Extending the holdup time for a wide-input DC/DC converter

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Introduction

In telecommunication applications, network devices often need input status data so that they can send out dying-gasp messages to users in the event of a power interruption. These network devices rely on temporary energy storage such as capacitor banks, which enables graceful shutdowns and the generation of dying-gasp messages. The backup (holdup) circuity is designed to last from 10 to 20 ms in order to perform these tasks. This extended time is called the holdup time.

If you are a power supply designer, you likely have two design questions about the holdup circuitry, especially for a wide-input DC/DC converter:

- Should you place the holdup capacitor on the input side or output side?
- For a wide input range, should you use the two-stage approach or single-stage approach?

In this document, two different backup solution sizes are compared and a new backup circuitry is proposed to meet a 15-ms holdup time for a 12-V/60-W flyback converter with a 9- to 60-V wide input range. This backup circuitry uses an auxiliary boost converter to charge up a high-voltage capacitor bank and a fast-acting, power-limiting switch to release the energy during power interruption, saving 50% board space without insertion losses and significantly extending the holdup time in a wide-input flyback converter.

Where to place the holdup capacitor

Consider a 60-V input, 12-V/60-W flyback converter as an example with a design holdup time of 30 ms. Traditionally, the power supply has a bulky output capacitor bank. The output capacitor holds up the output voltage and slowly decays, thus extending operation time before total system shutdown. The holdup energy, E_{cap} (**Equation 1**), is quadratically proportional to the capacitor voltage, V:

$$E_{cap} = \frac{1}{2}C_{cap}V^2 \tag{1}$$

where, C_{cap} is the capacitance.

Since the output voltage is slowly decaying, it requires a downstream system with a wide input voltage tolerance. If the input range is limited, the energy utilization is poor. In **Equation 2**, the energy utilization rate, EU%, is defined as a percentage of energy used over the energy stored:

$$EU\% = \frac{E_{MAX} - E_{MIN}}{E_{MAX}} = \frac{V_{O(MAX)}^2 - V_{O(MIN)}^2}{V_{O(MAX)}^2} \tag{2}$$

For example, in a typical 12-V system operating with a minimum 8-V input, the utilization on the capacitor bank would be 55%. For sensitive equipment with a tight voltage tolerance, such as 10%, the utilization rate would be merely 19%.

It is also possible to use high-voltage capacitors on the input side. If the input voltage is allowed to discharge from 60 V to 9 V, the energy utilization rate improves to 97.8%.

A high-voltage capacitor has higher energy density than a low-voltage capacitor. For example, a 1,200-µF, 80-V aluminum capacitor is the same size as a 6,800-µF, 16-V aluminum capacitor, but its energy density is 4.4 times higher than the low-voltage capacitor.

Now, compare two design approaches:

- The first design uses a simple and straightforward approach, with holdup capacitors on the output side. This design requires seven 6,800-µF, 16-V, 16-mm-by-40-mm output capacitors, which occupy more than half the board space. The holdup time is an estimated 32 ms with a full 60-W load.
- The second design uses one high-voltage, 1,200-µF, 80-V, 16-mm-by-40-mm input capacitor as the energy source. This single input capacitor provides a 32-ms holdup time at a full load, assuming 90% system efficiency. The system efficiency reduces the available holdup time, since the flyback converter processes the input-side energy.

The first design (**Figure 1**) measures 4.6 by 3.7 inches, which is twice as big as the second design (**Figure 2**). Again, the holdup time is 32 ms for both designs. This comparison clearly shows that placing the high-voltage capacitor on the input side enables you to use fewer capacitors given their superior energy utilization rate and higher energy density. Therefore, the input-side holdup solution reduces holdup capacitor bank size – and cost – by half.

