Experiments and Computational Theory for Electrical Breakdown in Critical Components

Verle Bigman, Richard Gallegos, Fred Zutavern (PI), Harold Hjalmarson

Researchers at Sandia are developing a new diagnostic technique to image electrical breakdown phenomena, which will help to better model and predict how electrical components will function in extreme environments.

Controlling and preventing electrical breakdown is a key issue for many electrical components. Disruptive devices (e.g., lightning arresters, insulators) are used to protect electrical systems in the presence of sufficiently large voltages. Predicting the behavior of disruptive devices in extreme environments, particularly for stockpile and other critical applications, is a key issue of national importance. Science-based modeling of electrical breakdown has had limited success in predicting many of the observed characteristics without the help of diagnostic discovery experiments. A new diagnostic technique is being developed, using pulse terahertz (THz) radiation to image electron distributions in conventional and electron-hole plasmas. This innovative technique will provide previously unavailable information to help model and predict electrical breakdown phenomena, which are present in all aspects of science and engineering, for research and commercial applications.

Images of electrical breakdown phenomena often show the recombination of electrons and ions (or holes in a semiconductor). Recombination radiation requires the presence of both polarities of charge. Thus, in cases where electron densities exceed ion or hole densities, recombination radiation is improbable and will not reveal the highly mobile electronic charge or current distributions. Because visible or shorter wavelength light does not couple strongly to electron densities in plasmas—which are common to the initiation of electrical breakdown phenomena—this new technique utilizes THz radiation, which has a strong coupling to these densities. In fact, the plasma frequencies of electron densities from 10^{12} to 10^{18} cm^{-3} are in the 0.01 to 10 THz range, so they radiate *and* strongly absorb radiation in the THz regime.

This approach uses three amplified pulses from an ultrashort pulse laser to: (1) trigger the electrical breakdown event, (2) create the pulsed THz radiation, and (3) detect the image formed from the THz radiation electro-optically after it is scattered and re-radiated from the event. Synchronized pulses, with lengths from 5×10^{-13} to 3×10^{-9} seconds, are used to provide extreme time resolution of the images and relatively efficient THz generation. Until recently, the alignment and timing of the system was determined theoretically, resulting in very noisy imagery. Now, alignment is close enough that the THz radiation and shadows of simple objects are visible above the background noise (following the integration of many images in the camera and the subtraction of the time-averaged background). These images (Figure 1), although simple, illustrate the promise of the method to ultimately gain insight into electrical breakdown physics. Current work is focused on improving imaging capability by using real-time feedback to optimize system adjustments/setup and testing multiple ways to increase the signal and reduce the many sources of noise in the images.

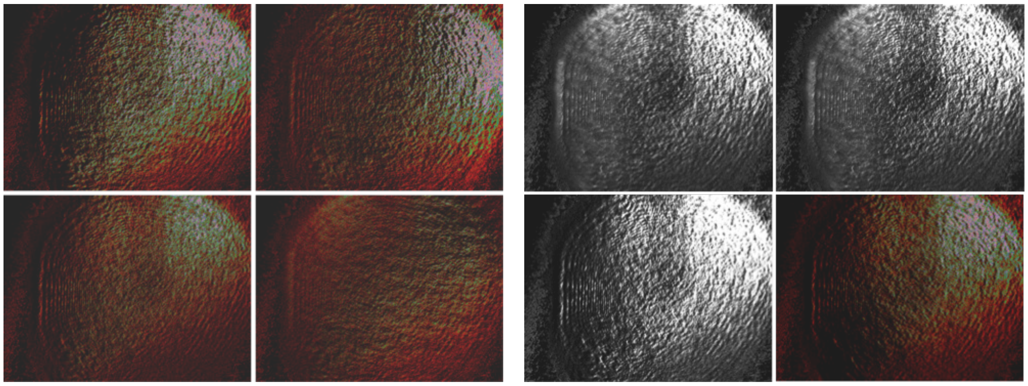

Figure 1. The first column on the left shows two images with a weak shadow of a ¼ inch metal post hanging from the top center of the photo after electro-optical detection of ninety 65-femtosecond THz images and integration in the camera before read-out. The second column from the left shows the same type of images without the THz radiation (background images). The four images in the last two columns on the right show the results of additional averaging (after internal averaging, before read-out) with up to 60 selected signal and background images.

