltage. This operation is fine if the load can tolerate a higher voltage. In the bypass mode there are no switching losses but the load may show a higher current consumption. If this is not acceptable, a linear regulator should be added to the output of the boost converter. In that case, the boost converter has to maintain a slightly higher output voltage than the load voltage, to compensate for the required voltage drop of the linear regulator, which is typically 0.1-0.2 V.

2.2 Buck Converter

A buck converter is used to step down the input voltage. If the input voltage is lower than the required output voltage, the output can be disconnected or the input can be fed through to the output. In the latter case, Figure 2 shows the output voltage of the buck converter versus the battery state of charge.

As in the case of the boost converter, in the feed-through mode the output voltage is not regulated. At lower than nominal voltages the load might perform poorly, or it should be turned off. Moreover, close to the end of the regulated region (V_{IN} close to V_{OUT}), load transients may cause voltage drops large enough to force the converter out of regulation, resulting in poor load transient behavior. The voltage drops can be caused by the impedance of the input path, cables, connectors and the battery internal impedance. To make the matter worse, the internal battery resistance in general rises significantly as the battery enters deep discharge.

2.3 Buck-Boost Converter

A buck-boost converter is used to step down or step up the input voltage. Here we are considering the 4-switch non-inverting buck-boost converter which is essentially a buck and a boost converter sharing the same inductor. The buck-boost converter always regulates the output voltage keeping it constant while the battery is being discharged, as shown in Figure 2. It will also always compensate for voltage drops on the battery and the input impedance caused by load transients or other loads connected to the battery. The disadvantage of the buck-boost converter is that its price is usually higher than the price of a similarly specified boost or buck converter.

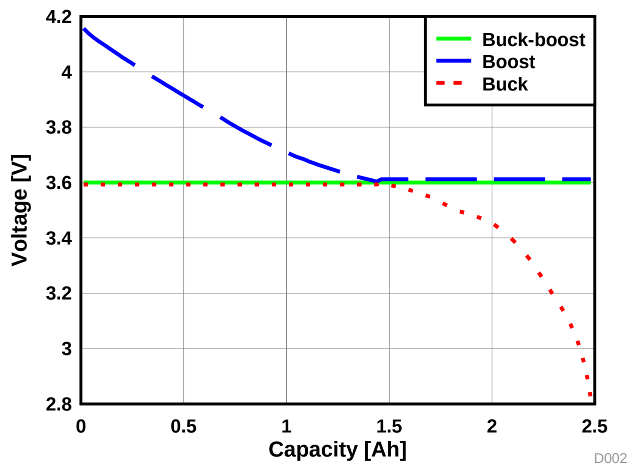

Figure 2. Voltage Obtained from Li-ion Battery Using Different Topologies

3 Case Study

If the load can tolerate only constant supply voltage, then the buck-boost converter might be the best solution. Otherwise we are wasting the part of the battery charge where the boost or the buck converter has to be turned off, or they would go into bypass/feed-through mode. Nevertheless, even if the load can tolerate non-constant voltage, we can compare the performance of all three converter topologies.

Consider a system consisting of a battery, a DC/DC converter and a load. The battery is 2500 mAh Li-ion type, with the discharge curve at 1 A shown in Figure 1. We can consider three types of loads:

- Constant current load – this can be a linear LED driver, or a linear regulator used for additional filtering, or for obtaining a different voltage,
- Resistive load – this can be an MCU, a DC motor, or any other resistive-like load,
- Constant power load – this can be a second DC/DC stage, or a device with an integrated DC/DC converter such as some RF power amplifiers.

We will compare three devices: buck-boost converter TPS63802, boost converter TPS61280A and buck converter TPS62826. Some device parameters are listed in Table 1.

Table 1. Devices Compared in the Case Study

Device	Topology	V_{IN} [V]	V_{OUT} [V]	$I_{OUT,MAX}$ [A]	Peak efficiency [%]
TPS63802	Buck-boost	1.3 - 5.5	1.8 - 5	2	97
TPS61280A	Boost with bypass	2.3 - 4.8	2.85 - 4.4	4	97
TPS62826	Buck	2.4 - 5.5	0.6 - 4	3	97

The TPS61280A boost converter can operate in bypass mode when the input voltage is higher than the required output voltage. In bypass mode, an internal low resistance switch bypasses the main switch and the inductor, decreasing the conduction losses. The TPS62826 buck converter operates in feed-through mode when the input voltage is lower than the required output voltage. In feed-through mode, the input is connected to the output through the main switch and the inductor. Therefore, the output voltage for the boost and the buck converter behaves according to Figure 2.

In the measurements, the battery is discharged at constant current, resistance or power, while the DC/DC converter generates fixed output voltages, unless it is out of regulation. Figure 3, Figure 4 and Figure 5 show the measured battery life achieved with the three devices used to generate voltages from 3 V to 4 V. In case of the buck converter, the time measurement is stopped when the output voltage drops by 5% due to loss of regulation. In case of the buck-boost and the boost converter, the time measurement is stopped when the battery is fully discharged.

