BOB BELL, Applications Manager
National Semiconductor, Phoenix, Ariz.

Get Your Isolated Power Converter Off to a Smooth Start

One of the most misunderstood concepts of designing an isolated dc-dc power converter is how to ensure the output voltage rises smoothly to the final regulation value.

Power converters are often categorized into two basic types: isolated and non-isolated. These categories refer to the relationship between the input power ground (primary) and the output power ground (secondary).

Many applications require isolation between the grounds. In large systems with multiple power rails, isolation between the grounds eases single-point grounding, preventing ground loops. Often, the isolation requirement is specified by various safety agencies, depending upon the application.

ISOLATED POWER CONVERTERS

Isolated power converters are implemented with transformer-based topologies. Some of the more commonly used topologies are flyback, forward, push-pull, current-fed push-pull, half-bridge, and full-bridge. The transformer provides the ground isolation in the power path.

A power converter in which the output voltage rises smoothly and monotonically, and has no overshoot, is much more difficult to accomplish in an isolated design than it is in a non-isolated design. A smooth, controlled rise is necessary in many applications so that the load circuits start correctly.

For example, a digital controller will often have a power-on reset circuit that monitors the power rail. Once it detects a minimum level, the reset state is removed and the controller starts issuing commands. If the power-rail voltage dips, then the controller will be reset and stop issuing commands. When the power rail rises again above the start threshold, a second start-up sequence begins and the product or process being controlled will appear to have erratic start-up behavior.

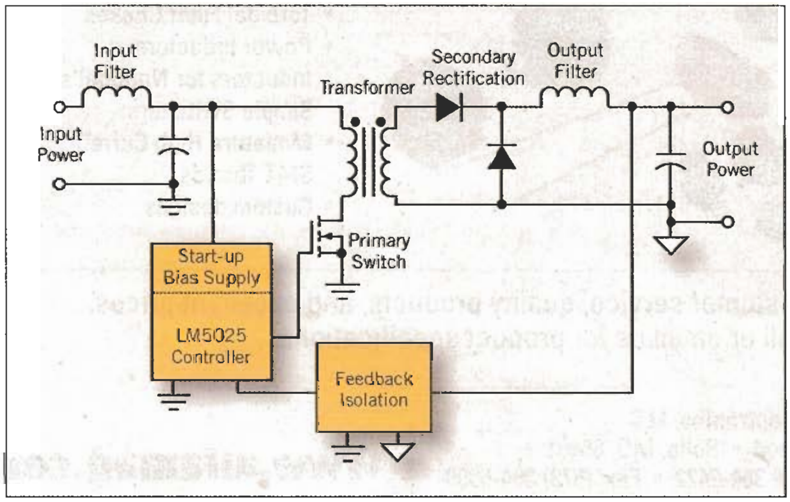

Fig. 1. An isolated switching converter with a primary-side referenced configuration.

CONTROLLERS FOR POWER CONVERTERS

All isolated switching power converters include an input filter, output filter, transformer, primary side switch(es), secondary side rectification, and a controller. The controller can be referenced to either the primary- or secondary-side ground. *Fig. 1* shows a primary-side referenced configuration while *Fig. 2* shows a secondary-side configuration. Both configurations use a scheme where bias power for the controller is initially derived from a startup circuit before a more efficient auxiliary winding takes over when it reaches its normal operation mode.

The problem with the secondary-side referenced controller is that the bias power must be derived from the primary-side power (the wrong ground) upon initial power up. This problem can be overcome with a separate isolated bias power converter to supply the few watts needed for the controller. The separate bias supply ensures an orderly startup under all conditions. Designs with secondary-side referenced controllers and a dedicated secondary bias supply have good start-up characteristics but the cost, complexity, and size of the bias supply is a big burden to carry in your design.

