Application Report
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# TPS61020 Boost Converter Start-Up and Precharge

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**ABSTRACT**

The TPS61020 is a highly integrated, low-power, boost converter ideally suited for portable battery-powered equipment. To improve start-up performance from a power-limited source such as a battery, the TPS6102x family uses different steps and modes to reduce demand on the battery. This prevents the battery bus from sagging during start-up and improves start-up operation at low voltage.

Typical start-up behavior for a boost converter requires a large amount of current from the input bus to charge the output capacitor up to the output voltage, even with no load on the output. During no-load start-up, a typical boost converter operates at the main power-switch current limit to charge the output capacitor quickly. The TPS61020 main power-switch current limit is 1.5 A, which results in a 1.5-A input current at start-up. An input current this large presents problems for some input power sources.

Batteries have some internal resistance because resistance increases as the battery is discharged. This internal resistance combined with large peak currents at start-up causes the battery voltage to drop at start-up. If the battery bus voltage decreases below undervoltage lockout for the converter, the converter shuts down.

To prevent this large start-up current, the TPS6102x family uses a controlled start-up sequence with four operating phases to provide smooth start-ups.

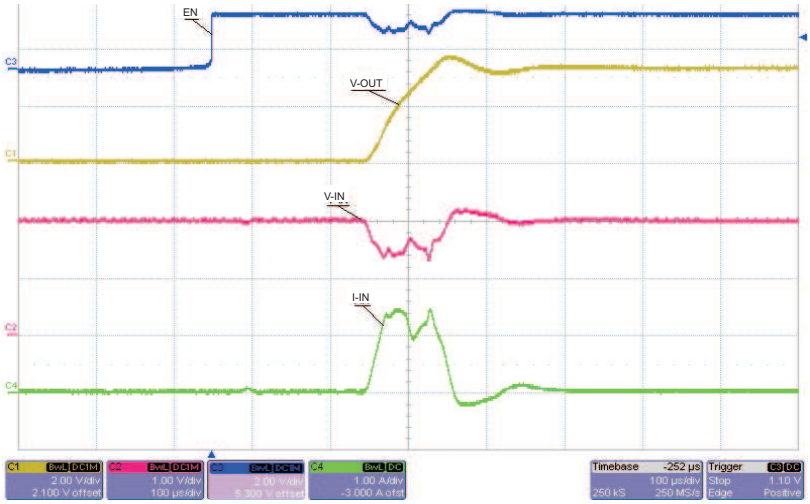


**Figure 1. Standard Boost Converter Without Controlled Start-Up**

Figure 1 shows a typical boost converter start-up from a battery at 2 V. This is a no-load condition; the output capacitor is the only load. A 0.5-Ω resistor has been added to the power supply input to simulate battery impedance. Note that the input current increases to 1.5 A for 100 µs, and the bus voltage decreases in response to the load.

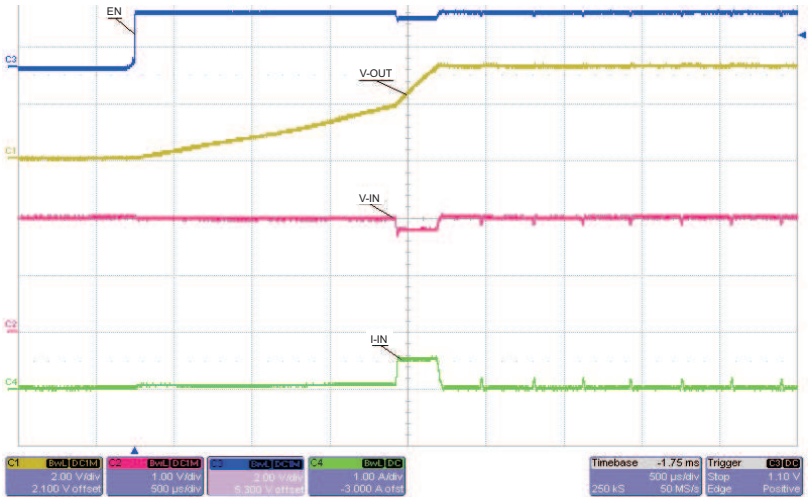


**Figure 2. TPS61020 Start-Up Current**

Figure 2 shows the start-up of a TPS61020 converter in the same set up as Figure 1, with an input voltage of 2 V and a battery impedance of 0.5 Ω. Note that the TPS61020 soft-start circuitry keeps the peak input current below 600 mA, thereby minimizing the input bus voltage drop.

