Fiber Optic Sensing Association
Connect and Protect

Utilizing Distributed Fiber Optic Sensing to Protect and Modernize the Electric Grid

This paper contains four sections outlining how distributed fiber optic sensing (DFOS) as a ‘smart grid’ technology can be used to add resiliency, reliability, and help modernize the electric grid in the United States. The first section explains the technology behind DFOS; the second section explains the resiliency, reliability, and physical security challenges facing the electric grid in the United States; the third section explains how DFOS can help solve these challenges; and the fourth section provides recommendations to generate awareness and education on the benefits of this technology to support smart grid modernization in the US.

Fiber optic sensing has been demonstrated to contribute to dynamic line rating (DLR) by enabling more precise real-time thermal rating in electric power transmission (RTTR). By enabling more precise real-time temperature monitoring, fiber optic sensing permits an increase in power transmission capability and reliability. Using fiber optic sensing can contribute to load maximization, without compromising safety, when environmental conditions permit it.[1]

I. What is Distributed Fiber Optic Sensing (DFOS)?

Distributed fiber optic sensing (DFOS) systems are sensor technologies used around the world to constantly and consistently monitor power stations, terrestrial and subsea power cables, international borders, critical infrastructure, telecom networks, railways, roads, bridges, and pipelines. DFOS systems connect interrogator units (IUs) to a fiber optic cable converting the optical fiber to an array of distributed sensors. The fiber becomes the sensor when the interrogator unit injects laser light into the fiber to detect events along the fiber over very long distances.

More specifically, DFOS systems consist of a fiber optic cable, IUs, and intelligent monitoring software. The IU pulses light 10,000 times/second down the fiber optic cable. Changes in vibrations/acoustics, temperature, or strain at or near the fiber optic cable are identified and classified in real time by intelligent monitoring software, which then alerts the operator of the system to what the disturbance is and precisely where it is located. These technologies can span hundreds of miles and provide real-time readings at roughly three-foot (one-meter) intervals along the entire span.

There are three basic types of DFOS systems:

1. Distributed Acoustic Sensing (DAS)
   DAS systems turn fiber optic cables into a series of thousands of sensitive microphones or vibration sensing devices. Using specially developed algorithms

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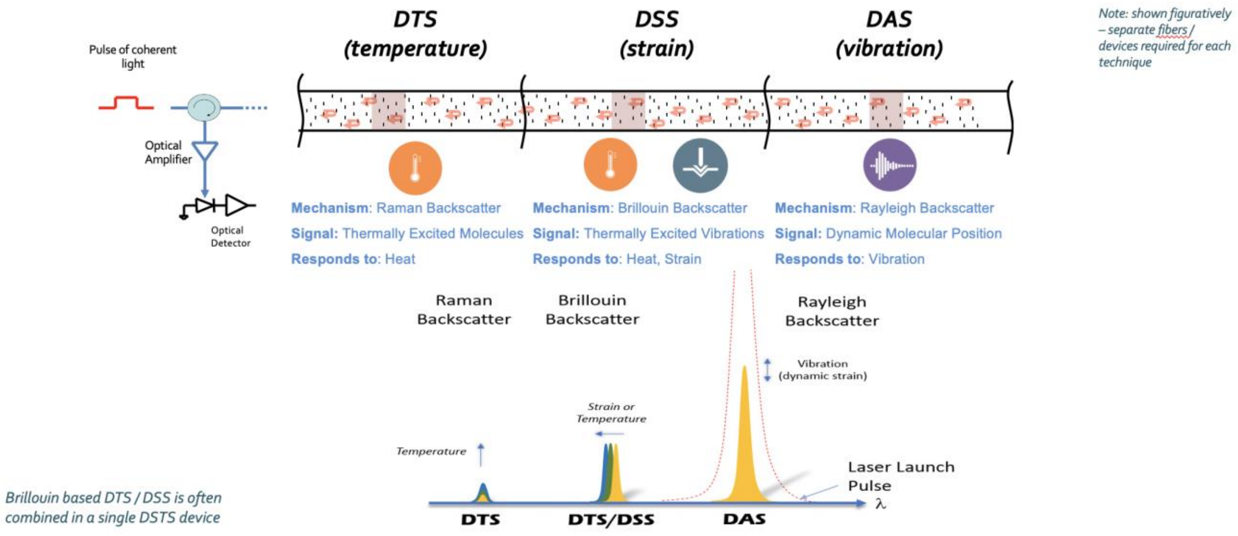
[1] For more information, see: *Distributed Fiber Optic Sensing and Dynamic Rating of Power Cables*, Sudhakar Cherukupalli, George J. Anders; ISBN: 978-1-119-48770-8 October 2019 Wiley-IEEE Press

