Application Report

Selecting a DC/DC Converter for Maximum Battery Life in Pulsed-Load Applications

Milos Acanski

ABSTRACT

When designing a battery powered system, maximizing battery life is one of the most important design goals. Battery powered systems, such as smart meters, IoT sensors or wireless medical equipment often require a power converter to obtain fixed supply voltages for time varying loads. In order to minimize the conversion losses it is important to look at the overall efficiency, together with the load profile. This application report shows how to interpret efficiency under different load conditions in order to maximize the battery life when selecting a suitable converter.

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1 Converter Operation Modes Under Different Load Conditions

In many battery powered devices, current consumption is approximately pulse-shaped with a period T, as shown in Figure 1-1. Typically, there is a short activity, characterized by a high current $I_{BAT,HI}$ and a duty cycle D, followed by a period of inactivity, characterized by a low current $I_{BAT,LO}$. Such load profiles can be found in wireless sensor applications for example, where measurements are periodically transmitted via an RF transmitter. When selecting a power converter for the system, a common pitfall is to consider only the heavy-load efficiency, neglecting the battery consumption during the period of inactivity.

With a pulse-shaped consumption profile, different operating modes of a converter can be considered. Which ones are important depends primarily on the load profile, that is, how much time the device or load spends in the certain mode and what is the actual load current. The exact combination of operating modes determines the current consumption and the battery lifetime. We will here consider different operating modes for the TPS63805, which is a buck-boost device. When looking at the power level and the conversion efficiency, there are three different modes of operation to consider.

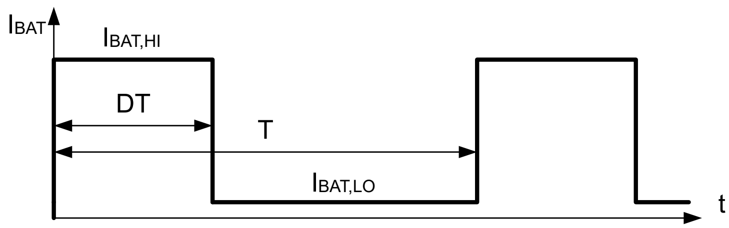

Figure 1-1. Battery Current Profile with a Pulsed Load

1.1 Operation Under Heavy Load

When the device operates under heavy load, the internal power stage operates in pulse-width-modulation (PWM) mode where it is constantly switching. For the TPS63805 this is the case when the peak inductor current is above 700 mA typically. The conversion losses depend on the particular device and the passives around the device, in the first place the inductor. The efficiency curve for the TPS63805 operating in PWM mode is shown in Figure 1-2. Using the efficiency curve, it is easy to map the load current into the battery current consumption. As it can be seen, while operating under heavy loads the device reaches highest efficiency. However, forcing the power stage to always operate in PWM mode penalizes the efficiency at light loads, as various losses due to constant active operation become larger than the load power.

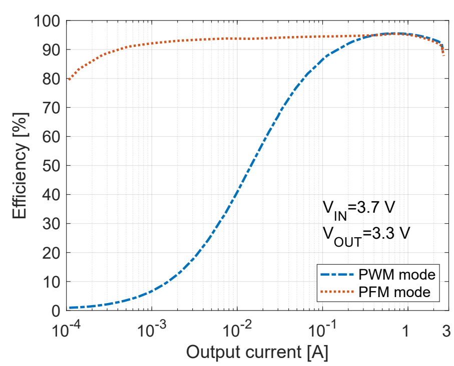

Figure 1-2. TPS63805 Efficiency vs Output Current

1.2 Operation Under Light Load

To improve efficiency at light load, power-save (PS) mode can be enabled. In PS mode, under light load the converter operates in short bursts, frequently enough to maintain the output voltage. Within one burst the converter operates under current higher than the load current, and therefore at higher efficiency, while for the rest of the period the converter is inactive. This way of operation is called pulse-frequency-modulation (PFM). Using PFM at light loads, the resulting efficiency is significantly improved over PWM, as shown in Figure 1-2.