From Figure 3 and Figure 4, for constant current or resistive load, it can be seen that the buck converter is the best choice if the required output voltage is close to 3 V. For output voltages up to around 3.6 V, the buck-boost converter achieves the longest battery life time. Above 3.6 V, the boost converter is the best choice. For constant power loads, the best device is the one that has best overall efficiency for the given conditions, which is in this case the boost converter.

If the load does not tolerate a variable supply voltage, the achieved battery life with the boost converter would be shorter, since feed-through mode is not allowed. An additional linear regulator would be required then. For the constant current load, the resulting curve in Figure 3 should be shifted left by the amount of voltage drop required for the linear regulator, resulting in shorter battery life. For resistive load, a linear regulator would take over some of the power loss that would be otherwise dissipated in the load. However, it would also change the load type to the constant current one, which could in the end result in either longer or shorter battery life, depending on the load current.

As a final note, the shown results apply for the particular use case described here. In general, the battery discharge curve changes with load, temperature and age, and as it becomes more flat, it might make more sense to use either boost or buck converter. Moreover, if the load current profile is not constant, the efficiencies at different load levels will also affect the achieved battery lifetime.

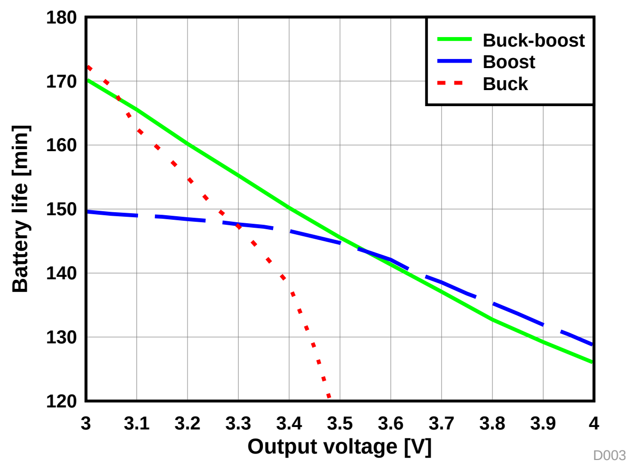

Figure 3. Battery Lifetime vs. Output Voltage: Constant Current Load (1 A)

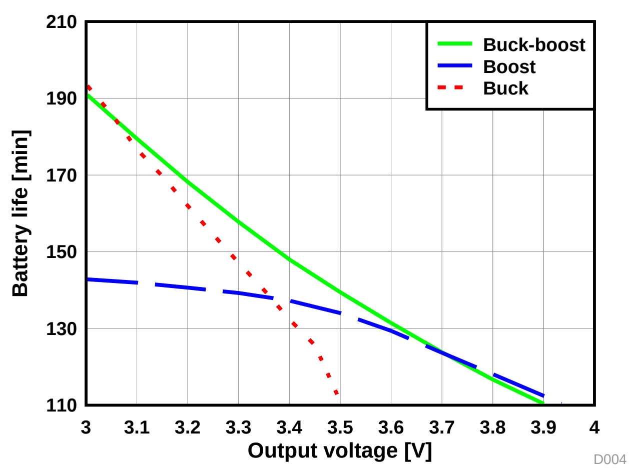

Figure 4. Battery Lifetime vs. Output Voltage: Resistive Load (3.6 Ω)

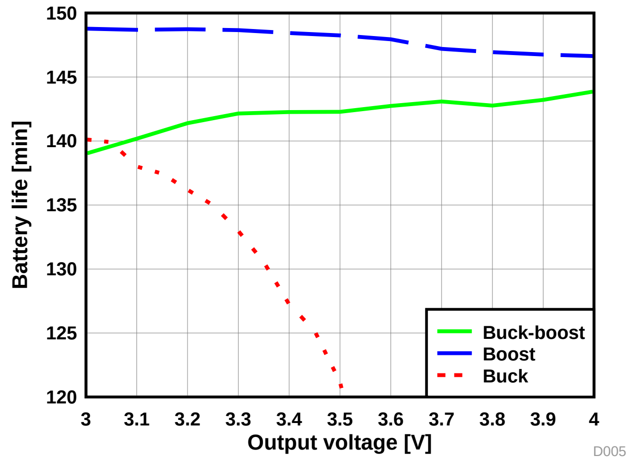

Figure 5. Battery Lifetime vs. Output Voltage: Constant Power Load (3.6 W)

4 Conclusions

Choosing the best converter topology for a battery application should take into account the battery discharge profile and the type and profile of the load, beside the voltage levels. Depending on specific conditions, all three basic topologies may be the best choice to achieve the longest battery life. The best way to select the right device is to compare them directly through measurements.

5 References

1. *TPS63802 2-A , High-Efficient, Low I_Q Buck-Boost Converter with Small Solution Size*, TPS63802 Datasheet, SLVSEU9A
2. *TPS6128xA Low-, Wide- Voltage Battery Front-End DC/DC Converter Single-Cell Li-Ion, Ni-Rich, Si-Anode Applications*, TPS61280A Datasheet, SLVSCG9B
3. *TPS6282x, 2-, 3-, 4-A Step-Down Converter with 1% Output Accuracy in 1.5-mm × 1.5-mm QFN Package*, TPS62826 Datasheet, SLVSEF9B