Better Understanding of Distribution Arc Flash Improves Worker Safety

An arc flash erupting from a distribution circuit fault can be life threatening for nearby workers. Electric utilities have long tried to prevent arc flash injuries by disabling circuit reclosing during work, by adopting practices that keep personnel at a safe distance from potential flashover points, and by issuing flame-resistant clothing. Unfortunately, the severity of an arc flash is difficult to predict because it depends on a variety of complex factors, including the worker's position relative to a fault, the duration and current level of the fault, and the arc length. No single approach to analyzing these factors has been universally accepted.

To better understand such risks, the National Electrical Safety Code (NESC) and the Occupational Safety and Health Administration (OSHA) are revising electrical safety rules, which will require utilities to perform additional analyses of arc flash hazards and could potentially make significant changes in worker protection. In 2008, EPRI launched a research project to help utilities prepare for these rule changes.

Assessing Current Models

The project's first phase has been completed, with results published in three reports. One research area evaluated methods currently used to estimate arc flash energy and provided guidance for utilities in applying these tools to choose the most suitable safety measures. Comparing results from current analytical models with data from field tests conducted by EPRI and study participants revealed some significant discrepancies.

Tests on arcing from overhead lines, for example, showed that arc lengths assumed in standards tables are unrealistically short and that in many scenarios an arc may quickly grow to several inches or even a few feet. Tests also showed that the fireball surrounding the arc tends to get pushed away from the source because of magnetic forces, especially in a phase-to-phase fault. Open-air testing to measure heat energy in arc flash exposure will be necessary to determine if and how work practices for line workers may need to be changed.

Additional testing and analysis are also needed to evaluate secondary network systems. Network protectors are of particular interest for utilities with secondary networks because fault currents often exceed 50 kiloamperes with long clearing times and because it can be difficult to de-energize the system to perform work. Project testing established that sustained arcs are possible in 480-volt network protectors and can produce a large fireball; similar tests on padmounted transformers, however, found no instances of sustained arcing.

Tests also showed that flame-resistant clothing may not provide sufficient protection from arc flashes, particularly if the worker is exposed to a focused fireball emitted from enclosed equipment. In 20 tests, samples of flame-resistant fabric were subjected to varying levels of incident energy (all below the fabric rating); in 75% of the tests, enough heat penetrated the samples to cause a second-degree burn.

Surveying Industry Practices

The EPRI research also studied existing and developing industry practices for analyzing and protecting workers against arc flash hazards. A formal utility survey and discussions at meetings revealed broad similarities but also specific differences in such practices. Gap distance assumptions did not vary greatly among utilities, but about half of utilities assume a line-to-ground fault for evaluating overhead hazards, while half do not. Significant differences were revealed in approaches to arc energy mitigation, with 46% of utilities reporting the ability to enable instantaneous tripping on all their feeders, while 17% reported that ability on fewer than a quarter of their feeders.

The project's second phase, now under way, will conduct tests that can help refine analytical techniques, improve worker protection, and enhance flame-resistant clothing. In particular, standard clothing tests, which have relied mainly on subjecting a fabric to radiant energy from an arc flash, will be supplemented with direct exposure to the fireball created. Additional equipment testing is also expected to provide better estimates of safe working distances.

For more information, contact Tom Short, tshort@epri.com, 518.374.4699, ext. 14.

Antenna Array Pinpoints Problems in the Substation

The insulation on high-voltage equipment deteriorates with time, and being able to identify and replace equipment that has degraded significantly in substations is important to both economy and safety. While deterioration may result from a variety of mechanisms, a certain marker can warn of impending problems: in many cases, degradation is preceded by electrical partial discharges. But because partial discharges occur intermittently, they are notoriously difficult to detect during inspection. Hard-wired continuous monitoring is one solution, but it is expensive, typically requiring many electrical connections between monitoring equipment and individual substation components.

Early research funded by Britain's Engineering and Physical Sciences Research Council (EPSRC) and National Grid UK proved that a non-contact remote-sensing technology was technically feasible and potentially more economical for detecting partial discharges. EPRI was instrumental in forming a large, multi-utility collaborative research and demonstration project to further this work. The new approach detects the radio-frequency emissions created by partial discharges rather than measuring the discharges themselves, identifying and locating degraded insulation from analysis of the pattern of impulse emissions.

The emissions are detected by an array of four antennas mounted within the substation—usually on top of a building or trailer. Using high-speed, wide-band digitizing hardware, custom software, and computational algorithms, the technology records the radio-frequency signal, analyzes the time of flight to the antennas, and triangulates on the location of the partial discharge source. The specially designed, omni-directional disk-cone antennas have a relatively flat frequency response over the range of 100–1,000 megahertz.

Technology Demonstrations

Expanding on EPSRC's proof-of-concept work, National Grid conducted the first demonstration of the antenna array on its power delivery system and subsequently installed the equipment at three additional sites. The system's effectiveness was first corroborated in 2003, when the array detected and pinpointed a failing current transformer in a 400-kilovolt substation.

As a result of EPRI's collaborative work, the demonstrations have grown to include 13 additional pilot installations on three continents, each of which is providing valuable data to refine the system's signal analysis. The demonstration program's results led to the creation of Elimpus Ltd, a spin-off company from Strathclyde University in the UK that will provide the equipment and related services to the industry.

Disk-cone antennas on the corners of a trailer detect radio-frequency emissions that indicate the location of deteriorating substation equipment.

The antenna array's monitoring capabilities are ideal for a number of applications: helping extend asset life, investigating suspected problems, checking components that have failed catastrophically at other utilities, and monitoring background partial discharges to alert site workers to health and safety issues. Because the array requires no physical sensors or communication cables on the equipment, the technology can provide continuous nonintrusive monitoring of an entire unmanned substation, resulting in significant savings in hardware and maintenance. By enabling the diagnosis of multiple substation components using a single, central device, the array reduces the time personnel would need to spend evaluating any one device.

Future Research

Drawing on the pilot demonstrations, EPRI is developing case studies that prove the technology's effectiveness in predicting and preventing failures of substation components such as instrument transformers, power transformers, and bushings. The comparatively low cost of antenna array equipment (compared with other solutions) is expected to drive its adoption by utilities, especially given their significant investment in the equipment that this technology protects from failure.

Further research is under way on real-time signal analysis to identify or classify discharge activity and intensity levels. Future data sets of monitored signal sources will form the base criteria for estimating the seriousness of discharge activity and will serve as a guide for developing maintenance practices.

For more information, contact Luke van der Zel, lvanderz@epri.com, 704.595.2726.