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Innovative Optical Fiber-based Monitoring of Overhead Power Transmission Lines

A. MOTIL[1], E. ROWEN[1], E. INBAR[1], A. ETTLINGER[2], C. XU[2], M. FUCHS[2]
Prisma Photonics[1], New York Power Authority[2]
Israel[1], USA[2]

SUMMARY

Monitoring a long-spanning transmission grid accurately and at a reasonable cost is a challenge. Various types of solutions and sensors exist for monitoring electrical phenomena and mechanical manipulation of the grid. However, these are point and discrete solutions and require costly, difficult deployment and maintenance.

Prisma Photonics' Hyper-Scan™ technology transforms the preexisting optical fibers within Optical Ground Wires (OPGW) cables into a distributed sensor that can monitor hundreds and thousands of kilometers of overhead power transmission lines [1,2]. Connecting to an optical fiber at a substation or a monitor room along the infrastructure every 100km or so turns the fiber's entire length into an ultra-sensitive array of sensors. It is a monitoring solution that is always there, at the right time, and in the right place. Tower tampering, vandalism, theft attempts, cable faults, insulator damages, corona, and partial discharges – all can be monitored, assessed, and alerted if necessary. Extreme environmental conditions can also trigger an alert – wildfires, extreme winds, lightning strikes, and even breaks in the cables that can be pinpointed to an exact location.

Apart from alerting to abnormal scenarios, such a monitoring solution collecting data on overhead power transmission lines 24/7 can generate invaluable operations insights and statistics. It opens new abilities to tie environmental information with the grid behavior, optimize maintenance operations (e.g., wash insulators on towers where Corona levels are high), and supports grid build-up.

Prisma Photonics and the New York Power Authority (NYPA) have jointly demonstrated such a monitoring solution. NYPA operates one-third of the major transmission lines in New York State. NYPA's 1,400 miles of transmission lines carry power from generation sources to substation distribution centers.

The PrismaPower™ system was deployed, connecting to a single dark optical fiber, out of the many fibers of the existing OPGW, to monitor a 35-mile section, part of the 345 kV transmission grid. During the operation period, vandalism acts, such as tower hits (as light as

eran@prismaphotonics.com

hand strikes), climbing, and tampering, were detected and localized to the exact tower location in real-time. Helicopter activity above the overhead lines was monitored, as well as other planned maintenance events.

In addition, electrical anomalies were detected, mainly high corona levels, which shows the importance of receiving informative insights on the electrical status of the monitored grid. Pinpointing phenomenon to an exact tower location makes operations far easier to handle. We expect to identify more correlation between electrical phenomena to weather conditions, pollution and other time-of-year related aspects such different air temperature, humidity, etc. We aim to continue developing the relevant models to sense and classify these events.

KEYWORDS

INTRODUCTION

The area of distributed fiber-optic sensing for monitoring power lines was overlooked in recent years. Partial applications are available, mainly for temperature sensing in underground lines and the use of the fiber as a communications channel to point sensors.

Prisma Photonics innovative technology is based on detecting and interpreting backscattered fragments of a light pulse propagating along an optical fiber. The information is then translated to acoustic signals, turning the optical fiber's whole length into an ultra-sensitive sensor.

Optical fibers were placed along with electrical infrastructure for many years, using the right of way, piggybacking the deployment effort, and allowing utility operators to sell bandwidth. Using fiber-sensing is a cost-effective solution for powerline monitoring, especially when installed on infrastructure with pre-deployed optical fiber communication networks – underground, overhead, and subsea. It has a relatively short ramp-up time and can cover long assets, in a distributed manner, with a few optical interrogator units.

While some fiber sensing applications can be found in underground and buried utilities, it has not been used to monitor overhead, hanging powerlines due to the existing technology's inherent limitations. Poor sensitivity and a very low signal-to-noise ratio completely prevented the translation of data gathered via OPGW cables into actionable information.

Prisma Photonics' Hyper-Scan™ technology is the only fiber sensing technology that overcomes these limitations and transforms the pre-existing optical fiber cables within Optical Ground Wires (OPGW) into an informative distributed sensor that can monitor hundreds and thousands of kilometers of overhead power transmission lines.

