HIGH VOLTAGE IMPULSE GENERATOR USING HV-IGBTs*

M. Giesselmann[ξ], **B. Palmer, A. Neuber**
Texas Tech University, Center for Pulsed Power & Power Electronics
Dept. of Electrical & Computer Engineering, M.S. 3102
Lubbock, TX 79409 USA

J. Donlon°
Powerex, Inc., 200 E. Hillis Street
Youngwood, PA 15697 USA

Abstract

We are reporting on a High-Voltage Impulse Generator, which consists of a step-up transformer, which is driven by new **HV-IGBT**s (**H**igh-**V**oltage **I**solated **G**ate **B**ipolar **T**ransistors). The new HV-IGBTs are individually packaged silicon-dies intended for Pulsed-Power Applications. The silicon dies are normally packaged in large modules for locomotive motor drives and similar traction applications.

In our work we used the Powerex QIS4506001 discrete IGBT and the QRS4506001 discrete diode, both with a nominal rating of 4500V/60A, derived from continuous-duty applications. Our experiments have shown that the devices are capable of handling currents in excess of 1 kA during pulsed operation.

I. INTRODUCTION

IGBTs are power switches that can be turned on and off by applying a control voltage in the range of 15V at the gate. IGBTs combine the advantages of bipolar junction transistors and MOSFETs such that the devices are capable of controlling large amounts of current and only require a low power control voltage at the gate. The gate driver is only required to deliver current (and power) during the turn-on and turn-off transitions [1]. IGBTs have been used for many years for power conditioning in industrial applications especially for variable speed motor drives [2]. In these applications, the IGBTs act as controllable switches in three-phase inverter topologies. In these applications, the IGBTs receive pulse-width modulated (PWM) control signals to generate three-phase voltages with controllable average amplitude and fundamental frequency. The range of fundamental frequencies for motor drives is typically in the range of 0 – 120 Hz. The switching frequencies of the IGBTs are ranging from hundreds of Hz to tens of kHz to create fundamental voltages in the aforementioned range with good approximation by supplying a pulse-train with varying pulse-width [1,3]. Recent advances in IGBT technology enable motor drives with continuous power ratings in the MW region [4]. Since motors consume more than 50% of the electric energy in industrialized nations, the efficient energy management enabled through motor drives makes a large contribution to energy conservation efforts [3].

A separate class of HV-IGBTs emerged recently extending the rated voltage up to and beyond 4.5 kV. Devices of this class enabled the design of motor drives with continuous power ratings in the tens of MW. However it was recently discovered that the long term voltages applied to HV-IGBTs have to be significantly below their rated voltages to avoid problems due to cosmic ray latch-up [5].

Pulsed Power applications however typically do not apply long term (months – years) voltage stresses to switching elements. In addition, switching devices can often be stressed safely far beyond their continuous-duty current ratings for short pulse applications. This makes the new class of HV-IGBTs particularly interesting devices for pulsed power applications. This paper is exploring the capabilities of these devices for a high-voltage Impulse Generator designed for investigations on surface flashover phenomena.

II. HIGH-VOLTAGE IMPULSE GENERATOR

In this section, the design of the HV-Impulse generator is discussed in detail and detailed data concerning its components is given.

A. *Overall Schematic of the High-Voltage Impulse Generator*

Figure 1 shows the overall Schematic of the High-Voltage Impulse Generator. The basic topology of the circuit is a DC-chopper circuit which is driving the primary winding of a HV-transformer. The transformer is

---

* Work supported in part by Powerex, Inc.