An important parameter associated with PS mode is the quiescent current I_Q. For TI devices, unless noted otherwise in the datasheet, the quiescent current I_Q is defined as the current drawn by the device in a no-load and non-switching but enabled condition. I_Q includes the current necessary for operation of all parts of the device except for the power stage. The current for operating the power stage, which is heavily dependent on external components, is not included in I_Q. Therefore I_Q is a device parameter, and not a system parameter, since I_Q is solely dependent on the device itself. For more information on I_Q, see Reference 2.

I_Q is often misinterpreted as the no-load input current, which is a current drawn by the converter from the input power supply when there is no load present on the output of the converter. The no-load input current also includes the current for the switching power stage. Being a device parameter, I_Q constitutes only a part of the no-load input current. Nevertheless, I_Q can still be used to estimate the input current under no-load or light load conditions, see Reference 2. The input current consumption is determined by both I_Q and the conversion efficiency. The share of I_Q in the input current becomes larger as the load current decreases to zero, and selecting the device with lower I_Q is likely to result in lower input current. Still, the light load efficiency can be heavily influenced by the external components around the converter, and the best way to determine it is to measure the efficiency directly. In case of the direct measurement, there are some important aspects that need to be considered, see Reference 3 and Reference 4.

1.3 Operation in Shutdown Mode

In some applications, it is not required for the load to be constantly on. In such cases the load can be turned off completely by disabling the converter and putting it in shutdown mode. In shutdown mode, the converter stops switching, all internal control circuitry is switched off, and the load is disconnected from the input. In case of the TPS63805, the input current in shutdown mode I_{SD} is 0.6 μA maximum. I_{SD} is usually much lower than I_Q. Nevertheless, as is the case with I_Q, I_{SD} should also not be neglected when dealing with load profiles with very small duty cycle D.

2 Case Study

The battery currents in different operating modes can differ by several orders of magnitude, but so can the times spent in the respective operating modes. Looking back at Figure 1-1, it is not uncommon to have an application with a load duty cycle D below 10^{-3}. If the ratio of input currents is in the same order of magnitude as the ratio of active and inactive period, the light load current should not be neglected when calculating battery life time.

Consider a battery powered system where a buck-boost converter is used to obtain fixed 3.3 V voltage from a Lithium-ion battery with a nominal voltage of 3.7 V. The load current has a pulse-shaped profile as shown in Figure 1-1, with corresponding values $I_{LOAD,HI}$ and $I_{LOAD,LO}$. The resulting battery currents $I_{BAT,HI}$ and $I_{BAT,LO}$ can be directly measured for different load currents $I_{LOAD,HI}$ and $I_{LOAD,LO}$, or estimated via efficiency curves and I_Q. The TPS63805 is compared with a similarly rated competitor's device which has higher efficiency at heavy loads resulting in lower $I_{BAT,HI}$, but also higher quiescent current I_Q and higher shutdown current I_{SD}, resulting in higher $I_{BAT,LO}$. The average battery current consumption can be expressed as a function of the load duty cycle D as:

$$I_{BAT}=DI_{BAT,HI}+(1-D)I_{BAT,LO} \quad (1)$$

The relevant device parameters are summarized in Table 2-1. As it can be seen, there is a difference between the quiescent current I_Q and the no-load input current. The no-load input current includes I_Q, but also the current due to losses in the power stage and the external components. In this case, using the TI device with lower I_Q resulted in lower no-load input current.

Table 2-1. Operating currents and efficiency for the TPS63805 and the competitors device

Device	Quiescent current I_Q	No-load input current	Shutdown input current I_{SD}	Peak efficiency
TPS63805	11 μA	17 μA	0.6 μA	95.5%
Competitor	40 μA	51 μA	1 μA	97.5%

The comparison between the TI and the competitor device for a range of load duty cycle D and different load profiles is shown in Figure 2-1. At high load duty cycles D, using the competitor's device results in up to 2% lower battery consumption, owing to its higher efficiency at heavy load. However as the D decreases, the TI device with its lower I_Q starts gaining advantage over the competitor's device. The turning point for $I_{LOAD,HI}$ = 1 A, for example, is at approximately D = 0.003, and for lower load duty cycles using the competitor's device results in up to 115% higher battery consumption for $I_{LOAD,LO}$ = 10 μA. As the load current for inactive period $I_{LOAD,LO}$ becomes lower, the advantage of having lower I_Q becomes more important.

