AC/DC power supply performance and international efficiency standards

Scott Brown - November 03, 2014

With the increasing restrictiveness of international power supply efficiency standards, power supply controllers are being pushed to their cost-performance limits. Meeting these new standards while keeping performance high and cost low, has forced the market to move to disruptive new technologies. New design techniques now enable AC/DC converters to achieve the stringent DC efficiency requirements without sacrificing AC performance, in particular, load transient response. This article will discuss the implications of these new efficiency standards on the power supply controller, how they affect the output voltage integrity and the latest design techniques used to improve performance without adding unnecessary cost or complexity.

International Power Supply Efficiency Standards

The US Department of Energy’s AC/DC external power supply efficiency standards enacted in 2007 established a strict combination of no-load power consumption and average efficiency at loads from 25% to 100% of rated load current. The European Union also has enacted similar standards, as have other countries throughout the world, although the DoE’s standards are the strictest mandatory standards. The DoE released an updated external power supply standard in February 2014, further restricting efficiency and no-load power consumption in off-line power supplies.

By limiting the maximum power consumption of a power supply when operating at no-load, the standard forces power supply manufacturers to reduce the amount of current drawn from the mains input during no-load operation. Starving a control circuit of current during standby saves energy, but it also hinders the power supply’s ability to transition quickly from no load to full load, a feature that we remarkably take for granted in our always-on, consumer electronics driven world.

Load Transient Response - Large Signal Response and Operating Current

Load transient response time directly impacts the quality of the output voltage; faster response time helps reduce the deviation from the regulated output voltage without having to use excessive
amounts of output capacitance, and slower response time does the opposite. With low power consumption controllers, the response time tends to be slower, forcing the power supply to depend upon the external components to take care of the output current changes. Load transient response is, in reality, a measure of the large signal response of the control loop and combines small signal stability with large signal factors such as the ability of the control circuit to slew the outputs of amplifiers and drivers quickly. When the slew rate capability of the device is poor and the small-signal bandwidth is low, the output responds slowly to a load change.

There are some fundamental relationships in electronics that are fairly universal, although not necessarily absolute. For example, op-amps or comparators with very low operating currents cannot slew their outputs as fast as those with a larger amount of operating current. Propagation delays also tend to increase as current decreases because cascaded input stages, used to reduce current, increase the amount of time it takes for the signal to work its way through the circuit. In the specific case of AC/DC converters, the added complication of the reflected impedance of the output transformer and the characteristics of the parasitic inductance create a complicated analysis of the large signal response. By focusing on what the controller itself can do, independent of the passive components, we can maximize performance while minimizing operating currents.

Load Transient Response Analysis

Load Transient Response Analysis

When a change in output current occurs on the output of any power supply, multiple factors impact how quickly and accurately the power supply output responds to the load change. Treating the power supply as a black box, non-ideal power source, we can analyze what factors determine the quality of the response time.

Figure 1 shows a generic load change and how the output responds to this load change. The output circuit used for this model is a black box power supply with an output capacitor modeled using equivalent series resistance (ESR), equivalent series inductance (ESL) and its rated capacitance. The initial change in current causes a sharp drop in the output voltage based on the actual slew rate change of the output current and the ESR and ESL of the output capacitance. The instantaneous drop in voltage is due to the ESR of the output capacitance and the snap-back characteristic of this initial spike is determined by the ESL.
Proper selection of low ESR, low ESL bypass capacitance can reduce this initial spike to virtually zero. Once the output capacitance starts to supply current to the output, the voltage will decay as a function of the output current and total capacitance on the output \((\text{d}V = \frac{I}{C}\text{d}t)\). The magnitude of the output voltage droop is entirely dependent upon how fast the power supply responds \((\text{d}t)\) to the stimulus and starts providing current to the output capacitor and load. Once the output starts to supply current to the output, the output capacitor will charge up to the nominal output voltage, with a small amount of offset on the output. That output offset is commonly referred to as load regulation and generally depends upon the gain characteristics of the control loop. The more gain in the system, the better the output voltage accuracy under load.

Controllers used in flyback converters are either analog or digital. Both technologies accomplish the same task, albeit in radically different methods. Analog controllers use analog amplifiers that monitor the feedback from the output to generate an error signal, which is compared to a reference and then the output stage is modulated in order to bring the output voltage back into regulation. Digital circuits convert the analog feedback signal to a digital word, compare that word to an established comparison point, and using a digital proportional-integral-derivative (PID) filter, modulate the output to regulate the output voltage. From a black box perspective, they do the same function. But, inside the black box are two very different worlds.

**Analog Controllers**

Power supply controllers based on analog technology have existed for decades. A well-known and understood technology, the advantages and disadvantages that come along with analog controllers have been thoroughly discussed for some time. At the core of any analog controller (figure 2), the
traditional error amplifier, relies upon bias current to determine its performance. Techniques do exist to allow higher performance at very low bias currents, but at the expense of silicon real estate, a costly tradeoff. But, once you starve these analog converters of current in order to meet the strict new efficiency standards, the response time degrades radically. When looking at the output load transient response time analysis discussed earlier and how the response time of the control loop affects the output voltage quality, it is clear that a fast loop offers better output voltage integrity.