Placing the controller on the primary ground negates the need for an isolated bias supply. A simple linear regulator is all that is necessary to bias the controller until the transformer bias winding becomes active. For this reason, primary-side referencing of the controller is the most common design approach. One drawback of a primary-side referenced controller is that feedback from the output must be brought back across the ground boundary, usually with an optocoupler. Located on the secondary is the reference, output voltage feedback divider, error amplifier, and loop compensation. The output of the error amplifier drives the optocoupler, thereby sending an error signal across the ground boundary.

The signal received back on the primary side from the optocoupler can be thought of as the power converter's throttle or gas pedal. The challenge is ensuring that output voltage rises smoothly and monotonically with the error amplifier and the reference located on the secondary-side ground, while the controller is located on the primary ground. We will explain the challenges and present a design approach that leads to good start-up characteristics for a power converter with a primary-side referenced controller.

The output of a well-designed power converter will rise slowly and monotonically, reaching its final value with no overshoot. These requirements must be met from no load to full load. The start-up sequence begins with the primary-side controller receiving bias from a linear start-up regulator. At initial start-up there will be no output voltage and no bias on the secondary for the error amplifier or reference. For the converter to start, the feedback must be set up such that with no bias power on the secondary, the polarity of the error signal requests full power.

Fig. 3 shows a common configuration for the secondary-side error amp, optocouplers, and primary-side controller. At initial start-up there is no secondary-side bias; the error amp will not conduct any current through the optocoupler, and the primary-side error signal (annotated as COMP) is pulled up towards 5 V.

Also detailed in *Fig. 3* is the soft-start function internal to the controller. The controller soft-start holds the COMP node low while the controller bias is below its undervoltage threshold. Once the controller bias is satisfied, the soft-start capacitor starts to charge and gradually allows the COMP node to increase. The rising COMP node will enable an increasing duty cycle that leads to an increasing output voltage.

One might ask if the power converter will start up properly if this controller has a built-in soft-start function. It is not sufficient to only use the primary-side controller's soft-start. The output may rise smoothly and monotonically, but by definition the output voltage will overshoot the regulation target and then settle back down to the final regulation level.

The reason for the overshoot is that the error amplifier will be saturated high (no current in the optocoupler) throughout

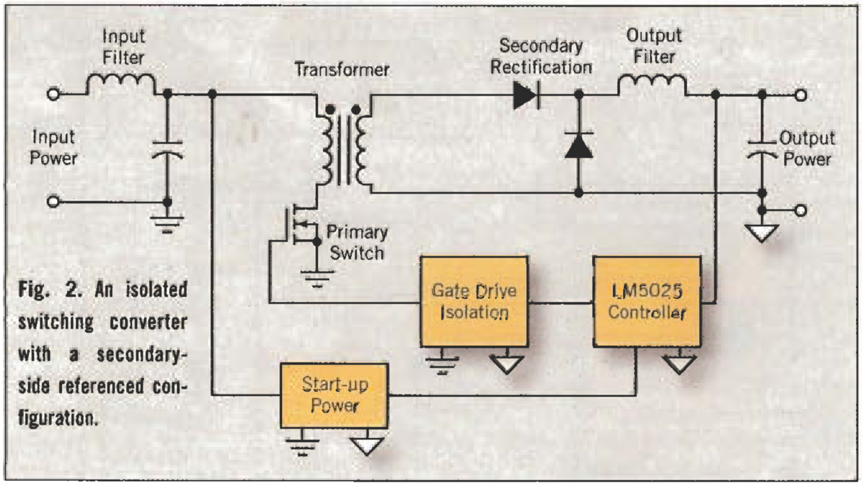

Fig. 2. An isolated switching converter with a secondary-side referenced configuration.

