The Optical Transconductance Varistor (OTV)

**Background**

Most solid state power electronic devices rely on a junction of dissimilar materials for control of power through the device. This junction limits the switching speed of the device because charge carriers must cross the device before conduction of the high voltage can occur. This is problematic because the longer a device takes to transition from off to on and vice versa, the more energy is lost in resistive heating. Secondly, the voltage drop through the device occurs only across the narrow region at the junction, concentrating the electric field in a small region. This concentration limits silicon based devices to 2000 Volts because of the breakdown properties of the material. More recently, higher power semiconductor devices using wide bandgap (WBG) materials such as SiC and GaN have been brought to market. Although these devices can handle higher voltages, long lead times and high development and manufacturing costs make them relatively expensive. Even so, individual devices are not capable of switching voltages that are commonly used in electric power transmission and distribution and many other high voltage applications. To achieve these voltages requires combining many devices in series. Additionally, for both silicon and wide bandgap based devices, electrical isolation of the low control voltage from the high voltage is difficult.

**Opticondistor Technology**

The opticondistor (OTV) overcomes the limitations of traditional semi-conductors because it does not rely on a junction of dissimilar materials to provide control. In the OTV, the voltage drop is across the bulk of the device, reducing the electric field concentration, allowing greater switching speed and voltage handling capability. SiC has a high breakdown voltage so that with the bulk control, much higher voltages can be switched and controlled than with silicon or silicon carbide junction devices. The OTV can handle 10’s of kV and over 10’s of A. The material and geometry of the OTV require much lower levels of light intensity to provide high conductivity and much higher gains are possible than with any other photoconductive switch.

Optical energy applied to the SiC material pumps charge carriers into the conduction band which cause the material to become conductive. As the intensity of the light is increased, more charge carriers are produced, increasing the conductivity. When the light source is removed, the charge carriers decay and the material becomes insulating again. The SiC material and the geometry offer high frequency operation and very fast transition time. Charge carriers are produced and the material becomes conductive within picoseconds of being illuminated by a light source. Full turn-on of very high voltage can be achieved in much less than a nanosecond. This faster transition time reduces the energy lost as heat during the transition, making the OTV more energy efficient. The specially doped SiC requires less light intensity to create the charge carriers for increased conductivity. Forward electrical gain is substantially improved. Because conduction through the device is dependent on the intensity of the controlling light source, zero
to full voltage control is possible. By controlling the intensity of the light source, the turn on and turn off characteristics may be controlled. As a bulk device, the OTV can conduct current in either direction. Once packaged as a unit, the OTV will be the only device capable of fast, high-voltage, high-current, bi-polar, and bi-directional power switching.

Optical control provides electrical isolation between the control electronics and the high voltage. This feature allows devices to be stacked in series to virtually unlimited voltage and paralleled to any current. The combined devices may be controlled by the same light source, ensuring simultaneous switching.

The lack of a junction also means the OTV is simpler to design and manufacture than junction semiconductor devices. It requires fewer manufacturing steps and so is expected to be easier and less expensive to manufacture than junction SiC-based devices. Moreover, the simplicity of design means that devices may be quickly designed to meet specific customer needs.

Under a National Science Foundation Small Business Innovation Grant, Opcondys demonstrated technical proof-of-concept by switching over 15 kV at 75 kHz and 50% duty cycle in a breadboard experiment. This is the fastest ever rate for repetitive switching at such high voltage. Kilowatt power levels were controlled using less than 10 watts of optical input power. Tests showed consistent results in switching across a range of voltages from 1 kV to greater than 15 kV.

The transconductance control properties of a semi-insulating photoconductive silicon carbide switching and control device were also proven. Varying the intensity of the light source illuminating the material caused correlated changes in the conductance of the switch material. As the light intensity was increased, conductance of the material increased as well. Opcondys is now developing a prototype and will produce a marketable device capable of greater power handling in a reliable, energy-efficient, compact form.

**Applications**

The unique capabilities of the OTV make it a desirable replacement for power MOSFET's, IGBT's, thyristors, thyratrons and other high voltage power switching devices. Its advanced capabilities greatly extend the range over which a solid state switching device may be used (Figure 1). It is particularly suited for applications in electric grid modernization, power supplies for medical and food processing and pulsed power.

In electric power production, transmission and distribution, the OTV's greater voltage capability means fewer devices will be required to switch at line voltages, simplifying switching circuitry. High voltage Direct Current (HVDC) is increasingly being used to carry electricity long distances. It is more efficient than alternating current (AC) and is becoming very important in connecting large renewable energy sources to markets where the electricity is used. Electricity must be converted from AC to DC for transmission and then back to AC before it is distributed to homes and businesses. The switching devices currently being used for conversion result in approximately 5% to 7% of the electricity being lost in these conversion processes. The OTV's fast transition time means that conversion is more energy efficient and could save half the energy now lost. On a typical 500 megawatt HVDC line, this is enough energy to supply 10,000 homes. Additionally, because fewer devices are needed and can be stacked more closely together, smaller conversion stations will save building and land costs. Interrupting faults in HVDC lines is also a difficult problem. The controlled transition time of the OTV means that it
can be used to quickly and controllably interrupt faults, preventing widespread interconnected power failures.

The OTV's high frequency capability will allow smaller and lighter transformers to be used in power inverters, such as are used in solar and wind energy. This saves energy not only in the switching process but also in hysteresis losses in transformers. This provides cost savings in both capital and operating costs.

In grid-tied energy storage systems, electricity flows both ways between the storage device and the grid. The OTV's bi-directional capability will allow the number of switching components to be reduced by at least half in these systems. Additionally, the OTV's voltage handling capabilities allow for transformerless connection to the grid. This reduces the size and cost of the conversion equipment and also reduces operating costs.

Other uses for the OTV include pulse generators for medical treatments, food processing and numerous military applications, including RF switching for radar and many other applications where a fast, efficient high voltage switch is needed. As a more versatile switching device, it offers greater control of high voltage power than existing devices in these applications. This will enable manufacturers to more closely meet their customers' requirements.

Company

Opcondys, Inc. is a woman-owned, early stage start-up company whose mission is to develop and provide the OTV to manufacturers of high voltage equipment. The company was founded in October of 2014 as a California Corporation.

Kristin Sampayan, MSME, is Chief Executive Officer and Research Engineer. She has experience in material modelling with finite element methods and computer modelling of other systems. She also has a broad range of management experience and has owned and operated a small business for the past nine years. She has participated in the Cleantech Open business accelerator program, the oldest and largest global accelerator for early-stage clean technology startup companies.

Stephen Sampayan, PhD, leads technical development of the OTV. Stephen invented the OTV at Lawrence Livermore National Laboratory and led a government sponsored, seven year, $25 million effort at the Lab to develop the technology on which the OTV is based. He has over 35 years of experience with high voltage and pulsed power equipment design and development. In his roles in technical leadership at LLNL over the past 27 years, he has led teams of scientists and engineers in many successful projects.

For further information, contact Kristin Sampayan at kristinsa@opcondys.com or (209)823-8272.