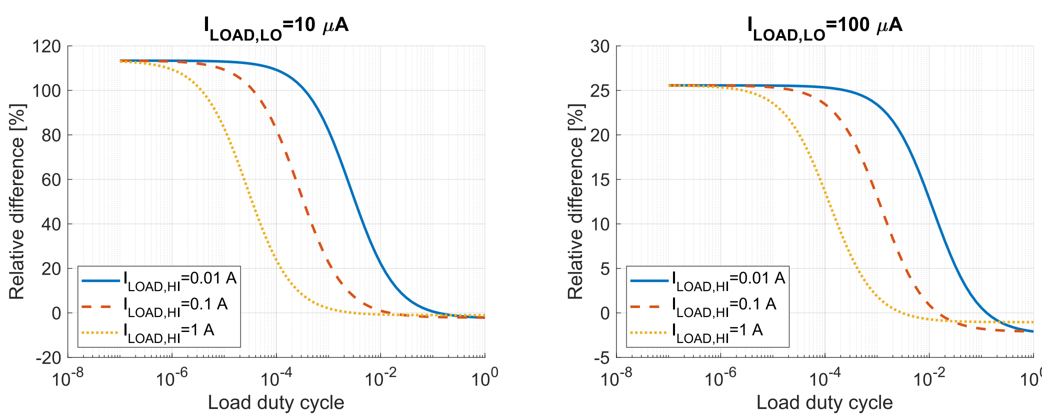

Figure 2-1. Relative Difference in Battery Consumption vs Load Duty Cycle

If the load is turned off during the inactive period by disabling the converter, the battery current $I_{BAT,LO}$ becomes the shutdown input current I_{SD} of the converter. The same results as for low I_Q apply here. For higher load duty cycles D, using the competitor's device results in slightly lower battery consumption. For low load duty cycles, selecting a device with lower shutdown current results in lower battery current consumption. The same two devices are compared and the result is shown in Figure 2-2. For high D the competitor's device has up to 2% lower battery current. For low D, the TI device gains advantage, having lower I_{SD} of 0.6 μA compared to the competitor's 1 μA, and using the competitor's device results in up to 66% higher battery consumption.

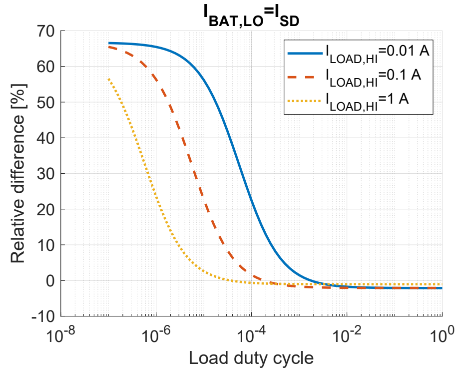

Figure 2-2. Relative Difference in Battery Consumption vs Load Duty Cycle

The same approach in comparing the average battery current consumption can be used in case of more complex load profiles than the one shown in Figure 1-1.

3 Summary

In many battery applications the current consumption profile of the load is pulse shaped, often with a low load duty cycle, with a short period of activity under heavy load, followed by a long period of inactivity under light load. When selecting a power converter for such applications, it is important to take into account all operating modes when calculating battery consumption, especially for applications where the load operates with a low load duty cycle. In such cases, significantly longer battery life can be achieved by selecting a device with lower quiescent current instead of a device with higher heavy-load efficiency.

4 References

1. "2-A, High-Efficient Buck-Boost Converter with Small Solution Size," TPS63805 Datasheet, SLVSDS9
2. Chris Glaser, "Iq: What It Is, What It Isn't, and How to Use It," Analog Applications Journal (2Q, 2011), SLYT412
3. Jatan Naik, "Performing Accurate PFM Mode Efficiency Measurements," Application Report, SLVA236
4. Chris Glaser, "Accurately Measuring Efficiency of Ultralow-Iq Devices," Analog Applications Journal (1Q, 2014), SLYT558.

5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (November 2018) to Revision A (July 2021)	Page
• Updated the numbering format for tables, figures and cross-refrences throughout the document....................	2