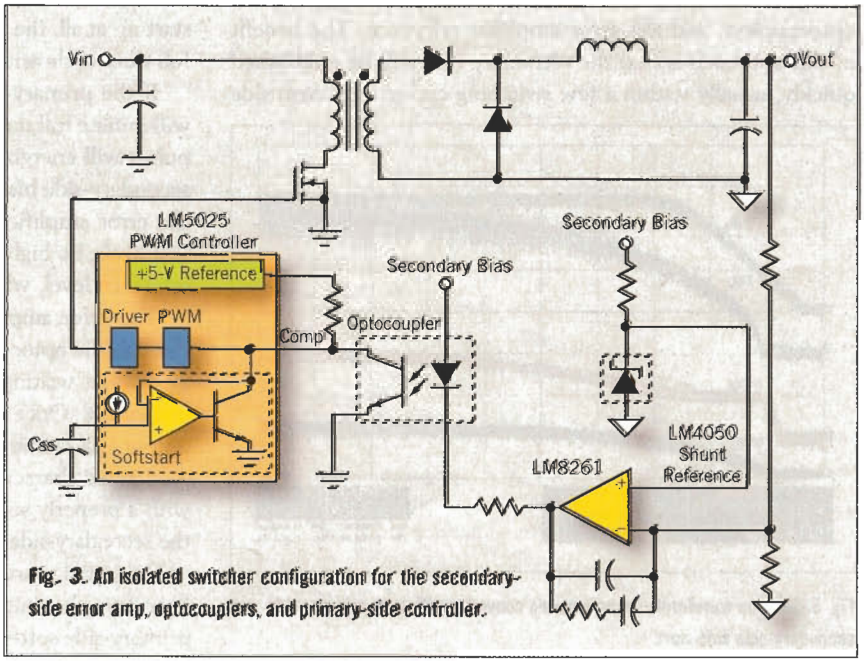

Fig. 3. An isolated switcher configuration for the secondary-side error amp, optocouplers, and primary-side controller.

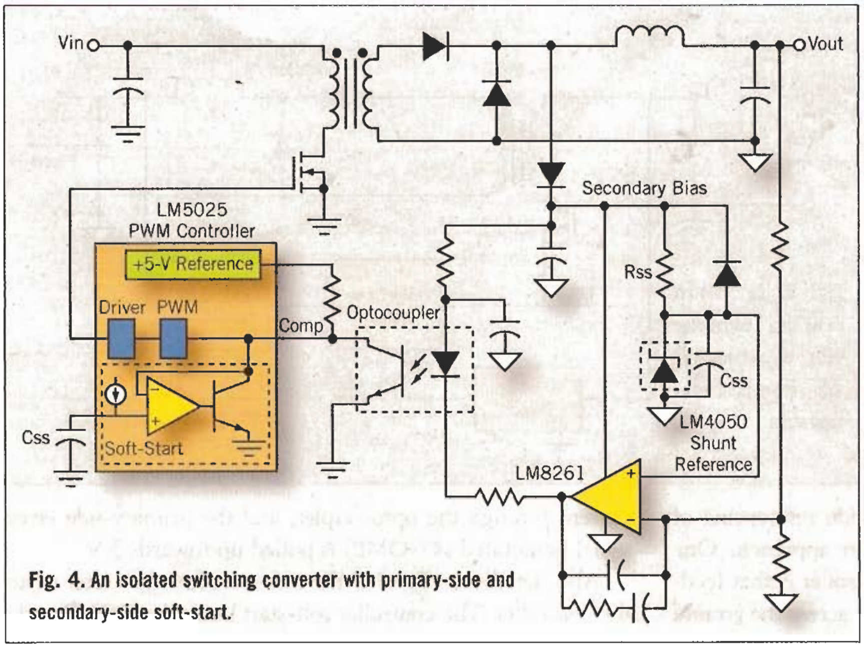

Fig. 4. An isolated switching converter with primary-side and secondary-side soft-start.

the startup sequence and will not start to react until the output voltage reaches the regulation level. It will take a fairly long time for the error amplifier to come out of saturation and slew its output to the nominal control level. While the amplifier is in the process of slewing to the nominal control level, the output is exceeding the regulation target. The amount of overshoot can be significant, depending upon amplifier characteristics and the values of the compensation components.