In the 2020-2021 winter, The New York Power Authority (NYPA) and Prisma Photonics jointly demonstrated such a monitoring solution. NYPA operates one-third of the major transmission lines in New York State. NYPA's 1,400 miles of transmission lines carry power from generation sources to substation distribution centers.

A 35-mile (56 km) section of NYPA's 345 kV transmission grid was connected to PrismaPower™, Prisma Photonics' powerline monitoring system. Over the course of the following weeks, planned testing and unplanned events were detected and classified. Hits to towers and climbing were identified as well as a helicopter hovering above the lines. While monitoring the electrical performance, some anomalies were discovered further away from the monitoring system. All these were detected from a substation without any need for manual inspection or deploying line workers.

It is a monitoring solution that is always there, at the right time, and in the right place. There is no need for point sensing solutions, manual inspection, or UAV, and very long parts of the grid can be monitored 24/7 at any weather conditions, alerting for abnormal events in real-time.

THE TECHNOLOGY

Distributed fiber optic sensing is a powerful technology to measure and monitor different activities along the entire length of the optical fiber. It relies on a physical phenomenon called Rayleigh-backscattering, where a fraction of the light traveling through an optical fiber is reflected back due to the fiber material (Silica) microscopic imperfections along its length. A sensitive interrogator unit transmits laser pulses into the optical fiber and then translates the back reflected light into acoustic information. The information later needs to be classified into actual events affecting the fiber and the infrastructure it is coupled with. It is a passive solution that does not require any amplification or external power source along the monitored grid.

Fiber sensing has been deployed for many years to monitor buried infrastructure such as oil & gas pipelines and perimeter control. The reason fiber-sensing is not a prevalent sensing solution for powerlines is the complex environment powerlines operate in. Sensing relies on the mechanical vibrations, thermal energy, and acoustic signals which affect the fiber. In underground and subsea scenarios, the fiber is deployed near the power cables, so these share the same stimuli. When deployed overhead, as part of the optical ground wire (OPGW), there are many different stimuli (winds, environmental noises, weather conditions, etc.) that make sensing far too difficult. The signal-to-noise (SNR) ratio in such deployments is relatively low, making it harder to isolate and identify events.

Prisma Photonics' Hyper-Scan™ technology completely overcomes these difficulties. PrismaPower™, the powerline monitoring solution, transforms the pre-existing optical fibers within Optical Ground Wires (OPGW) into a distributed sensor that can monitor hundreds and thousands of kilometers of overhead power transmission lines. The Hyper-Scan™ technology allows for far better sensitivity and detailed data that carries enough information to be translated into real-world events and actions.

The information, often depicted in a waterfall type plot, is fed into a machine-learning-based algorithm to classify anomalies [3]. PrismaPower™'s algorithms can classify events such as tower tampering, vandalism, theft attempts, cable faults, insulator damages, corona discharges, and partial discharges – all can be monitored, assessed, and alerted if necessary. The smart classification algorithms can also detect and trigger an alert in case of extreme environmental conditions. Wildfires such as those seen in recent years in California can be identified early on. Extreme winds, lightning strikes, and even breaks in the cables can be pinpointed to an exact location.

A PrismaPower™ interrogator unit connects to an optical fiber at a substation or a monitor room placed along the powerlines. Each unit covers about 62-mile (100km) or so of powerlines, transforming the entire length of the fiber into an ultra-sensitive array of sensors (see Figure 1)
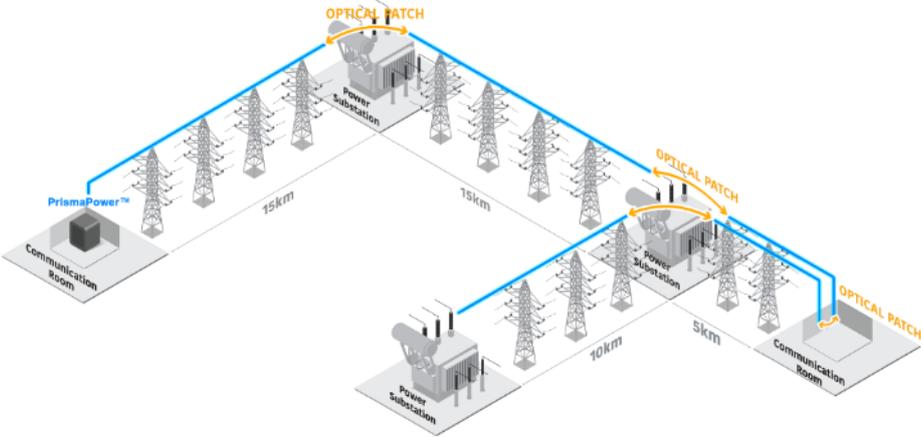