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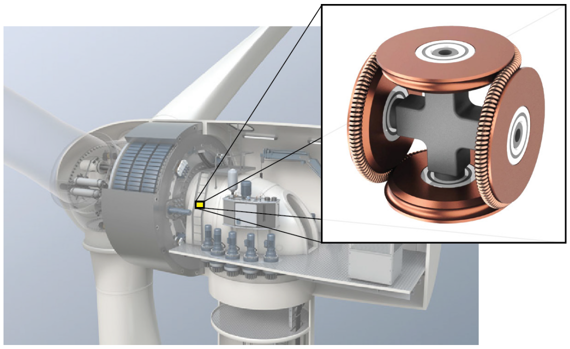
Sandia's Twistact Technology: The Key to Profileration of Wind Power

Jeff Koplow, PI

Twistact technology, developed by Sandia researchers, is a new topology for rotary electrical contacts and represents a critical step forward in bringing cost-effective wind energy to the grid.

Wind power represents a significant renewable energy source—wind power is abundant and multi-megawatt (MW) wind turbines have the potential to be extremely cost effective ($0.04/kW-hr). But the traditional gear-box-plus-induction-generator wind turbine architecture is difficult to scale up in size, often resulting in failure to key components at multi-MW operation. Direct-drive generators, which are less complex and lower maintenance at multi-MW scales, have traditionally relied on rare earth magnets. While this approach addresses the reliability problem, reliance on exotic rare earth magnet materials has significantly hampered growth of the wind power industry. The alternative is to implement direct-drive generators with rotors based on electromagnets (copper and steel) rather than rare-earth permanent magnets. But this approach has not been widely adopted because of short operational lifetime and high maintenance associated with state-of-the-art brush/slip ring technology; these are required to transmit very high electrical current to and from the rotating frame of the rotor. The Twistact is a fundamentally new topology for rotary electrical contacts that eliminates the longstanding problems of sliding contact and electrical arcing. Twistact's potential to eliminate the need for rare earth magnets in wind turbines, thereby allowing for large-scale proliferation of wind power, is not only important from the standpoint of phasing out fossil fuels. It also addresses a critical technological vulnerability to US economic security identified by the DOE (2011 *Critical Materials Strategy*).



Twistact-based generator technology will be designed to be a modular drop-in electrical generator for next-generation wind turbines.

The Twistact (see inset of Figure 1) consists of an electrically conductive belt and a planetary transmission device that provides a continuous ultra-low resistance path for current flow. The team developed test beds and belt technology, focusing on sheave/belt contact forces and optimizing belt design and fabrication quality. These iterations resulted in 2000 amp operation at a resistance of 0.65 milliohms (the initial project goal was 1000 amps and no more than 1 milliohm) and 20 million belt rotations (40% of the ultimate goal). Continued data analysis from the latest test beds will be used to develop proof-of-concept prototypes. These prototypes will undergo accelerated life testing to achieve 50 million rotation cycles (30-year service lifetime) and additional studies of materials reliability and environmental degradation will provide further insight into the component's longevity.

Recently, Twistact was selected for participation in the DOE's Lab Corps program. Lab Corps aims to teach technical staff the non-technical skills they will need to facilitate the eventual transfer of innovative clean energy technologies from the DOE's National Laboratories into the commercial marketplace.

UPCOMING LDRD EVENTS

APRIL 14 – MAY 21
New and Continuation LDRD Proposal submission

MAY 26 – JUNE 16
Technical and Programmatic Proposal Reviews

LDRD PROJECTED BUDGET AND STATUS

FY15 Q3 $146 MILLION 367 PROJECTS FUNDED AT $139.8 MILLION

AWARDS & RECOGNITION for LDRD Participants

Mark Boslough was the lead author on a paper entitled *Updated Population and Risk Assessment for Airbursts from Near-Earth Objects (NEOs)*, which garnered the Best Paper Award at the 2015 IEEE Aerospace Conference.

Tamara G. Kolda has been named a Fellow of the Society for Industrial and Applied Mathematics, one of 31 members selected for fellow status this year.

Hongyou Fan was selected by the Materials Research Society and The Kavli Foundation to deliver the 2015 Fred Kavli Distinguished Lecture in Nanoscience.

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