[ξ] email: Michael.Giesselmann@ttu.edu
°email: jdonlon@pwrx.com

increasing the voltage by a factor of 20 and is charging a section of High-Voltage (HV) coax cable through a resistor to avoid oscillations. The HV coax cable constitutes a transmission-line type pulsed power source with an impedance of 50Ω. It is capable to produce a square wave pulse with rise and fall times of less than a nanosecond (ns). The transmission line acts as a source to investigate ultra-fast surface flashover phenomena on dielectric surfaces. Since flashover processes develop in the ns time and sub-ns time scale, the transmission line is an ideal source for these investigations for the following reasons:

- If a discharge develops, the transmission line can deliver a surge of energy very quickly to enable the breakdown process to fully develop and be readily detectable.
- After the breakdown process is fully developed, the energy content of the transmission line is quickly depleted (in about 10 ns) and arc-damage to the dielectric surface is avoided.

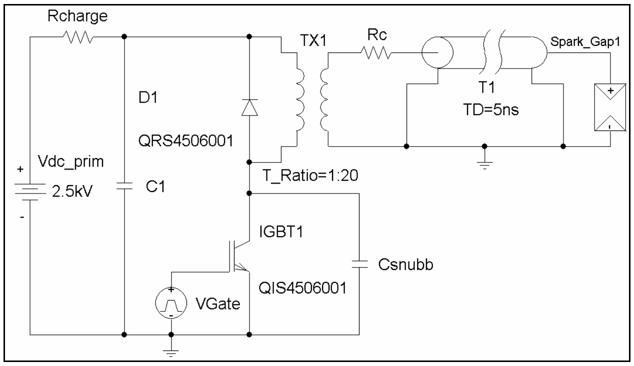


Figure 1. Schematic Diagram of the High-Voltage Impulse Generator.

This impulse generator is using several power-conditioning and pulse compression stages to generate an ultra-short high-voltage pulse starting from a low power 2.5 kV voltage source. Initially a combination of capacitors collectively labeled "*C1*" in Figure 1, is charged by the primary voltage source. This capacitor array is capable of being discharged in the µs time frame and can deliver pulsed discharge currents in excess of 1kA. The discharge of the capacitor array is controlled by HV-IGBT1. When IGBT1 is turned off, the current in the primary winding commutates into the HV-Diode D1. During the discharge of the capacitor array, the step-up transformer raises the voltage and charges the coax cable, which represents a distributed power source that is capable of producing ultra-fast rectangular pulses for surface flashover studies.

B. High-Voltage Semiconductor Switches

A QIS4506001 HV-IGBT [6] is used as the main switch and a QRS4506001 HV-Diode [7] is used as a free-wheeling diode across the primary of the transformer. Both devices are made by Powerex, Inc.

Figure 2 shows a picture of the QIS4506001 IGBT in its package prior to sealing. This package contains a single piece of silicon die which is otherwise packaged together with other IGBT and diode dies in a large package for motor drive applications. The two outside terminals are both connected internally to the emitter contact area of the die. The terminal in the center is directly connected to the gate without a gate resistor which is integrated into the larger modules for motor drive applications.

In the large IGBT modules such as the CM400HB-90H, the gate resistor forms a low-pass filter in combination with the gate resistance to limit the slew-rate of the switching transitions and the associated switching losses to values that are appropriate for continuous-duty applications. In this package the gate can be driven much more aggressively for pulsed operation, which was used for the work described in this paper.

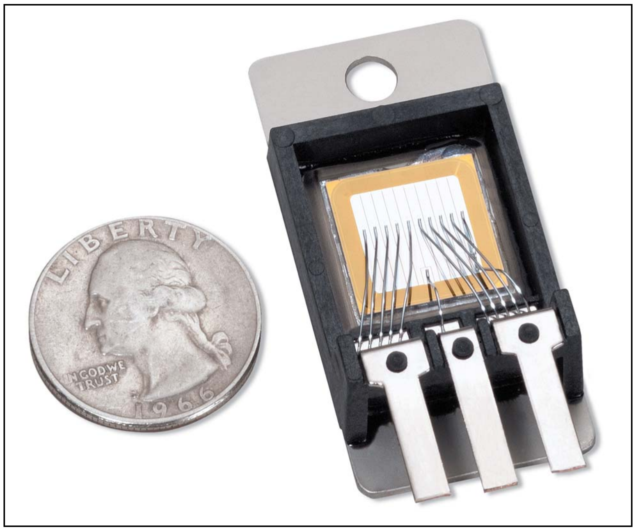


Figure 2. Picture of the HV-IGBT prior to sealing. (Courtesy Powerex, Inc., with permission)

As shown in Figure 2, the IGBT die is directly soldered onto the back-plate of the package. This means that the back-plate is not isolated and is used for the connection of the collector.

