EDF Energy Identifies High-Risk Cable Sections

EDF Energy uses on-line partial-discharge mapping to determine integrity of aging underground cable.

By **Matthieu Michel**, *EDF Energy*

THE DEVELOPMENT OF A ROBUST ON-LINE PARTIAL-DISCHARGE (PD) MONITORING TECHNIQUE HAS PROMPTED EDF ENERGY to perform routine on-line mapping tests on its underground medium-voltage (MV) cable network. EDF Energy is concurrently reviewing its long-term preventive-maintenance strategy, taking advantage of the increased functionality.

OUTLINING THE OBJECTIVES

EDF Energy, one of the largest energy companies in the United Kingdom, provides electricity to London, as well as eastern and southeastern England. EDF Energy's 11-kV and 6.6-kV (MV) underground cable network is 38,000 km (23,620 miles) long, with a total replacement cost estimated at £4 billion (US$7.7 billion). The financial and environmental costs of replacing all the older cables are prohibitive. Therefore, the utility is seeking to establish maintenance and replacement strategies that will avoid premature replacement and reduce unplanned outages.

The fault rate on the MV network is gradually increasing and, in the longer term, likely to accelerate. This trend conflicts with customer pressure and regulatory incentives to improve network performance and reduce operational costs. Hence, EDF Energy aims to develop a comprehensive suite of condition-monitoring tools to provide a reliable assessment of its cable network to optimize the investment of limited financial resources.

The utility's long-term objectives include improving system reliability, identifying high-risk network sections to objectively prioritize cable replacement and refurbishment, and developing systems and tools that would be suitable for other power-system assets as well.

Cables exhibiting a high level of PD have a greater risk of failure than cables with little or no PD activity. For the past 20 years, off-line PD measurement techniques have been used largely in a reactive capacity to detect potential future failures on cables with a history of poor-reliability performance. Off-line techniques are time consuming and require network outages, which present an operational risk.

On-line mapping techniques present no such issues, and

Fig. 1. The Portable Transponder and VLF testing equipment.

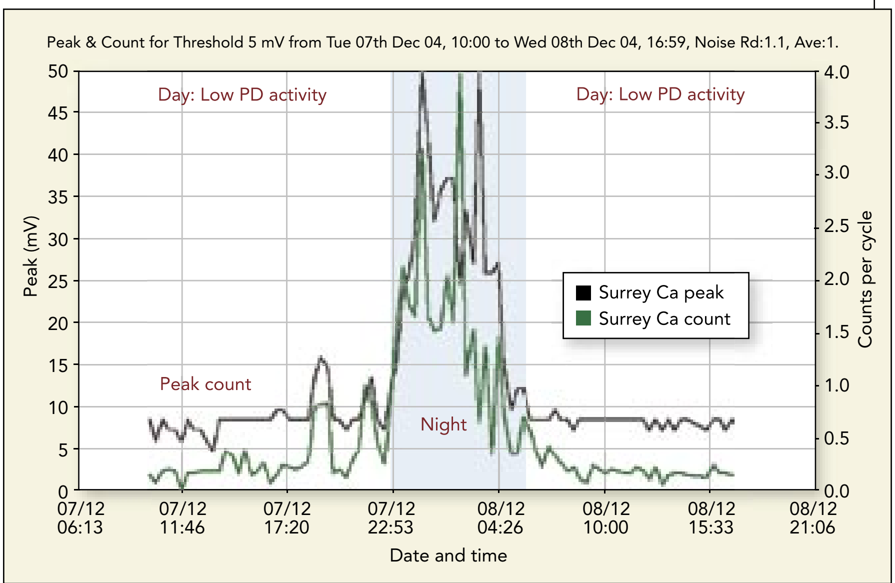

Fig. 2. On-line partial-discharge monitoring trend showing high partial-discharge activity during the night and low partial-discharge activity during the day.

On-line and off-line advantages and drawbacks.