Figure 1 - Connection Schematic

PrismaPower™ monitors the grid 24/7. This data can be used for intelligence and operation efficiency goals apart from alerting to abnormal scenarios. Invaluable operations insights and statistics are there in the data. It opens new abilities to tie environmental information with the grid behavior, optimize maintenance operations (e.g., wash insulators on demand) and help define future grid buildup and operative decisions.

DEPLOYING FIBER SENSING ON NYPA'S GRID

NYPA's cooperation with Prisma Photonics started by allocating a part of NYPA's grid to demonstrate and learn what can be achieved with PrismaPower™. A 35-mile (56 km) part of the 345 kV transmission grid near Albany, NY, was selected for the initial deployment. A single dark fiber was

used out of the many fibers that exist in the OPGW. After a few hours of deployment in a substation, the allotted 35-mile (56km) line was visible.

Initial testing conducted, starting with hits directly on transmission towers, simulating a vandalism act. As shown in Figure 2, a team went through the area, hitting pylons with a hammer.


Figure 2 - Power tower vandalism simulated

Those hits were detected immediately, in real-time in PrismaPower™, located in a substation far away. The depiction of the impact in a waterfall plot shows the energy-waves emanating from a specific tower location. While the energy waves traveling through the tower to the OPGW above show a busy and detailed pattern, the rest of the neighboring towers are not affected and show a less fragmented pattern. Several types of towers and poles were tested for tampering, each showing on the monitoring with distinct patterns (see Figure 3)
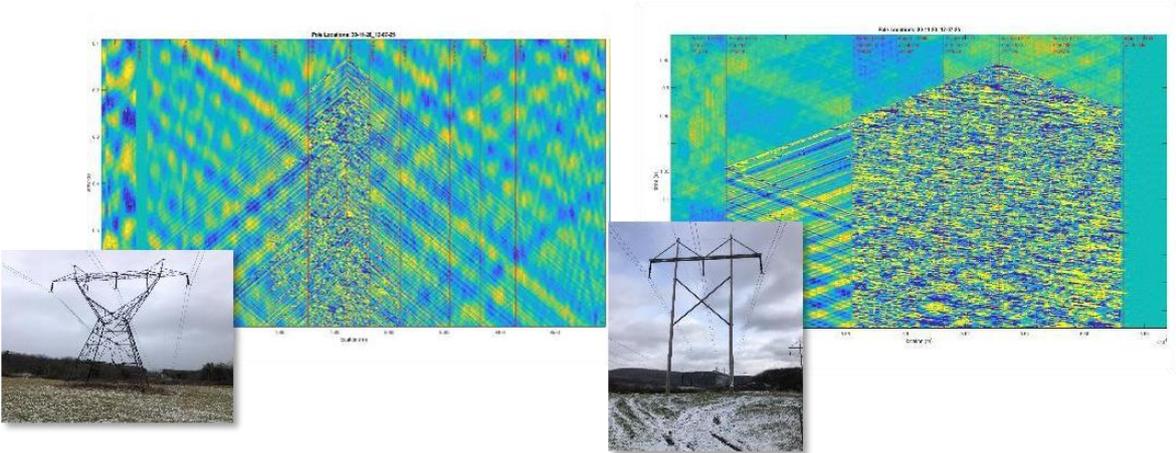

