APPLICATION NOTE AE-010

Comparison of IGBT Switching Waveforms using a Pearson Electronics probe with the Athena Energy Teflon Micro-coil and a competing Rogowski coil

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Abstract: The Athena Energy micro-coil is a Rogowski coil built on an all-Teflon® multi-layer tube which offers high-frequency performance with a traditional high bandwidth integrator circuit. The simplicity of the system lends itself especially well to fast rise-time measurements required in power electronic circuits. Because of the use of a basic ideal-approximation integrator, the range of frequencies measured is lower than other systems but was instead chosen to best accommodate power electronics switching applications. This makes the Athena-Energy Rogowski system best suited for these higher frequency applications.

Introduction

Athena Energy, LLC combines 30 years of power electronics measurement and applications experience in the fields of power, alternative energy, and analog circuit design with uncommon expertise in high temperature silicon carbide power conversion.

Figure 1. Athena Energy's All-Teflon® Rogowski Coil System

The all-Teflon® Rogowski coil is a direct off-shoot of Athena's need to measure currents in the high-temperature environment. Given the success of the coil design, it was decided to make these systems commercially available to power electronics designers. These designers typically wish to measure device currents without adding inductance to their circuits. The probe is especially well-suited to switching energy measurements done using double-pulse techniques.

Performance:

In the past, the most accurate high-bandwidth current measurement was done using the Pearson Electronics current measurement probe. This probe has historically provided high bandwidth measurements with excellent accuracy. However to do this without saturation has required these probes to be physically large and heavy, making their insertion into power converters difficult at best. Their fast rise time specification is still the standard for accurate measurement of diode reverse recovery and fast FET devices.

PEARSON™ CURRENT MONITOR MODEL 6585

Sensitivity	1 V/A ±1% 0.5 V/A into 50 Ω
Output resistance	50 Ω
Maximum peak current	500 A
Maximum rms current	10 A
Droop rate	0.8 %/μs
Useable rise time	1.5 ns
Maximum I•t typical	0.0005 A s 0.002 A s with bias
Low frequency 3 dB cut-off	400 Hz
High frequency ±3 dB	250 MHz
Maximum I²t / pulse	5 A² s
Output connector	BNC (UG-290A/U)
Operating temperature	0 to 65 °C
Weight	0.68 kg

Figure 2. Pearson current probe and specifications.

The measurements made in the test waveforms provided offer a look at the differences in probe performance between three models: the Athena Energy Rogowski coil, the Pearson electronics model: 6585, and a competitive high bandwidth Rogowski coil.

Switching Measurements

Turn-on of an IXFH60N25 IGBT with a built-in anti-parallel diode is shown in the following images. The trace colors correspond to the three current sensors used to measure the same data. The schematic in Figure 3 shows two IGBTs connected as a half-bridge with an inductor across the upper switch. The lower switch is connected to a double-pulse generator

