WBGlobalSemi, Inc.

High Power AC-DC Single Stage PFC Flyback Converter, White Paper, 2 August 2019

Development Utilizing 3.3 kV, 50 A Silicon Carbide Bipolar Junction Transistors (SiC BJTs)

The simple flyback converter is typically considered to be a ‘low performance’ power converter topology, suitable only for relatively low power levels, perhaps up to a few hundred watts. However, a “volt-amp/watt” analysis **[1]** showed that the net stresses for *most* component types in flyback converters are essentially identical to those in a forward converter, when operated in a comparable manner; thus the losses would be essentially the same.

The one exception is in the power magnetic components. The separate transformer and inductor required by other isolated, regulating converters are integrated into a single structure in the flyback converter, with significant savings in size, mass and power loss, with associated cost savings.

The high power potential of flyback converters has been demonstrated at 50 kHz and 4.5 kW, with ≥ 95% efficiency over a wide load range **[2]**. These single stage converters drew a sinusoidal current from a nominal 230 Vac input, with additional performance advantages over conventional two-stage converters consisting of a Power Factor Corrector (PFC) boost pre-regulator followed by an isolating dc-dc converter.

This efficiency was achieved despite an input bridge rectifier and a dissipative voltage clamp.

Prototype 50 kHz, 4.5 kW, Single Stage ac-dc PFC Flyback Converter, 45-65 Hz 185-265 Vac Input

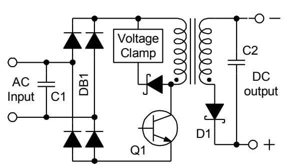
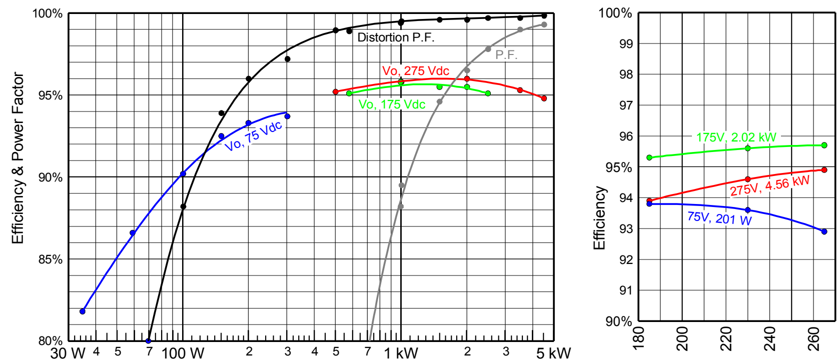


Fig. 1

Basic PFC, ac-dc Flyback Converter



Efficiency & PF vs. Output Power, @ 230 Vac Input Fig. 2 Efficiency vs. Vac Input

In a PFC flyback the input bypass capacitor C1 needs to be moved to the ac side of the bridge rectifier DB1 **(Fig. 1)** to prevent distortion of the ac input current. The capacitive input current is ≈ 10% of full load, resulting in a leading power factor (PF) at lighter loads **(Fig. 2),** but this is generally beneficial, by compensating in part for the lagging power factor of motors and distribution transformers. And the “distortion PF” from harmonic currents is considerably better.

The 4.5 kW flyback utilized two interleaved 2.25 kW converters to reduce switching ripple currents, each with one 1.2 kV, 34 A SiC MOSFET. A 3.3 kV, 50 A, SiC BJT would scale the output power per transistor to 7.5 kW at 480 Vac (and to 15 kW at 960 Vac with 6.5 kV, 50 A SiC BJTs).

Single transistor 7.5 kW modules will be connected line-line on each 480 V phase. With the dc outputs connected in parallel, the “sine squared” power flow of each module results in constant net dc output power. Multiple modules will be paralleled on each ac phase to increase power level while lowering relative HF switching currents, with redundancy achieved with one or more extra modules on each phase.

The advantages of flyback converters in general are:

1) Simplest possible power converter circuit;
2) Only “ground referenced” power transistors;
3) Most efficient utilization of magnetic elements;
4) High efficiency over a wide operating range of voltages and currents.

The limitations of flyback converters are few:

1) Requires higher voltage power transistors than other topologies;
2) “Sine squared” power flow in single phase PFC ac applications

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Applications would include:

1) Extra fast charging of electric automobiles (and trucks, busses, etc.)

2) Server farms with a dc distribution bus.

3) Hybrid electric aircraft, converting gas turbine 3 Φ ac power to dc for distribution.

4) Medium power SSTs, 20 kW to 1 MW, 3Φ 120/208 to 960 Vac input.

Development work required:

1) A lossless, non-dissipative (energy recovery) voltage clamp on the input transistor;
2) Active, lossless turn-off snubber;
3) Communication and control circuits to achieve interleaved switching, shared power flow between modules, detection of module failure, and related functions;
4) A PSU (power supply unit) for module control and drive power for higher input voltages.

Future "phase 2" development work:

1) A new, optimized control circuit/IC for high power PFC flyback converters [2];
2) A "magnetically biased" flyback transformer, for further size and loss reductions;
3) Non-dissipative output rectifier voltage clamp, for reduces loss and PIV;
4) Fast feedback clamping of output voltage deviation with load transients.

Other applications TBD, potential for high value IP in development.

Target specifications for a 480 Vac power module:

(Two identical outputs, which may be connected in series or parallel for voltages shown.)

Specification	Units	Min	Nom	Max	Notes
Input Voltage (40/70 Hz)	Vac	370	480	550	1
Output Power	kW	0	7.5	8.0	1
Output Voltage	Vdc	250/500	300/600	350/700	2
Distortion P.F.	%	98	99		3, 4
Efficiency	%	96	97		3, 5
Efficiency	%	97	98		3, 6

Notes: (1) For one 3.3 kV, 50 A BJT/module. 6.6 kV BJTs double input voltage & output power.

(2) Output range can be modified with a change in transformer turns ratio*****.

(3) 10% to full load (see Fig. 2 for typical efficiency vs. load power).

(4) Neglecting input filter capacitance current, which is about 10% of full load current.

(5) Extrapolated efficiency from prior design, but with the non-dissipative voltage clamp.

(6) Target efficiency, with the non-dissipative turn-off snubber (see "Development work").

*****Practical maximum output voltage for 1.2 kV SBDs. Up to 500 Vdc per transformer secondary for 1.7 kV SBDs. Additional outputs may be "stacked" for higher voltages. Outputs to 48 Vdc or lower may be practical when very high dc currents are required (e.g., plating applications?)

[1] *B. Carsten, "On the Fundamental Performance Similarities of Flyback and Forward Converters at High Frequencies", Proc. of Power Conversion Int. Conference, September 14-17, 1987, Long Beach, CA.*

[2] *B. Carsten, "Multi-Kilowatt Flyback Converters; Advantages and Practical Design Considerations", a Seminar presented at PCIM 17 Conference, May 14, 2017, Nuremberg, Germany. (schematics included)*