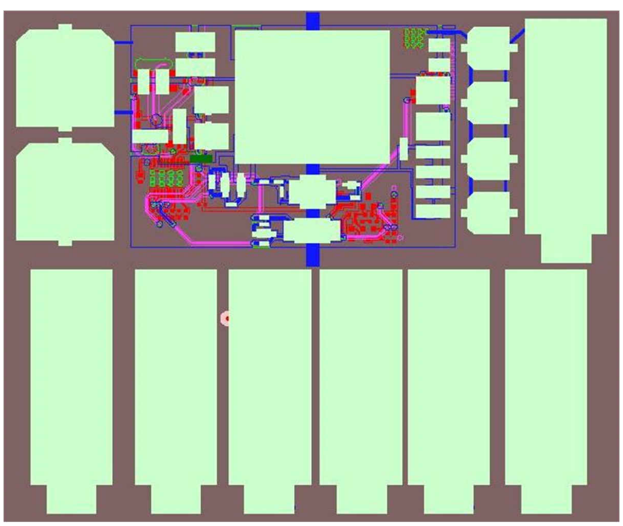

Figure 1. *Comparing output- and input-side holdup solutions: the output-side holdup solution with seven 6,800-µF, 16-V, 16-mm-by-40-mm output capacitors is 4.6 by 3.7 inches.*

Figure 2. *Comparing output- and input-side holdup solutions: the input-side holdup solution with one 1,200-µF, 80-V, 16-mm-by-40-mm input capacitor is 4.6 by 1.85 inches – half the size.*

Comparing a two-stage and single-stage approach

If the converter has a wide input range, such as 9 V to 60 V, the stored energy and energy utilization rate will drop significantly as the input voltage level drops. At the minimum 9-V input, the high-voltage input capacitor offers virtually zero holdup capability.

One quick remedy is to add a boost converter in the front end. As shown in **Figure 3**, the boost converter steps up the wide input to 60 V or higher. This two-stage approach has a couple of drawbacks, however: it lowers system efficiency and adds extra cost.

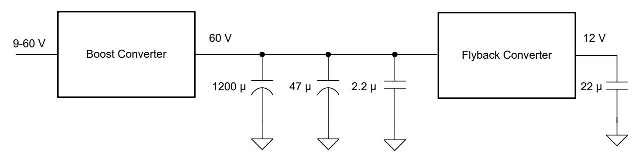

Figure 3. *The traditional two-stage holdup solution.*

An alternative is to use an auxiliary boost converter to charge the high-voltage capacitor to 60 V and switch in the capacitor when the holdup circuitry detects a power interruption. **Figure 4** shows this proposed high-voltage holdup solution. Since the boost converter is not in the main power path, it does not affect system efficiency. The converter size is small given the low power level, which is just enough to charge up the high-voltage capacitor. The diode in **Figure 4** could be a hot-swap device or an ORing device, which is commonly available for telecommunication applications.

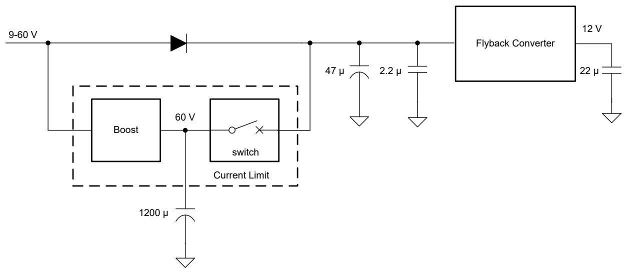

Figure 4. *A proposed single-stage holdup solution maintains high efficiency.*

The energy transfer switch also needs special attention. It has to be fast acting; otherwise, the design needs a large amount of fixed input capacitance. It also has to be power-limiting. During energy transfer, the flyback converter may drop to minimal operation levels while the holdup capacitor is fully charged, creating a large differential voltage across the switch. At the same time, a large amount of current is injected into the flyback input, thus generating tremendous electrical stress on the switch. **Figure 5** illustrates a scalable current source with on/off control.

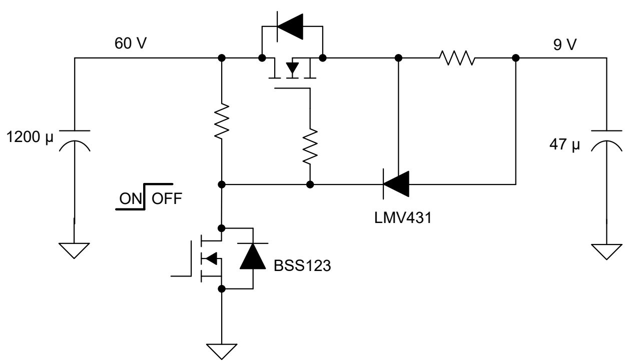

Figure 5. *A scalable current source with on/off control.*

This energy transfer switch has a delay less than 2.5 µs, which is fast acting. It has an adjustable current limit set by the current-sense resistor. Connecting multiple current sources in parallel extends the power level. When the control field-effect transistor (FET) gate is high, it pulls the main FET gate down, thus turning off the main transfer switch.