it is possible to listen to, track, detect, and pinpoint various activities and events along assets, including vehicle and foot traffic, digging, excavation, tunneling, seismic activity, rock falls, anchoring of ships and landslides. It can also be used for asset condition monitoring by detecting events such as cable faults, cable sag/strain, pipeline liquid and gas leaks, broken rails, damaged rolling stock, and much more.

2. Distributed Temperature Sensing (DTS)
   DTS is a fiber-optic sensing technology for measuring temperature profiles along fiber-optic sensor cables installed near linear assets as well as on two- or three-dimensional objects. Major applications of DTS are power cable and overhead line temperature monitoring; fire detection in fuel storage facilities, tunnels and buildings; monitoring of industrial equipment such as ovens and reactors and oil and gas in-well production, as well as leak detection in pipelines and storage tanks.
3. Distributed Strain Sensing (DSS)
   DSS is a fiber optic sensing technology that measures changes in strain at any point along the length of a fiber optic cable. DSS is commonly used for monitoring large structures, where changes in strain may be indicative of an impending failure. Aging and modern infrastructure like power cables, pipelines, dams, levees, bridges, tunnels, and roadways are all assets that can benefit from DSS monitoring. Similarly, industrial process monitoring, as well as pipeline deformations, tunneling, subsidence and landslides can be detected by DSS measurements.



Note: shown figuratively – separate fibers / devices required for each technique

Brillouin based DTS / DSS is often combined in a single DSTS device

The technology is not constrained by line of sight or remote power access, and can be deployed in continuous lengths over hundreds of miles with detection at every point along its path. Electricity is only required to power the interrogator equipment while the fiber optic cable installed along the asset to be monitored is completely passive, requiring no electricity and immune to the effects of radio frequency and electromagnetic interference. The technology can even use existing dark telecommunication fibers. Oftentimes and preferably, the fiber cable used is located within conduit pathways which enable rapid and easy repairs to the fiber cable if required, in addition to possibly desired future fiber cable additions or replacement.

II. Electric Grid Reliability, Resiliency and Physical Security Challenges in the United States

The U.S. power grid is a 19th century system operating under the stresses of a 21st century climate and is experiencing more blackouts and brownouts every year. The electric grid is comprised of more than 240,000 miles of high-voltage transmission lines operating at 230 kilovolts and greater, over 1.1 million megawatts of generating capability, and nearly 3,500 utility organizations serving over 334 million people whose total electricity demand exceeds 830 gigawatts (830,000 megawatts). The first electricity systems were independent of each other, serving local communities or regions, but as demand increased and systems grew, the systems interconnected.

Aging Equipment

Most of the country’s power transmission and distribution network is old and well past its intended life cycle. The grid is unable to keep up with the increasing demand for more electricity. The high-voltage transmission lines and substations of the distribution network are not designed to handle the growing power load. The power plants supplying energy to the grid are also old. Coal plants, hydroelectric power plants, and nuclear power plants are well past their prime by the time they are retired.

Substations and transmission lines of the U.S. electric grid are already laboring at peak capacity. In the case of a failure, the electrical power gets diverted through these overworked parts. Whenever equipment exceeds its rated capacity, it gives off extra heat. The longer it runs past its limit, the hotter it gets. Overheated as well as overloaded, these cables eventually fail. Every new failure forces the power grid to place heavier loads on the remaining functional substations and transmission lines. The result of the domino effect is cascading power failures across large swaths of the country.

