Case Study: 1kW PFC – ICERGi vs. GaN

Features

- Up to 50% Lower Switch Cost
- Up to 4x Less Switching Loss
- Up to 8x Lower Temperature Rise
- Up to 75% Smaller Inductor
- Up to 1% Increase in Efficiency
- Up to 9x Lower EMI Noise

1kW Bridgeless Totem-Pole PFC Comparison

The advantages of ICERGi technologies are clear when compared to conventional PFC approaches based on conventional topologies. However, incremental steps in the efficiency are no longer enough and the global trend requires a leap. In order to do this, the industry is adapting the Bridgeless Totem-Pole PFC topology. Unfortunately, Bridgeless Totem-Pole is a hard-switched topology and Superjunction MOSFETs are not suited for this task. This is where GaN comes in, with the promise of very low ON resistance (further boost in efficiency) and much faster switching frequency (allow using smaller inductor).

ICERGi PFC designs use MOSFETs in a 5x6mm SMD package. This is an industry standard package and many transistors from various manufacturers are available for multisourcing. Unfortunately, GaN has not been standardised yet and the packaging not only varies with each manufacturer but, in some cases, with every revision. GaN Systems Inc. produce GaN FETs in a 5x6mm SMD package and therefore have been selected for a like-to-like comparison with ICERGi.

Loss Breakdown: 1kW @ 230Vac

1kW Totem-Pole PFC	ICERGi 65kHz Si	65kHz GaN	260kHz GaN
Switches	28mR 150V MOSFET TPH3300CNH	100mR 650V GaN GS66504B	100mR 650V GaN GS66504B
Inductor Volt-Seconds	768Vμs	3072Vμs	768Vμs
Relative Inductor Size	0.25x	1x	0.25x
Switching Loss	4W	3.2W	12.8W*
Core Loss	0.4W	0.8W	0.6W
Conduction Loss	7.69W	7.9W	7.69W
Control & Drive Power	0.7W	0.5W	1W
Total Loss	12.79W	12.4W	22.09W
Efficiency	98.73%	98.77%	97.83%

* Switching loss is linearly proportional to switching frequency. Therefore, 4x higher switching frequency will result in 4x higher switching loss.

A lot of messages about GaN mention increase in efficiency and increase in switching frequency (reduced inductor size) which may lead people to believe that both hold true for any scenario. However, the loss breakdown reveals that in a hard-switched topology these advantages do not come together. ICERGi design overcomes this and offers highest efficiency together with reduced inductor size.

EMI Noise: 1kW @ 230Vac

1kW Totem-Pole PFC	ICERGi 65kHz Si	65kHz GaN	260kHz GaN
Fundamental (First) harmonic as dictated by inductor frequency	130kHz	65kHz	260kHz
Main noise component that needs to be dealt with for EMI standard	360kHz (Third harmonic)	195kHz (Third harmonic)	260kHz (First harmonic)

Fourier theory states that the amplitudes of the harmonics are reversely proportional to square of the harmonic order. This means that the third harmonic will be 9 times smaller than the first (fundamental) harmonic.**

** B. Lu, W. Dong, S. Wang and F. C. Lee, "High frequency investigation of single-switch CCM power factor correction converter," Nineteenth Annual IEEE Applied Power Electronics Conference and Exposition, 2004. APEC '04., Anaheim, CA, USA, 2004, pp. 1481-1487 Vol.3.

260kHz implementation will face significant EMI challenges because the first harmonic has to be suppressed. This will result in a complex and costly EMI filter. This observation applies to any conventional design with switching frequency above 150kHz.

ICERGi Si implementation has two significant EMI advantages:

- It is much easier to filter out 390kHz noise as compared to 195kHz or even 260kHz.
- Third harmonic has 9 times lower amplitude than the fundamental harmonic.

Control and Drive Requirements

1kW Totem-Pole PFC	ICERGi 65kHz Si	65kHz GaN	260kHz GaN
Modulation	65kHz PWM Variable duty ratio	65kHz PWM Variable duty ratio	260kHz PWM Variable duty ratio
Sampling frequency	65kHz	65kHz	260kHz
Minimum ON time (Duty ration=0.05)	800ns	800ns	200ns
Drive requirements	8 x ICERGi proprietary low-cost drive	2 x High-performance floating drive	2 x High-performance floating drive
Current sensing	Low-side resistor & Low-cost Op-Amp	High-side resistor & Costly Isolated Op-Amp	High-side resistor & Costly Isolated Op-Amp
Digital Control Hardware Demand	Low cost Proprietary control algorithm with multi-mode operation	Low-Medium cost	High cost High sampling frequency and fast control loop

Aside from reduced cost of current sensing, ICERGi has implemented a cycle-by-cycle control on a low cost, low memory variant of an ARM® Cortex™-M0 microcontroller. An M0 is limited to 48MHz operation and in order to implement similar control strategy on a GaN converter running 4x faster switching frequency one would have to upgrade to a much faster microcontroller. Some industry examples use a much more expensive Cortex™-M4. An M4 comes with a many advanced peripherals and lots of memory, all of which are not necessary and were never intended for SMPS applications. So if one needs a faster core, one must bear the extra cost of all the unnecessary functionality too.

Thermal Management

1kW Totem-Pole PFC	ICERGi 65kHz Si	65kHz GaN	260kHz GaN
Switches	8 x 150V MOSFETs in 5x6mm SMD	2 x 650V GaNFETs in 5x6mm SMD	2 x 650V GaNFETs in 5x6mm SMD
Total loss in power switches	7.4W	6.3W	15.9W
Loss per switch	0.925W	3.15W	15.9W
Relative Thermal Impedance*** (Device junction to heatsink)	1x	1x	1x
Relative Component Temperature Rise (Difference between device junction and heatsink)	1x	3.4x	8.59x

*** Heatsink size is assumed to be similar for all three designs.

ICERGi Si implementation enables significantly cooler operation of power switches resulting in various benefits such as:

- Longer life span
- Higher reliability
- Capability to handle higher power - lower cost per Watt
- Easier thermal management
- Improved convection-cooled performance

It is worth noting that this could be a much worse scenario for GaN implementations because other manufacturers use much, much smaller packaging which results in very low surface area and multiple times higher thermal impedance, making it very difficult to keep the switching devices cool.