Shown in *Fig. 4* is a schematic that includes more detail for the secondary-side bias generation. The bias for the secondary-side circuits is usually implemented by peak detection from a transformer winding or the main switching node, as shown in *Fig. 4*. The secondary bias powers the error amplifier, the optocouplers, and the error amplifier reference. The benefit of this approach is that the secondary bias will be established quickly, usually within a few switching cycles. The downside is that the voltage generated is essentially unregulated, proportional to the input voltage. A clamp may be required to limit the bias voltage, especially while operating at high input-voltage conditions.

An additional secondary-side soft-start has also been added in *Fig. 4*. This secondary-side soft-start is implemented by a capacitor (Css) in parallel with the LM4050 shunt reference. The capacitor slows down the rate of rise of the secondary-side reference with a time constant proportional to Rss x Css. The diode in parallel with Rss speeds the discharge of Css when the converter is turned off. Implementing a soft-start on the secondary-side reference allows the error amplifier to control the rate of rise of the output voltage in a closed loop during start-up. Since the reference starts at zero and gradually increases to the target level, the output voltage will track the reference.

During start-up, the output of the error amplifier will not be saturated; instead, it will be moving and in control to accommodate the increasing reference level. There will be no overshoot, since the bandwidth of the error amplifier and the loop-gain crossover frequency is high relative to the slowly rising reference. The exponential nature of the rising reference voltage also reduces the likelihood of an overshoot.

That seems like a perfect fix. Can the primary-side soft-start be discarded? No. The primary-side soft-start is still needed, but the time constant of the primary soft-start must be very short. As explained earlier, for the power converter to start up at all, the polarity of the COMP signal must be set for full duty cycle with no optocoupler current.

If the primary-side soft-start is omitted, the COMP node will initiate full duty cycle upon initial power-up. The first few pulses will energize the transformer and start to establish the secondary-side bias. As the secondary bias gets established and the error amplifier starts to take control, the output voltage will likely be higher than the target level as requested by the reference level, which has barely started to rise.

The error amplifier will then start to pull a lot of current through the optocoupler in an effort to reduce the output voltage, while waiting for the secondary-side reference to catch up with it. Once the reference reaches the output level, the output will continue to rise to the final target value. This non-monotonic characteristic is undesirable, but it can be corrected with a properly sequenced primary-side soft-start working with the secondary-side soft-start.

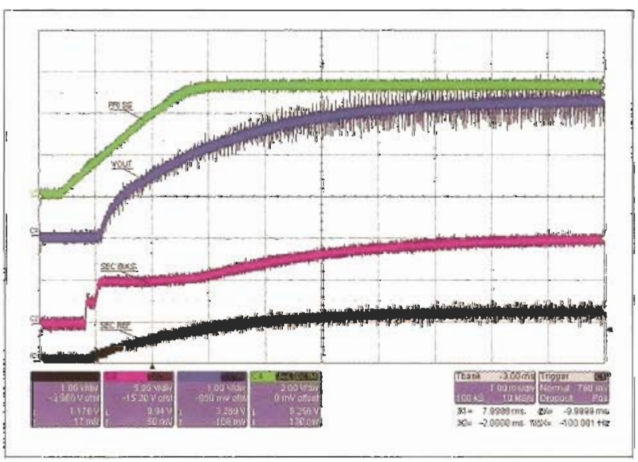

Fig. 5. Start-up waveforms for an isolated converter with both primary-side and secondary-side soft-start.