On-line technique	Off-line technique
Advantages	**Advantages**
No need to isolate the circuit	Proven technology
Circuit loaded when tested	Better sensitivity
Economical	**Drawbacks**
Teed circuits can be tested	Circuit not loaded during testing
Drawbacks	Outage required
Data interpretation can be difficult	Expensive
Earthing Prerequisites	Teed circuits cannot be tested easily

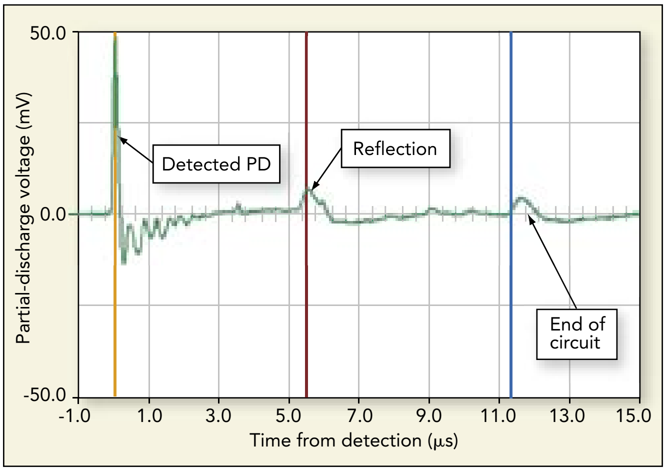

Fig. 3. Partial-discharge detected using off-line mapping equipment.

they provide a continuous monitoring capability. The on-line techniques that are now available have the potential to offer easy, cost-effective solutions and, importantly, to detect the onset of incipient failures on cables with a previously good reliability record.

MAPPING EQUIPMENT AND TECHNIQUES

More than 600 of the 11-kV feeders on the EDF Energy network are now monitored for PD on-line. In most cases, on-line monitoring data shows that there is an increase in PD activity for an extended period prior to cable failure. The utility also has observed that, immediately prior to cable failure, the level of PD activity can decline as voids cease discharging and start conducting.

The latest IT infrastructure enables the shape of the discharge pulses to be downloaded remotely and analyzed, and the classified results are displayed so that cables requiring further investigation can be quickly identified.

Very-low-frequency (VLF) testing is an example of an off-line mapping technique. VLF was developed some two decades ago and is in widespread use by utilities as a diagnostic tool. However, application is restricted to circuits without tee connections, and testing is limited to use on de-energized circuits.

On-line mapping techniques such as the Portable Transponder and GPS synchronization, which have been available for about three years, are now being accepted as the preferred method of mapping, because they are easier to use and more economical than the off-line alternative.

Both mapping techniques have their advantages and short comings as shown in the table.

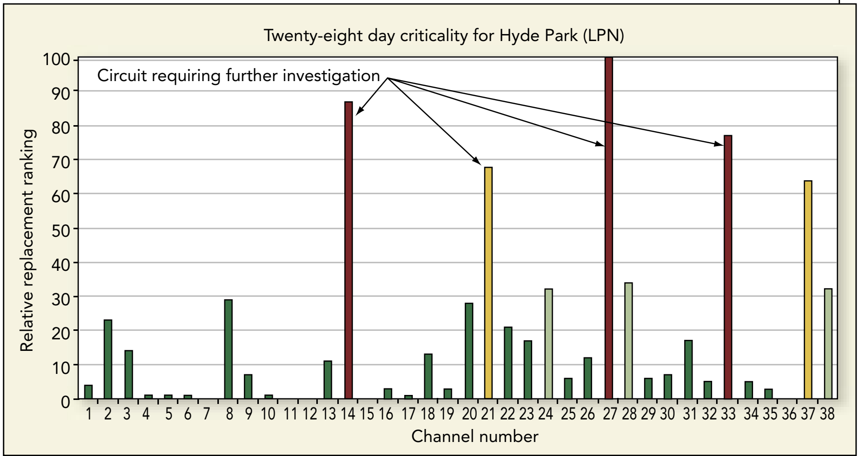

Fig. 4. Medium-voltage feeder criticality classification for a 38-panel substation.