Figure 3 - Hits on towers, as seen in an acoustic waterfall

Later, operating on that same grid section, PrismaPower™ detected unplanned tampering on a specific tower, 30 miles (48km) away from the substation – a hit, planned maintenance, or as it happens in these areas, shots fired by hunters on a pole.
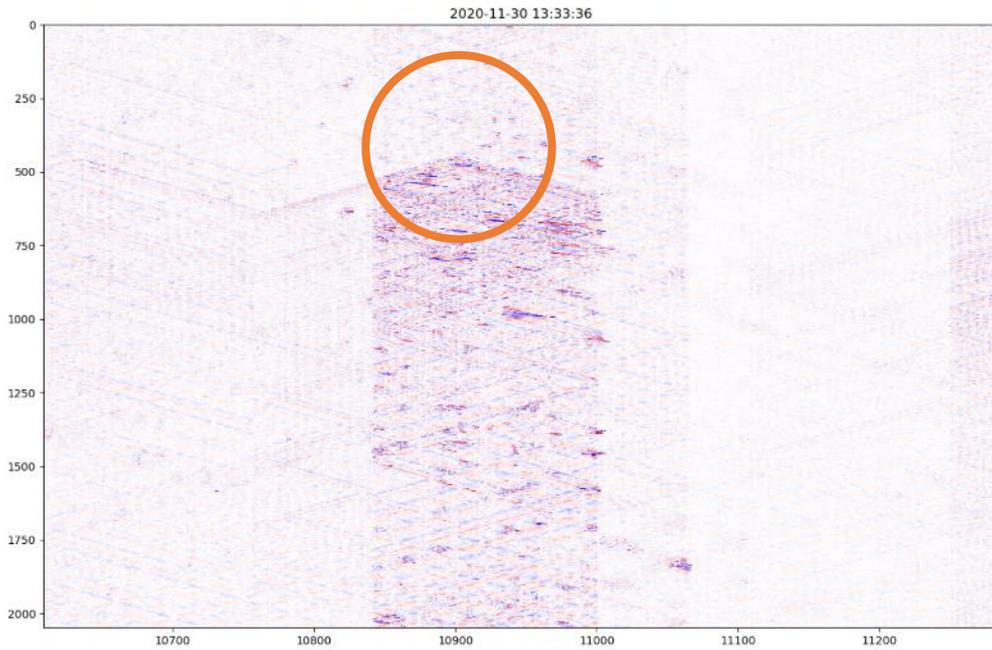
Figure 4 - Unplanned tower tampering

Sawing activities were recorded as well. These might happen in metal theft scenarios where bits and pieces of a tower are taken (leading to tower structural weaknesses). The waterfall representation showed wiggles on the OPGW (marked with arrows in Figure 5)
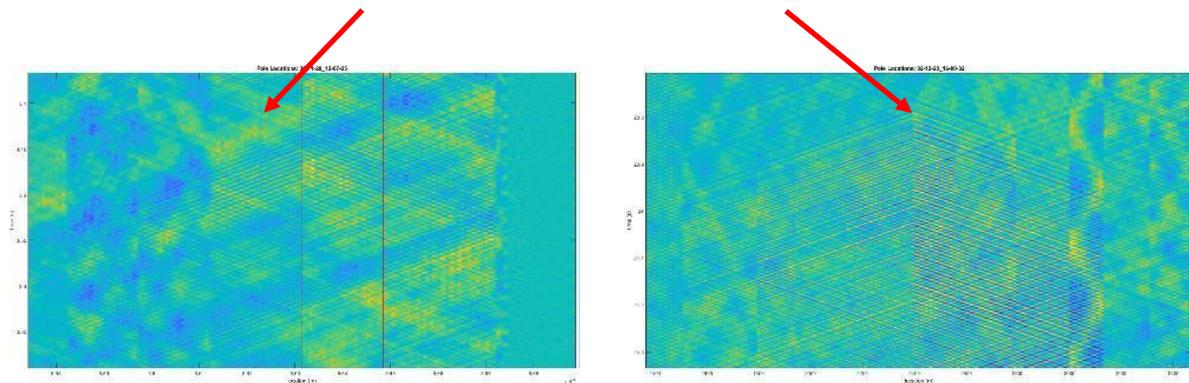

Figure 5 - Metal sawing scenario

Planned maintenance activities were captured as well. These included climbing several tower types and an inspection helicopter flying close to the lines (as shown in dddd where the doppler waves of the rotors are shown in the waterfall diagram). PrismaPower™ had detected these activities with an accurate location.
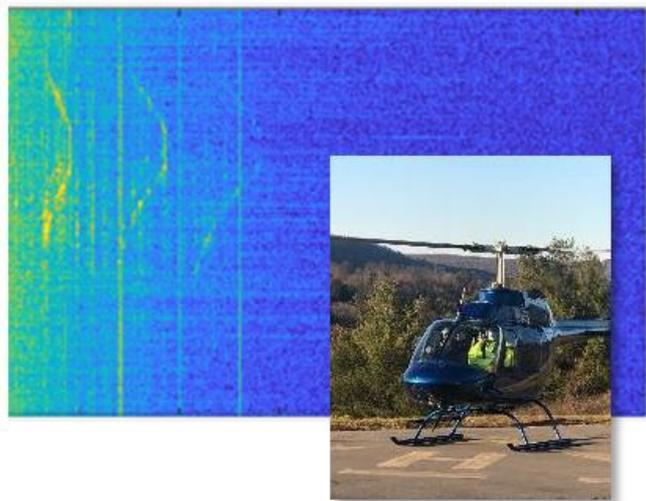
Figure 6 - Inspection helicopter detection