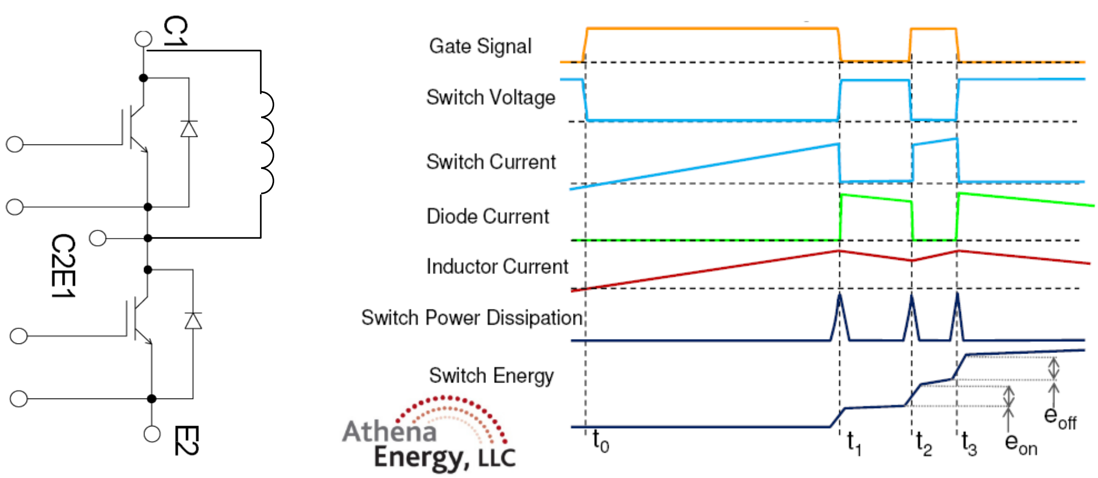
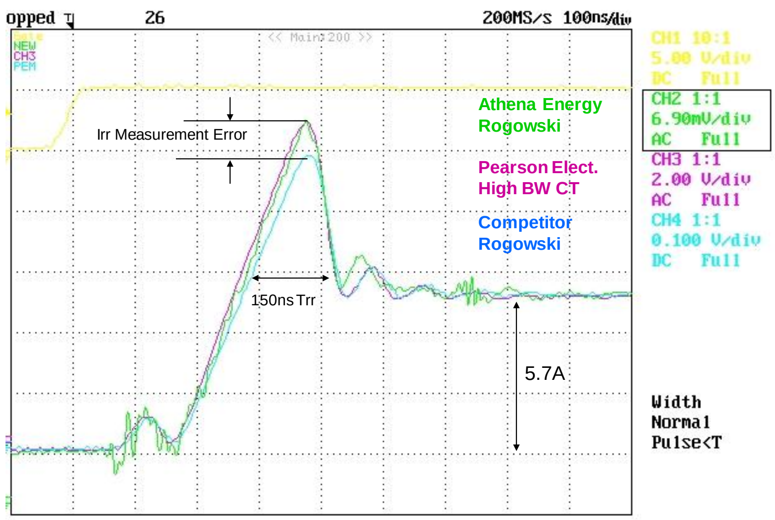
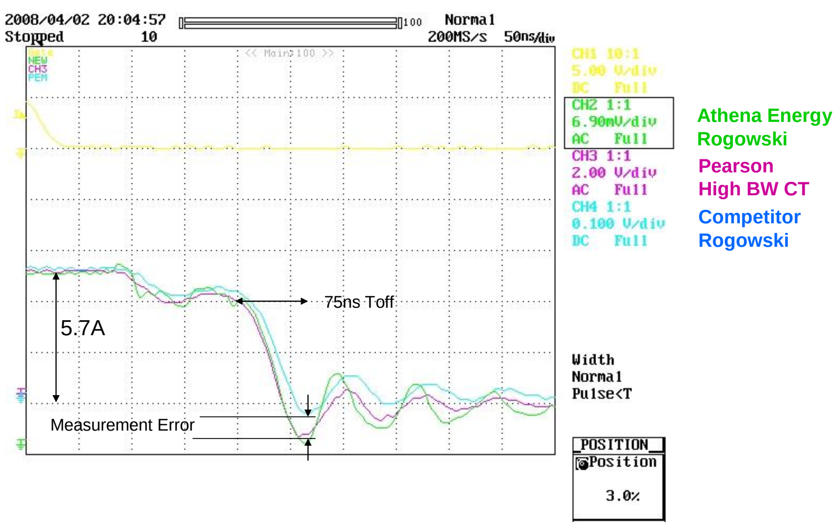


Figure 3. Double-Pulse Test Circuit with waveforms.



Irr peak value is most accurately shown by Pearson and Athena-Energy Rogowski.

Figure 4. Turn-on waveform measured at t2.



Measurements done using a double-pulse clamped inductor circuit.

Toff peak value is most accurately shown by Pearson and Athena-Energy Rogowski.

Figure 5. Turn-off waveform measured at t3.