The QRS4506001 HV-Diodes are mounted in the same 'High-Voltage Discrete' package. Here the two outside terminals are connected to the anode and the back-plate is used for the cathode connection. The center terminal is not connected.

C. Gate Drive Circuitry

As mentioned above, in the High-Voltage Discrete package the gate is directly connected to the center terminal. The gate control voltage is applied between the gate and emitter terminals. The gate terminal behaves electrically like a capacitor; however, the capacitance is highly non-linear during the switching transitions. As soon as the gate-emitter voltage crosses the turn-on threshold, the effective gate capacitance appears to grow significantly [1,2] requiring much more charge for additional gate-emitter voltage increase. Therefore a driver with high transient current rating (>10A) is needed to achieve fast current rise & fall times.

For the work reported here we used a DEIC420 ultra-fast MOSFET driver mounted on an EVIC420 evaluation board made by the IXYS-RF division of IXYS Corporation [8]. The DEIC420 driver has a peak output current capability of 20A and a maximum output voltage of 30V. The driver has a complimentary MOS output stage that actively pulls the output to the positive or negative supply voltage rail. Since this driver is designed for very high frequencies (45 MHz rated at +15V supply), it comes in a low-inductance, RF strip-line package. For effective use, it must be mounted in an appropriately designed printed circuit board (PCB) and surrounded by low-inductance buffer capacitors in close proximity. Since the EVIC420 evaluation board has the required layout and support circuitry, it was used in our experimental setup. In order to achieve pulsed currents in the order of 1kA, we drove the gate with voltages as high as 30V.

D. High-Voltage Step-Up Transformer

The High-Voltage Step-Up transformer was constructed from two AMCC80 C-Core sections made from iron-based METGLAS® amorphous Alloy 2605SA1 Ferro-magnetic material. The cross section of the core is 680 mm^2. The average magnetic path is 210 mm. The primary winding is a single turn with several parallel paths. The secondary winding has 20 turns.

E. Primary Energy Storage Capacitors

A combination of capacitors is used for primary energy storage. The capacitors are buffering the low power HV-DC supply and are able to deliver the pulse current needed to drive the primary of the transformer. In close proximity to the HV-IGBT, a series combination of ultra-low inductance (< 15nH) film capacitors, rated at 1µF/1200V provide the primary transient buffering. These capacitors are from the MP88 series made by Electrolytic Concepts, Inc [9]. For additional energy storage, a 15µF, 5kV capacitor made by MAXWELL was connected in parallel using a short (10 cm) coax cable to minimize the inductance.

F. Construction of the HV- Impulse Generator

Figure 3 shows a picture of the experimental setup. In the foreground a Pearson current monitor, model 411 is visible, which was used to measure the current in the primary winding of the transformer [10]. The HV-Impulse generator was constructed on a dual sided printed circuit board (PCB) measuring 110 x 70 mm. The bottom layer was a continuous ground plane. The ground plane and the circuit traces on the top layer extended close to but not all the way to the edge of the board, leaving a buffer-zone of about 1.5mm to prevent breakdown across the edge of the board. The gate driver board was connected to the main PCB via a micro-coax cable of about 3ft. length.