ON-LINE PD MAPPING

When a PD event occurs, the pulse travels in both directions from the discharge point. In an ideal case, both the first pulse, or the direct pulse, and the second pulse, the pulse reflected from the far end of the cable, are measurable at the point of measurement.

If both pulses are identified, the position of PD is easy to locate by the time difference between the direct and reflected pulses. However, location by this simple analysis is often not possible because the reflected pulse is too small or subject to distortion caused by other reflections, noise and so forth. Under these circumstances, it is necessary to increase the amplitude of the second pulse in order to locate the PD position.

For example, the Portable Transponder, manufactured by IPEC Engineering Ltd. (Manchester, U.K.), is designed for PD location in the following situations:

- Attenuation that is too large, caused by excessive cable length
- Waveforms that are difficult to interpret
- Networks that include tees or joints
- Networks with multiple cable terminations.

The Transponder allows the signal from the remote end of the cable to be "amplified" and seen as a return pulse for the PD location system to use. The equipment is essentially a trigger system coupled to a large output-pulse generator. When the pulse is received, which exceeds the trigger level, the Transponder responds by sending a large pulse down the cable, effectively converting the single-ended location system into a double-ended location system. This feature provides an advantage over the single-ended system as the effective location distance is doubled.

The on-line detection of PDs and the use of boosted pulses are achieved by using a split-core high-frequency current transformer operating in the frequency range of 50 kHz to 20 MHz. OSM-Longshot Test units, also manufactured by IPEC Engineering Ltd., are connected on the cable earth (ground), at the cable end box or around the cable immediately after the cable earth.

ON-LINE TESTING STANDARDS

Because on-line mapping is still a relatively new technique, there are currently no standards or instructions for its application. However, EDF Energy has identified major factors that have contributed to its successful application of on-line mapping tests:

- On-line detection of PD pulses is difficult if there is no insulated earthing gland (ground tab) on the cable termination. On the EDF Energy net-