**Figure 2. Generic Analog Controller**

**Digital Controllers**

A digital controller offers the same function as its analog equivalent, but with some pretty big differences inside the black box. A typical digital power supply controller consists of a PID filter, digital reference, digital pulse width modulation (PWM) generator and an output driver (figure 3). The feedback signal is converted to a digital word, compared to a digital reference and then the PID filter determines what the digital PWM circuit will output to the main power device.

A standard PID-based digital controller responds relatively slow to load changes unless very high-speed ADCs are used in conjunction with a very high clock speed digital core. In high current applications where the load is always active, that approach is feasible and can give good response time, but once light load performance enters into the equation, similar to analog controllers, the simple digital controller suffers performance degradation.
When comparing a standard analog controller side-by-side with a digital controller, there is no reason for there to be a major difference in performance between the two end circuits. But, digital designs have advanced to the point where several degrees of freedom can be added to the controller design that analog controllers struggle to achieve. In parallel with the main digital PID control block, additional analog or digital circuitry can be used to boost performance of the overall circuit without compromising performance.

Analog struggles to achieve this because extra control circuitry can wreak havoc on frequency compensation. One control loop is hard enough to stabilize in analog, but having multiple loops operating in parallel requires extremely complex compensation that oftentimes causes unacceptable trade-offs in bandwidth just to achieve stability. This comparison is equally valid when comparing DC/DC controllers or AC/DC controllers, the key component in off-line power supplies.

**Impact of Fast Dynamic Load Response**

Power supplies with fast dynamic load response provide the obvious benefit of maintaining the voltage integrity, specifications and performance required for the end application, but having fast response time can also reduce the overall circuit size and cost by reducing the amount of bulk capacitance needed to hold up the output voltage. A typical application that demands high performance and low cost, while meeting international energy efficiency standards is USB compatible output, universal off-line input voltage wall adapters for charging smartphones.
The USB BC 1.2 specification for battery chargers using a USB connector specifies both a DC voltage for constant voltage output and an AC output voltage range to ensure proper operation of any smartphone using a USB BC 1.2 compatible charger. The specification also calls out a recovery time under which the output can drop from the nominal DC voltage to the minimum AC voltage and then recover. The output needs to be back within the DC tolerance in the time specified.

Table 1 shows the specifications required for compatibility to the USB BC 1.2 specification. The response time and voltage seem easy to achieve, especially when compared to DC/DC converters, but AC/DC power supplies have to comply with the DoE specifications, making this quite a challenge.

<table>
<thead>
<tr>
<th>USB Battery Charging Specification Rev 1.2</th>
<th>AC</th>
<th>DC</th>
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</thead>
<tbody>
<tr>
<td>Charging Port Max Voltage</td>
<td>6.0V</td>
<td>5.25V</td>
</tr>
<tr>
<td>Charging Port Min Voltage</td>
<td>4.1V</td>
<td>4.75V</td>
</tr>
<tr>
<td>Maximum Undershoot Time</td>
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The iW1760 from Dialog’s Power Conversion Business Group (formerly iWatt Inc.) offers compatibility to the USB BC 1.2 specification while meeting both the DoE’s newest efficiency standard effective February 2014 and the EU’s strictest efficiency standards, the Code of Conduct Version 5, Tier 2. Figure 4 shows the response time of the iW1760 in a 10W USB charging application where the output responds to a 2A load step within 6ms and keeps the output voltage within the required USB BC 1.2 AC specification with some margin.
A faster responding part can offer better response time with less capacitance while meeting the energy standards. The iW1786 is an example of a digital controller that works with a secondary-side component (iW671), a companion IC that detects changes to the output voltage and sends immediate feedback to the primary side, allowing the output to be enabled quicker than compared to standalone primary-side feedback. Quicker response time and less voltage droop add a significant amount of design margin to the adapter design. Alternatively, the designer can reduce the amount of bulk capacitance used to hold up the output during these transitions.

An initial review of this idea of adding a secondary IC might seem like a neutral size and cost trade-off, but the iW671 incorporates a synchronous rectification circuit for the secondary side which removes two Schottky diodes while improving efficiency. The improved response time permits lower output capacitance on the output, improved efficiency reduces the necessary heat sinking requirements and removing secondary-side components enables an overall compact solution.

Figure 4 shows the transient response of the iW1786+iW671 (companion IC), with a noticeable improvement over the iW1760 original response. The dynamic load response improves significantly, providing ample margin to meet the USB BC 1.2 charging specification\(^{(1)}\).

The minimum AC voltage on the output of figure 5 is 4.8V, giving a total 200mV droop vs the 700mV droop shown in figure 4. The response time measured in figure 5 is approximately 3ms, about half of the response time in figure 4. This improved speed accounts for the droop of less than half of the original droop shown in figure 4.
The iW1786 uses a complex and proprietary digital core that has multiple control loops. Modern digital control loops such as the technology integrated in the iW1786 controller, enable a combination of very fast response time with small external components while maintaining stability over multiple control loops with no external compensation components. Analog circuits are more than capable of achieving the same type of circuit, but the end result is larger, more costly and much more difficult to compensate.

Digital technology is ushering in a new era of power supply design offering flexible solutions and ease of use, even for the non-power savvy design engineer. Fast response time is now possible thanks to advancements in digital power management technology, permitting consumer electronics power supplies to meet international efficiency regulations without sacrificing performance.

Notes

(1) The circuit used to test the two different devices was identical, using the same magnetics and passive components. The only difference was the device under test (DUT) used to generate the two waveforms in figures 4 and 5.