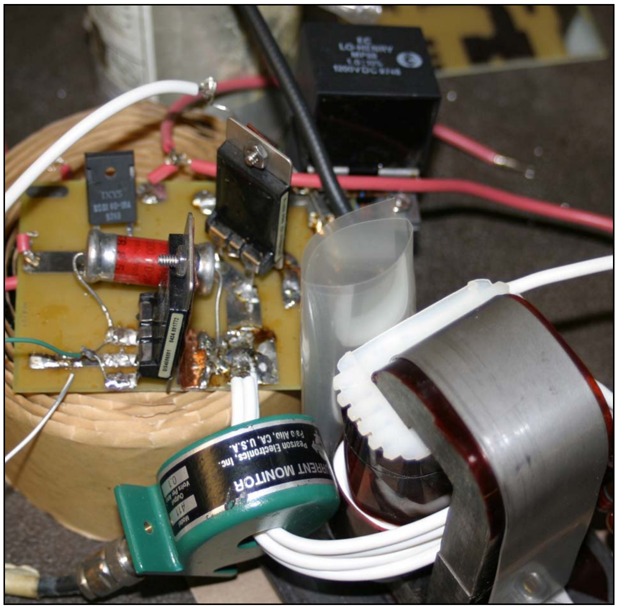
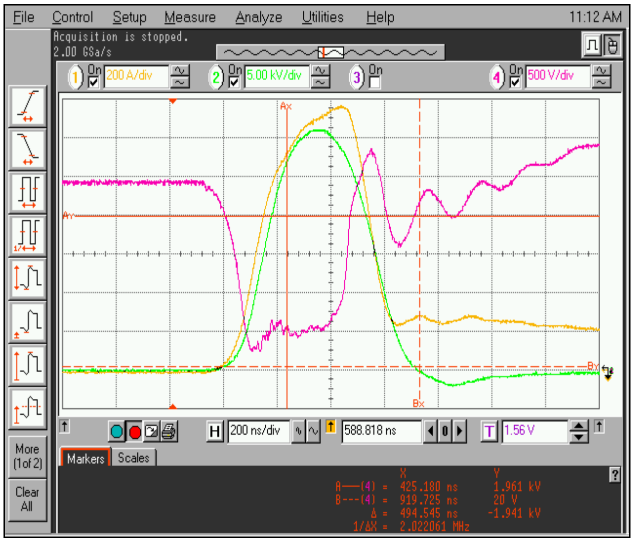


Figure 3. Picture of the Experimental Setup.

III. RESULTS

In this section we report the performance of the Impulse Voltage generator and the HV-IGBT as its major enabling component. The principal parameter that controls the output voltage, output power and current levels is the charging voltage of the primary capacitor array, symbolized by "*C1*" in Figure 1. We show typical waveforms for primary voltages of 1.0, 2.0 and 2.5 kV.



```
Acquisition is stopped.
2.00 GSa/s
```

1 On ☑ 200 A/div
2 On ☑ 5.00 kV/div
3 On ☐
4 On ☑ 500 V/div
H 200 ns/div
588.818 ns
T 1.56 V

```
                X             Y
A——(4) =   425.180 ns     1.961 kV
B---(4) =  919.725 ns     20 V
      Δ =  494.545 ns    -1.941 kV
   1/ΔX =  2.022061 MHz
```

Figure 4. Oscilloscope traces for 2.5 kV primary voltage.

Figure 4 shows traces of the Collector-Emitter voltage across the IGBT, the current in the primary of the transformer and the output voltage of the Impulse generator for 2.5 kV input voltage. The current in the primary of the transformer is equal to the collector current of the IGBT as long as the IGBT is turned on. The input pulse length for the grate driver was a rectangular pulse with 560 ns width. The supply voltage for the gate driver was 30V. The traces show the collapse of the C-E voltage of the IGBT and the rise and fall of the collector current and output voltage. The horizontal scale for the traces shown in Figure 4 is 200ns/div. The vertical scale for the C-E voltage of the IGBT is 500V/div. The vertical scales for the current and the output voltage are 200A/div and 5kV/div respectively. While the trace for the output voltage is almost shaped like a perfect gaussian pulse, the current pulse is peaking after the peak of the voltage, possibly due to beginning saturation of the magnetic core. The peak of the current pulse is almost 1,400A.