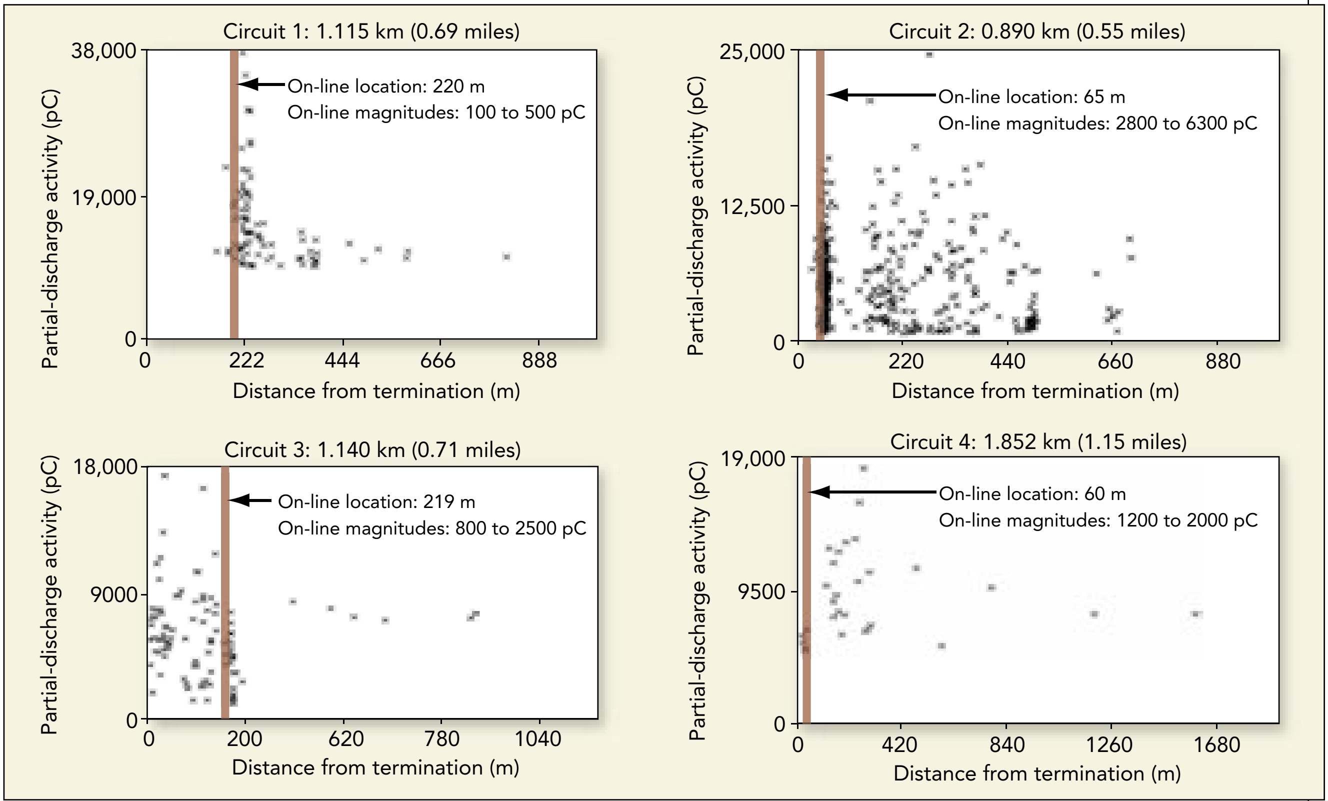

Fig. 5. On-line versus off-line cable partial-discharge mapping results.

works, some 70% of cable terminations are suitably insulated on the Southern Network, 60% on the London Network and only 5% on the Eastern Network.

- Field tests have proved that PD pulses propagate through the bus bars at the primary substation. Hence, they also will be seen on the phase and earth bar of adjacent MV panels, which means simple time-of-arrival timing checks must be made to identify the first pulse, to ensure the origin of the PDs.
- Continuous 24-hour monitoring has shown that PD activity can depend on the type of defect and the load pattern. As shown in Fig. 2, on-line mapping undertaken in the middle of the day would not reveal any problem here.

OFF-LINE PD MAPPING

Off-line PD mapping is undertaken on a de-energized section of cable using a discharge-free VLF power supply (usually 0.1 Hz, as this requires 1/500th of the power supply required by 50 Hz) with an adjustable voltage output.

Detection is achieved directly on the phases by a capacitive-coupling detection circuit, and the PD waveforms are recorded on a digital oscilloscope. The locations are determined using timings from the PD pulses, detected in the same way as the on-line PD mapping technique. Figure 3 shows a mapping waveform from an off-line PD mapping test.

COMPARING THE TECHNIQUES

To determine which mapping technique would work best for EDF Energy, the utility compared the on-line and off-line techniques. The circuits EDF Energy selected for the comparative tests were identified using the on-line analysis tool. Automatic analytical processes and knowledge rules classify circuits according to the PD magnitude and activity trend as shown in Fig. 4. The use of this automation process enabled a quick selection of several circuits to be subject to on-line and off-line mapping. However, due to limitations of the off-line equipment, only circuits without tee junctions were selected.

The comparison tests were conducted on four EDF Energy feeders with circuit lengths ranging from 1 km to 2 km (0.63 miles to 1.26 miles). The Fig. 5 graph reveals the results, identifying the location of the maximum PD activity. The off-line PD maps for each cable are marked by X's in the figure, which show that on each cable there is a wide variation in terms of the location and magnitude of maximum PD activity.