System demonstration

Figure 6 illustrates the verification of this concept in an Internet of Things application. The flyback converter has a wide input range from 9 V to 60 V; the output is 12 V/5 A. There is only one holdup capacitor. The boost converter is a small size. Three current sources are connected in parallel, placed on the back side of the board, to relieve the device stress.

The worst-case test condition is when the input voltage is 9 V. The small boost converter charges the holdup capacitor up to 60 V. The power interruption detection circuitry sets the threshold at 8 V. When the input voltage drops below 8 V after a power interruption, the energy transfer switch turns on, thus transferring the energy from the holdup capacitor to the main flyback input capacitor and extending the holdup time by 17 ms.

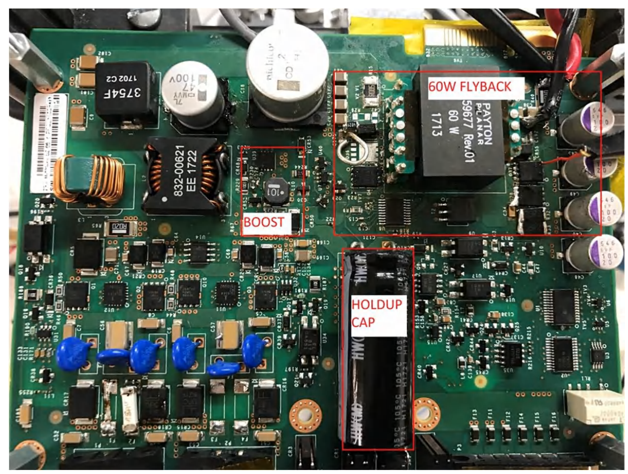

Figure 6. *Experimental system showing a 60-W flyback converter, holdup capacitor and a small boost converter.*

The test data in **Figure 7** shows that the flyback voltage rose from 9 V to 40 V during the energy transfer. The holdup capacitor voltage dropped from 58 V to 43 V; then both voltages depleted to supply the flyback converter for 17 ms.

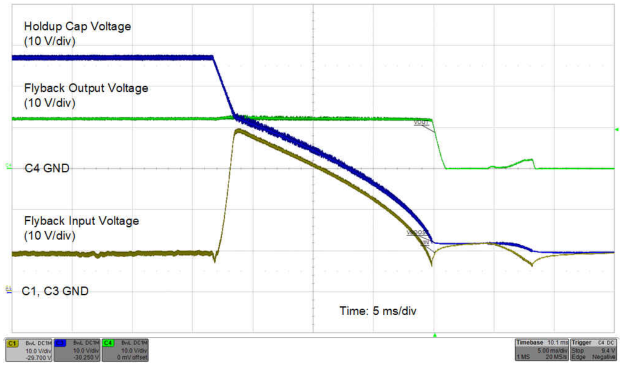

Figure 7. *Test data shows the energy transfer and 17-ms holdup time: blue (C3) is the holdup capacitor voltage, dark green (C1) is the flyback input voltage, and light green (C4) is the flyback output voltage.*

Conclusion

To meet the increasing holdup time requirement, a capacitor bank is often used. For the capacitor bank, energy density and the energy utilization rate are two major considerations. Comparing to an easy-to-implement output-side holdup solution, an input-side holdup solution saves 50% board space by taking advantage of the energy density and utilization rate of a high-voltage capacitor. A novel backup circuitry designed to minimize insertion losses uses a small auxiliary boost converter to pump up the high-voltage capacitor and a fast-acting, current-limiting switch to relieve stress during power dump. This proposed “pump-and-dump” solution maintains system efficiency, while the conventional two-stage solution takes a 5% efficiency hit because of the additional boost converter stage. The implementation of this backup circuitry in a 60-W Internet of Things application achieves a 17-ms holdup time with a single 1,200-μF holdup capacitor. This holdup solution is ideal for a wide-input DC/DC converter where efficiency, space and cost are top design priorities. It reduces the costly and bulky capacitor banks and significantly extends the holdup time of the energy storage capacitor.