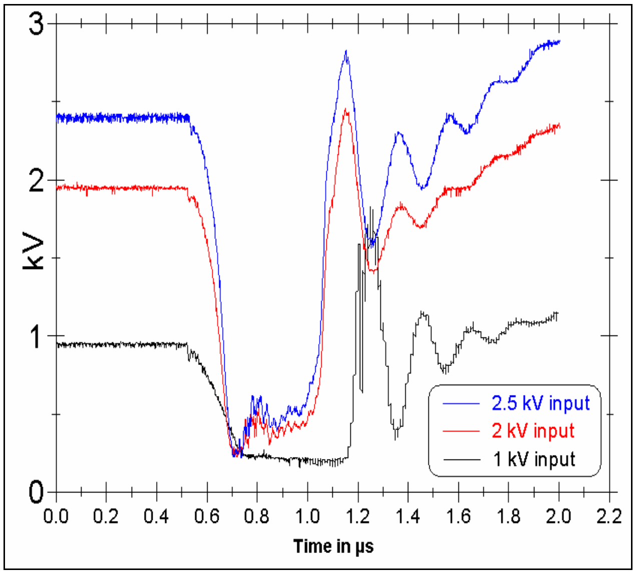


Figure 5. IGBT C-E Voltage for different primary Voltages.

Figure 5 shows the traces for the Collector-Emitter voltage of the IGBT for a range of primary charging voltages. The initial voltage is at the level of the measured charging voltage when the IGBT is holding off the voltage. After the beginning of the turn-on process, the voltage collapses to a residual value of several 100V and recovers to the original hold-off value after the pulse while undergoing several converging oscillations.

IV. SUMMARY

We have described a novel High-Voltage Impulse Generator based on a new series of 4.5 kV High-Voltage IGBT switches made by Powerex, Inc. We have shown, that these devices can switch pulsed currents in excess of 1kA with aggressive gate drive.

V. REFERENCES

[1] N. Mohan, T. Undeland, W. Robbins, Power Electronics, Media enhanced 3rd edition, John Wiley & Sons, © 2003.

[2] S. Abedinpour, K. Shenai, "Isolated Gate Bipolar Transistor," in Power Electronics Handbook, M. Rashid, Ed., New York: Academic Press, 2001, pp. 101-116.

[3] A. M. Trzynadlowski, Control of Induction Motors, Academic Press, San Diego, 2001.

[4] D. Krug, M. Malinowski, S. Bernet, Berlin University of Technology, “Design and Comparison of Medium Voltage, Multi-Level Converters for Industry Applications”, Paper 0-7803-8487-3/04, Proceedings of the 39th IEEE IAS Annual Meeting, Seattle, WA, Oct. 3-7, 2004.

[5] Nando Kaminski, “Failure Rates of HiPak Modules Due to Cosmic Rays”, Application Note 5SYA 2042-02, ABB Switzerland Ltd, Semiconductors, November 2004.

[6] QIS4506001 Datasheet, High-Voltage discrete IGBT module, Powerex, Inc., 200 E. Hillis Street Youngwood, PA 15697, http://www.pwrx.com/.

[7] QRS4506001 Datasheet, High-Voltage discrete Diode module, Powerex, Inc., 200 E. Hillis Street Youngwood, PA 15697, http://www.pwrx.com/.

[8] EVIC420 Datasheet, IXYS Corporation, IXYS RF Division, 2401 Research Blvd. Fort Collins, Colorado 80526, http://ixysrf.com/.

[9] Electronic Concepts, Inc., P.O. Box 1278, Eatontown, New Jersey 07724, http://www.eci-capacitors.com/.

[10] Pearson Electronics, Inc., 4009 Transport Street, Palo Alto, CA 94303, USA.
http://www.pearsonelectronics.com/.