Extreme Weather

In 2012, Superstorm Sandy cut power to over a million Con Edison customers in New York. In 2017, Hurricane Maria laid waste to Puerto Rico’s power grid, causing the largest blackout in U.S. history. Six months after the storm, more than 100,000 Puerto Ricans were still without electricity. Recently, strong winds in California led Pacific Gas and Electric Company (PG&E) to cut power to nearly 500,000 customers in 38 counties as a precaution during red-flag fire condition weather. The electrical impacts of a major earthquake or tsunami also can be catastrophic.

Since 2000, there has been a 67% increase in major power outages from weather-related events. Extreme weather events are causing frequent damage to our aging electric grid, costing Americans and the economy tens of billions of dollars each year and impacting public health (i.e. loss of electricity at health care facilities and stalled sewage treatment plants forcing the release of raw sewage into waterways). The aging U.S. power grid was not built to withstand more frequent and more intense weather.

Increased Demand

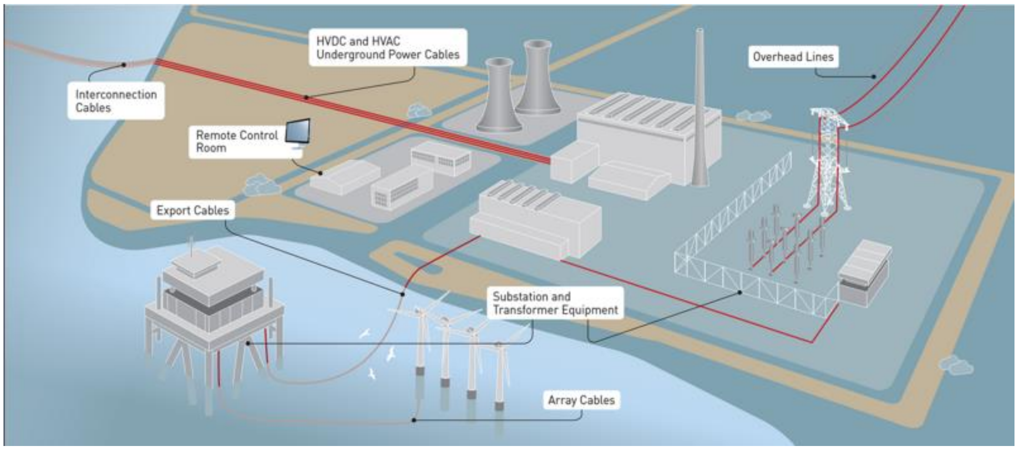
In the 21st century we increasingly depend on energy-consuming technologies in a connected world that streams vast amounts of data almost instantaneously. The number of electric vehicles (EVs) on U.S. roads is also increasing. The number of EVs in the U.S. is projected to reach 26.4 million in 2030, up from 8.7 million projected in the 2018 report. Weather is also a primary driver of year-to-year fluctuations in electricity demand – hotter summers and colder winters lead to increased demand.

Increased Reliance on Renewable Energy

While fossil fuels (coal, oil and natural gas) still dominate, solar and wind use has grown at a rapid rate over the past decade (but still accounts for less than 4% of all energy used in the U.S.). One grid problem created by renewables is that solar panels and wind turbines are often located far from where retired coal and nuclear plants were sited. Conventional power plants were generally fairly close to load centers; whereas, renewable generation could be spread out or built in wide-open spaces far from urban areas. Renewable generation also fluctuates much more than conventional generation. This increased transmission distance and fluctuation can thermally strain the cables feeding the grid.

Subsea Cable Challenges

The environment poses many natural and man-made risks, among which are: scour resulting in the exposure of the buried cables, changes in the seabed morphology and environment (e.g.: underwater seismic activity and rising sea levels), tidal currents that redistribute sediment and migrating sand waves, currents that can wash off the cable's protective covering, and dropped objects, dragged anchors, and fishing tackle. The challenge for operators is to know when their cables are compromised before they fail. In the case of submerged cable failures, power production from entire wind farms can be lost, causing costly, time-consuming repairs. It is therefore essential to localize defects precisely to enable predictive maintenance and avoid catastrophic failure.