Discussion

Rogowski coils do have inherent limitations such as effective low freq. bandwidth, offset droop, and a requirement for measurement of AC-coupled signals. The Athena Energy Rogowski coil system does require using an AC-coupled, 1MΩ, ~28pF oscilloscope input. Long pulses will cause integration error in this Rogowski system especially when the V/div sensitivity is high. This accuracy change is not much different than behavior of competing current systems and can be easily accounted for in the final measurement by only looking at current measurements taking during a switching transient. A switching transient for example can be short and easily resolved by a Rogowski coil amplifier without perceptible offset error due to integrator windup; however a longer pulse can cause inaccuracies. These inaccuracies can be addressed by continuously bleeding off charge in the integrator circuit. Opamps with low bias offset further assist this process and are used in the Athena Energy system. A long pulse example is shown in Figure 7.

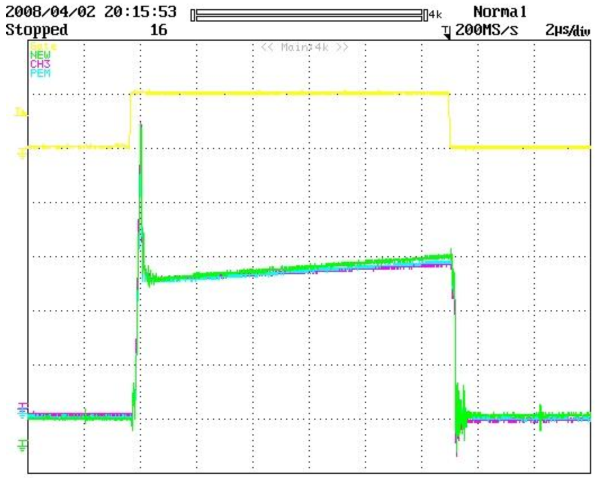


Figure 6. Rogowski coil measuring a short 11us pulse without integration error.

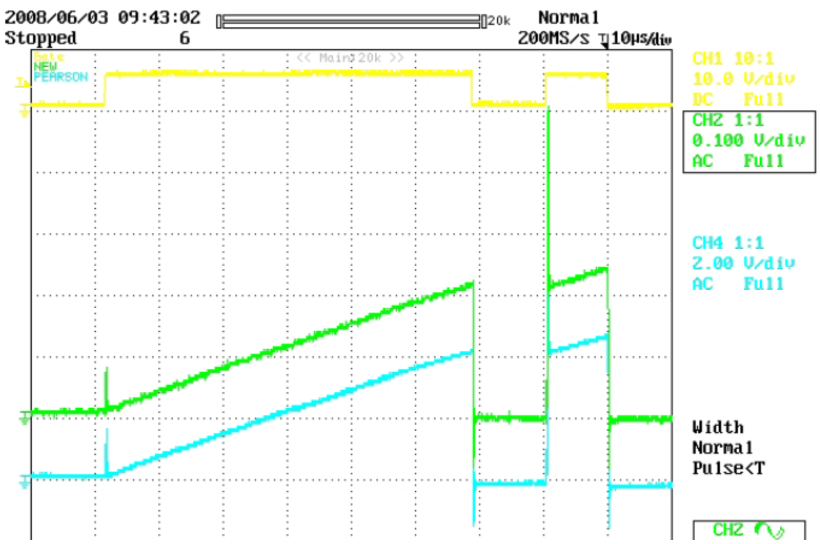


Figure 7. Rogowski coil measuring a long 80 us pulse with minimal integration error.

The user must note however that any Rogowski coil system needs to be time-domain calibrated. The typical Rogowski coil signal must be shifted back by at least 25-40ns relative to the voltage signal in order to correctly calculate switching power and energy. This is also determined by lead lengths and interconnection cables between amplifier and oscilloscope.

Conclusion

The Athena Energy Rogowski coil system demonstrates excellent di/dt measurement capability for fast rise-time signals. This is based on comparison with the industry-standard equipment available from other Rogowski coil suppliers and the capabilities shown using a high performance CT from Pearson Electronics. Power electronics applications can therefore benefit from the inherent capabilities offered by this system for accurate measurement of diode recovery, switching times, and switching energy. The added capabilities of high temperature (up to 200°C) operation and tiny coil diameter make this a more versatile device for power electronics applications, especially for applications in silicon carbide power conversion.