### Start-Up Phases

The TPS61020 implements four distinct operating modes during start-up. These modes are designed to minimize current draw from the input bus during start-up. Each of the phases provides limited output current to reduce input current. As output voltage increases, the converter switches to the next phase. The subsequent phases have higher output current in the final phase, when the device transition to full current limit output voltage is near the set point.

**Table 1. Start-Up Phases for TPS61020**

| PHASE | ENTER | EXIT | COMMENT |
|---|---|---|---|
| Phase 1 | EN or UVLO | Vout ~ Vin | Limited current to output capacitor |
| Phase 2 | Vout ~ Vin | Vout ~1.4 V | Switching starts at fix 50% duty cycle |
| Phase 3 | Vout ~ 1.4 V | Set point –1.6% | Switch current limit reduce to 40% |
| Normal operation | Set point – 1.6% | | Switch current limit to normal |

### Phase 1 Precharge

Precharge is the first phase of start-up. During precharge, the TPS61020 delivers a constant current to its output capacitor. The constant current linearly charges up the output capacitor to approximately Vin. The TPS61020 does not switch during precharge. This eliminates the large inrush currents present in standard boost converters when the input bus is directly connected to the output capacitor through the synchronous rectifier. Precharge is implemented by setting the internal synchronous rectifier FET connected between the SW pin and the Vout pin into its linear region. TPS61020 enters precharge after the device is enabled from EN or UVLO. The TPS61020 remains in precharge until the output voltage increases near the input voltage, approximately at input voltage of 0.1 V.

Precharge current is not a fixed value but is determined by input voltage and to a lesser degree by output voltage.

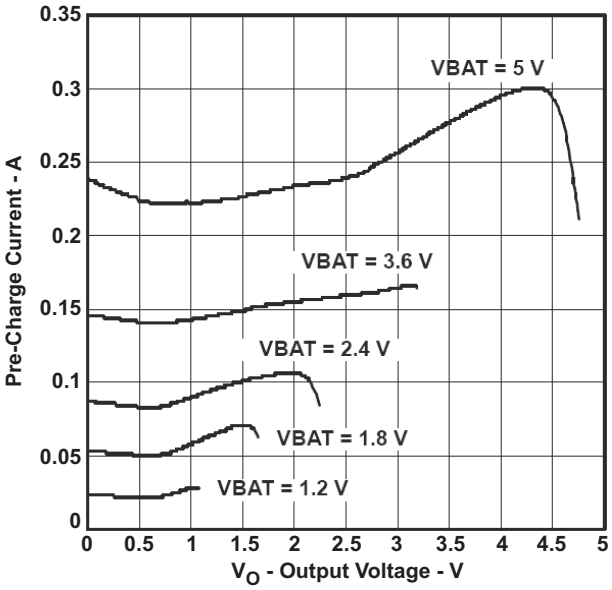


**Figure 3. Short-Circuit Precharge Current**

### Phase 2 Fixed 50% Duty Cycle

Fixed 50% duty cycle is the second phase of start-up; this is an optional step that does not have to be used. During this mode, the converter begins switching but at a fixed 50% duty cycle. Output voltage during this phase increases from Vin to 1.4 V. By switching at a fixed 50% duty cycle, an inherent current limit is set by the rate of rise of the inductor current and rate of discharge of the inductor current. If the input voltage is above 1.4 V, then Phase 1 increases output voltage to 1.4 V and Phase 2 is not required; the device switches directly from Phase 1 to Phase 3.

### Phase 3 SW-Limit to 40%

SW Limit to 40% is the third and final phase of start-up. This mode starts at about 1.4 V and ends when output voltage is at 1.6% of the set point. Phase 1 or Phase 2 has increased the output voltage, and it has reached a minimum of 1.4 V. The main power switch current limit is reduced to 40% of nominal value, from 1.5 A to 600 mA.