In terms of electrical phenomena detection, possible corona discharges were recorded at specific locations along the monitored grid (see **Figure 7**). As partial discharge, pollution, and similar scenarios cannot be simulated, further investigation will have to occur during the spring and summer seasons to find and classify electrical anomalies.
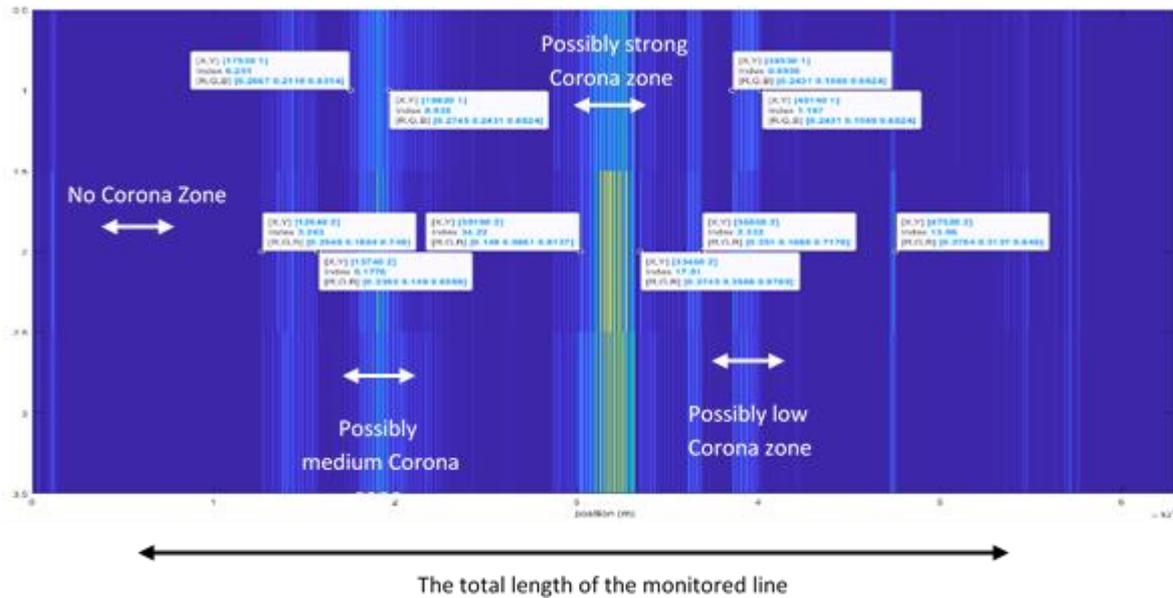
Figure 7 - Electrical phenomena detected along the line

CONCLUSION AND NEXT STEPS

Prisma Photonics and NYPA have demonstrated that the OPGW can be used for Fiber Sensing to monitor the overhead transmission line in real-time. The 35-mile (56km) section of NYPA's grid was monitored 24/7, and many types of mechanical tampering with transmission towers and cables were detected. This comes to prove PrismaPower™'s high signal-to-noise ratio, which enables superior detection sensitivity.

Future plans include identifying more electrical phenomena and its correlation to time-of-year weather conditions (e.g., winter air temperature, winds and humidity differs from summer conditions). Relevant models will continue to be developed to sense and classify these events.

The project ties in with NYPA's new VISION2030 strategy [4], which prioritizes the management of long-running assets, focuses on the transmission portfolio needs, and positions the state utility as an innovative leader in power transmission in the state of New York.

Prisma Photonics wants to thank our partners at NYPA for the opportunity and look forward to making PrimsaPower™ Hyper-Scan™ abilities prevalent in power transmission line operations.

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