Intentional Physical Attacks and Unintentional Intrusions
On April 16, 2013, PG&E's Metcalf Substation sustained millions of dollars in damages from a gunshot attack that destroyed several transformer oil tanks at the facility. And on September 25, 2016, an unknown gunman with a high-powered rifle knocked out the Garkane Energy Cooperative Inc.'s Buckskin substation in rural south-central Utah cutting off electricity to 13,000 customers. Buried cables are at risk of excavation activities by third parties who are not aware of the exact position of all the cables. Few substations, outside of those subject to FERC CIP-014 compliance, have cameras, intrusion detection, or robust perimeter security. Cables are mostly not under surveillance. Situational awareness at most transmission and distribution substations is severely lacking. Electric utilities in North American are not prepared for a planned and coordinated attack against their infrastructure.

III. How Can DFOS Help Solve These Challenges?

DFOS' "distributed" nature ideally complements the physical aspects of long-length power transmission cables, overhead lines and lengthy perimeters associated with power generation, substations, and controls facilities. All three DFOS technologies can be used to permanently monitor and protect electric grid infrastructure in a cost-effective manner.

The temperature of a power cable reveals much about its condition. By monitoring the line temperatures closely, capacities can be increased, preventing curtailments. Distributed Temperature Sensing (DTS) provides continuous monitoring of high-power cable temperatures, detecting hotspots before they become an issue (e.g. 2018 Camp Fire), delivering operational status, condition assessment and power circuit rating data. DTS in combination with real-time thermal rating (RTTR) can even be used to enable a safe transient extra load at cables without exceeding temperature limits and to plan future load scenarios based on the actual thermal state of a cable system. DTS data are also useful to analyze the depth of burial of submarine cables by looking at the thermal response to load variations.

Distributed Acoustic Sensing (DAS) provides accurate cable fault detection and location as well as protection of electric grid infrastructure from third-party interference on land (excavation, digging and drilling) and subsea (anchor drops and drags). Power and communications services for DAS systems are needed only every 50 to 65 miles (~80-100 km). These systems can be concatenated to cover spans hundreds and thousands of miles if necessary.

Distributed Strain Sensing (DSS) adds the capability to monitor the earth surrounding or supporting buried electric transmission cables to alert when conditions of ground disruption occur. It is also well suited to monitor cable strain during cable production, installation, and operation. Additionally, in operation, DSS is ideally suited to detecting cable sag/strain due to over-heating in warm climates and ice-loads in winter. With ice loads, increases in electric transmission can be used to elevate cable temperatures as mitigation for ice loading.

IV. FOSA Recommendations

FOSA supports funding for the modernization of electric grid infrastructure to make the grid more reliable, resilient and secure. Specifically, FOSA requests the following:

- Introduction, consideration and passage of legislation to spur investment in middle-mile broadband build-out while also enhancing the resilience, diversity and security of our electric grid. Include language that incentivizes monitoring of threats to the electric grid, including with respect to purposeful physical attacks, extreme weather impacts, and wildfire detection and enhances the ability to sense and monitor power characteristics, such as temperature or acoustic monitoring of the conductor, in near-real time in order to optimize grid operations.
- DOE prioritization of DFOS-enabled projects in the Grid Resilience and Innovation Partnership (GRIP) Programs as well as the Transmission Facilitation Program.
- Policymakers should encourage voluntary industry standards organizations groups such as IEEE and CIGRE, to update appropriate standards for DLR to reflect fiber optic sensing capabilities that can monitor the entire perimeter of substations; complement common pan, tilt and zoom (PTZ) video surveillance systems through integration; and provide real-time, 24/7 alerts and alarms should substations be “cased” prior to the attack, offering the advantage of predictive and preventative tools for electricity operators. As a model, FOSA and its member companies have previously worked with the oil and gas pipeline industry through the American Petroleum Institute’s recommended practices process to update leak detection standards to more fully reflect the technology contributions that fiber optic sensing can make.

About the Fiber Optic Sensing Association (FOSA)

The Fiber Optic Sensing Association (FOSA) is a non-profit organization composed of organizations that manufacture, install, test, evaluate, support or use fiber optic sensing systems and equipment. FOSA’s mission is to educate industry, government, and the public on the benefits of fiber optic sensing and how it can be used to secure critical facilities, enhance public safety, and protect the environment.