**Normal Operation** — Vout is within 1.6% of the set point, and the switch current limit is set to normal.

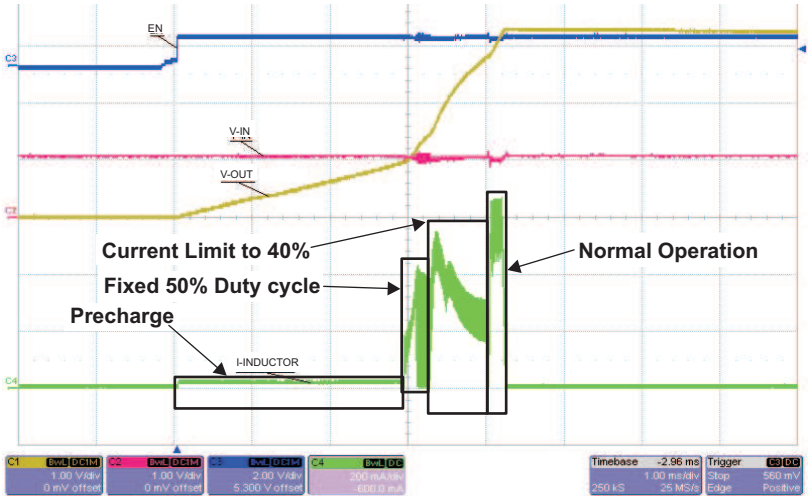


**Figure 4. TPS61020 Start-Up From 1 V**

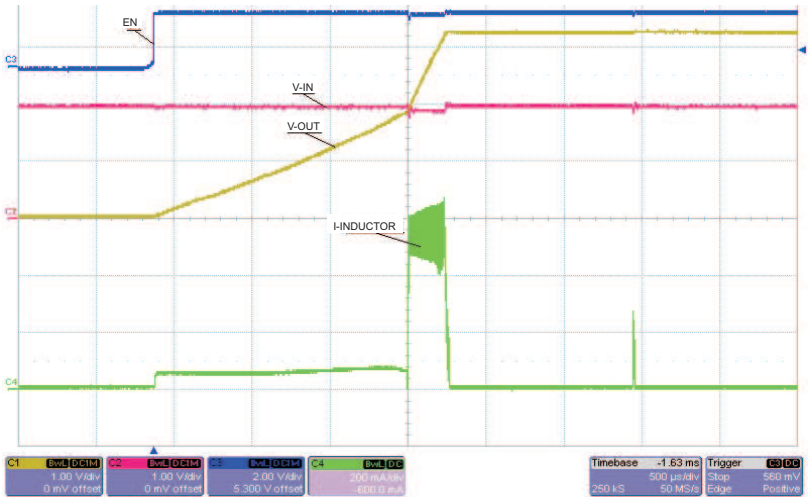


**Figure 5. TPS61020 Start-Up From 2 V**

### Down Mode Start-Up

The TPS61020 down mode is used when Vin is higher that Vout. This is normally a condition when a buck converter is used to regulate the output, but the mode allows the TPS61020 to operate both above and below output voltage. For start-up in this condition, only the precharge phase mode is used. Normal mode and switching starts when output voltage is within 1.6% of set point. During precharge, the current into the output is approximately 100 mA.

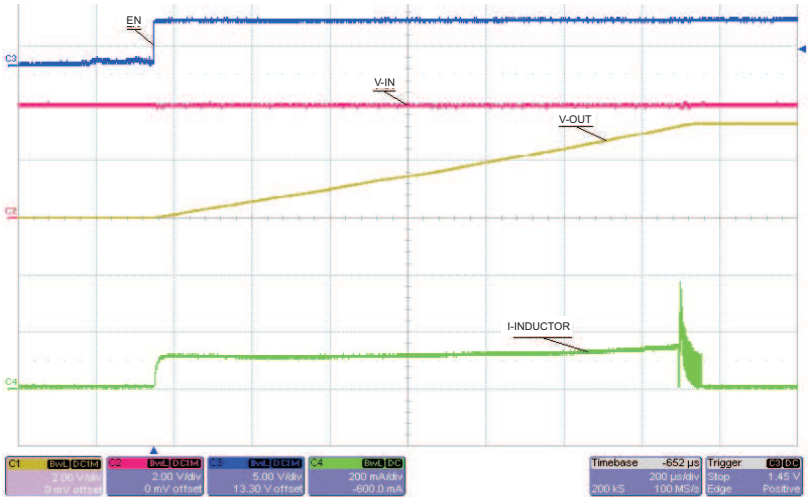


**Figure 6. Down Mode Start-Up**

### Return to Precharge:

If an output overload occurs during normal operation, the converter returns to precharge, preventing an input bus overload. If output voltage decreases below the input voltage by more than 100 mV, the converter returns to the first start-up phase which is precharge. This restarts the start-up sequence again and the original entry and exit requirements apply.