At initial startup there will be no optocoupler current; however, the initial duty cycle will be limited due to the primary-side soft-start. The objective is to set the primary-side

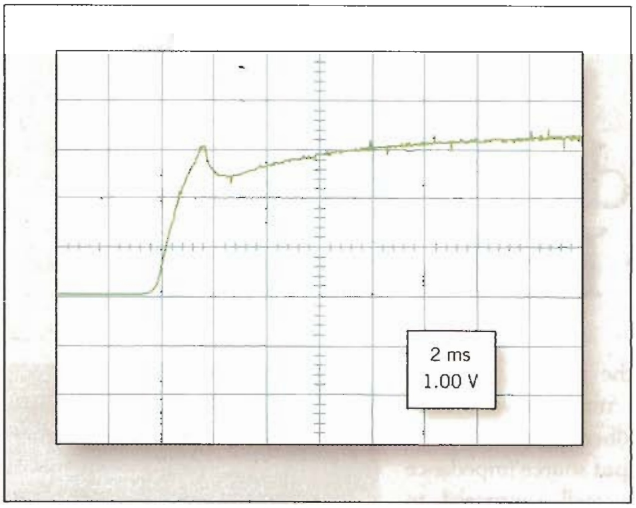

Fig. 6. Start-up waveform with secondary-side soft-start only.

soft-start to a relatively short time, just enough so that the first few pulses can establish the secondary-side bias without allowing the output voltage to rise very much. Then, the error amplifier and the secondary-side soft-start can take control.

The relative time constant of the secondary-side soft-start must be set much longer than the primary-side soft-start. The trick is to get the primary soft-start to limit the first few pulses and then get out of the way and let the output voltage rise while tracking a slowly rising secondary-side reference.

Fig. 5 shows the waveform of an isolated converter with both a primary-side and secondary-side soft-start. The LM5025 primary-side controller has a 1-V offset between the COMP pin and the pulse-width modulator (PWM). This offset ensures that there are no pluses when the COMP pin or the soft-start pin is grounded.

Upon initial power-up, the LM5025 monitors the input voltage and its own bias rails. Once the bias conditions are satisfied the soft-start is released and starts to rise. Due to the offset, there are no PWM pulses until soft-start reaches 1 V as shown on Channel 4. The initial small pulses establish the secondary bias shown on Channel 2. With the secondary bias established, the secondary reference (secondary soft-start) starts to rise toward its final value of 1.25 V as shown on Channel 1.

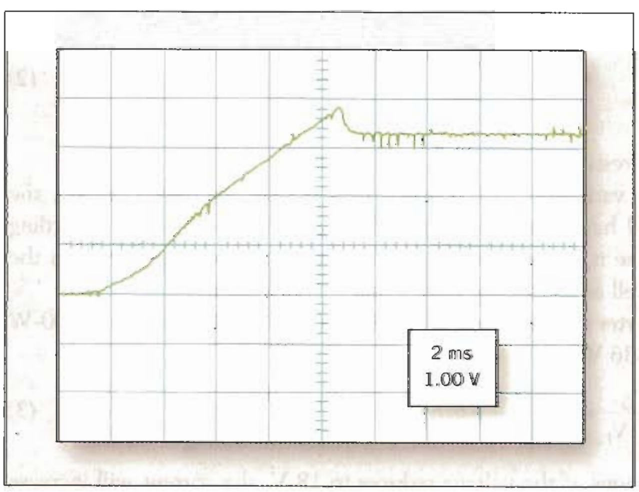

Fig. 7. Start-up characteristics of an isolated power converter with only a primary-side soft-start and no secondary-side soft-start.

The output voltage will track the secondary reference and rise slowly towards its final value of 3.3 V as shown on Channel 3. The apparent noise on the output and the other channels is an artifact of the long ground clips used in the measurement. The converter was loaded with resistive load.

Fig. 6 illustrates the start-up characteristics of a power converter with only secondary-side soft-start and no primary-side soft-start. The output is non-monotonic as described earlier. *Fig.* 7 shows the start-up characteristics of a power converter with only primary-side soft-start and no secondary-side soft-start. The output overshoots the intended target as described earlier.

The importance of an orderly start-up characteristic has grown as the complexity of the load has increased. When designing a power converter with a primary-side controller it is necessary to have a soft-start function within the primary-side PWM controller and the reference on the secondary side.