Although both the on-line and off-line mapping results indicated a similar location, the off-line results generally produced a greater spread of locations with higher PD magnitudes. There were two main reasons for this difference: First, during off-line testing, as the paper-insulated lead-covered (PILC) cable is not operating under normal conditions, voids that are normally filled with oil are discharging and, following re-energization, PD activity is seen to be higher. Second, the circuit is subject to more stress when tested off-line, as the test voltage is higher than the operating voltage.

More recently, EDF Energy applied the on-line mapping techniques to an 11-kV PILC cable 1 km in length, and the location that had the highest PD activity was determined with an accuracy of some 5 m (16 ft). To examine the extent of the damage, a 20-m (65-ft) section of cable was removed for laboratory examination. Carbon deposits were revealed on almost the entire section (Fig. 6). And, a degradation profile was de-

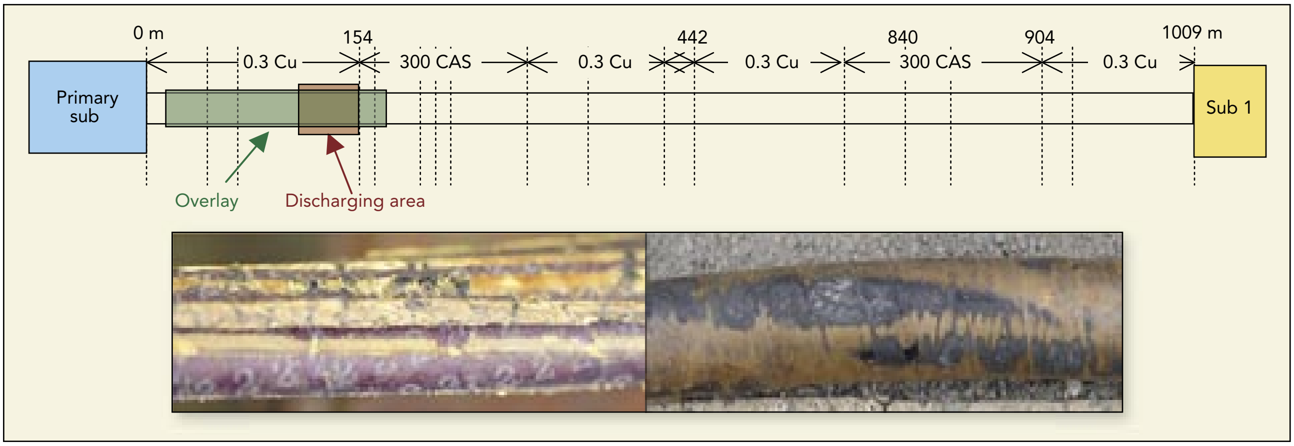

Fig. 6. Discharging section and insulation degradation from laboratory assessment.

veloped for the papers used to insulate the 11-kV cable, which had been laid in 1963. While there was substantial insulation deterioration, the cable was not judged to be in imminent danger of failure.

Based on the available evidence having identified a location of probable failure, a utility may choose to replace a cable section identified as showing PD activity. Nevertheless, as is common with many diagnostic-monitoring systems, interpretation of the measurements to predict the remaining fault free service life of the cable is a problem that still remains unsolved.

THE BEST OF BOTH TECHNIQUES

Worldwide interest in PD on-line mapping techniques and monitoring equipment is increasing as utilities seek to both improve system reliability and optimize capital expenditure by improving asset-management disciplines. Given the age and performance of EDF Energy's MV network, it is expected that the gradually increasing trend in PILC failures would continue unless an effective means for detecting incipient in-service failure is developed. EDF Energy believes that PD monitoring and mapping can provide an effective answer. After assessing the performance of both mapping techniques, EDF Energy has concluded that the best strategy is to use a combination of on-line and off-line techniques.

EDF Energy is now developing a long-term MV cable management strategy and, although research is still in progress, on-line techniques are expected to be included in the range of asset-management tools used by the utility to monitor the integrity of its MV cable networks. TDW

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