During Down mode, an overload condition and return to precharge is a decrease in output voltage of 10% below set point.

**Potential Problems:**

To exit start-up and enter normal operation, the output voltage must rise to complete each phase and then move to the next. If the output voltage does not increase, the converter can become stuck in start-up mode. This problem often occurs due to a load on the output during start-up; the limited current is not enough to increase the output voltage to the next level. None of these phases has a time limit or timeout circuit with which to trigger shutdown or exit.

This problem has been seen most often in the precharge start-up phase where the converter acts as a current source. Typically, a resistive load on the output draws additional current and prevents the output from rising to the input. This problem is worst at low input voltage due to precharge current decreasing as input voltage decreases (see Figure 3).

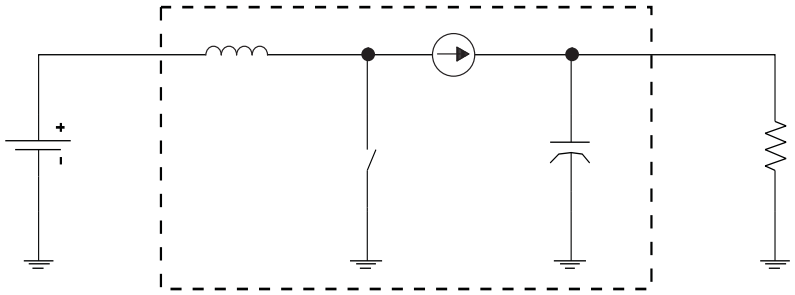

**Figure 7. Configuration for Precharge**

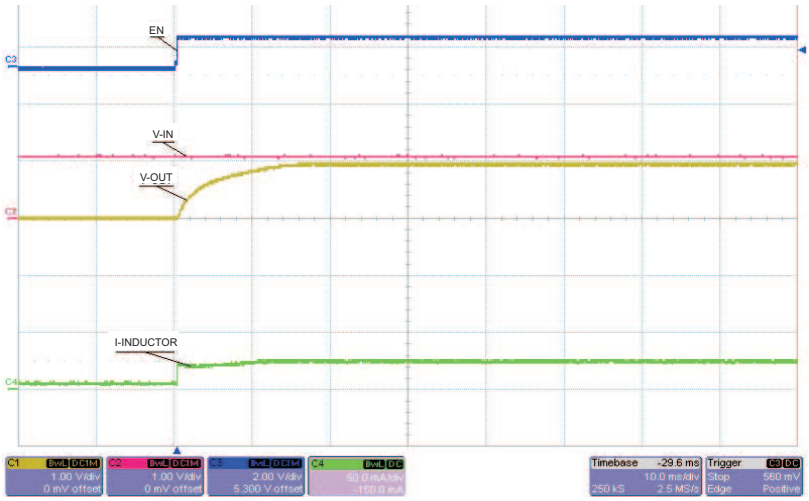


**Figure 8. TPS61020 Start-Up Stuck in Precharge, Load 45 Ω**

**Possible Solutions:**

Disconnection circuits have been used in some cases to resolve the start-up problem. These circuits disconnect the output load until the converter output voltage has increased. Often, it is unnecessary to hold the switch off the entire start-up cycle but only the precharge phase. This simplifies the control logic for the output MOSFET.

## Conclusion

The TPS61020 provides a graceful start-up from a power-limited source. This is a good solution for some applications. However, the mechanism used to achieve this may present problems in other application and output-load conditions.

## References

(A) *TPS61020/24/25/26/27/28/29, 96% Efficient Synchronous Boost Converter* data sheet (SLVS451)
(B) *TPS61020EVM, High-Efficiency Synchronous Boost Converters* User's Guide (SLVU100)

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