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Long-Term Monitoring of Local Stress Changes in 67 km of Installed OPGW Cable Using BOTDA

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SUMMARY

The initial results from continuous long-term monitoring of a 67 km length of an aerial fiber optic cable installed on a high voltage power line using a BOTDA are presented. The fiber cable used was an Optical Ground Wire (OPGW), designed to protect the power line from lightning effects and dissipate ground currents. As the highest conductor, the OPGW is susceptible to environmental effects. OPGW composition can lead to different fiber strain properties and this is demonstrated. The effects of thunderstorms and rime ice on the cable were identified by monitoring strain on OPGW fibers. Variations of strain between day and night on the OPGW cable were observed and can potentially be exploited. The use of DSTS technology opens the possibility to explore a tertiary role for OPGW fiber (aside from its primary role as a lightning protector and secondary role as a communication medium). OPGW can be seen in this context as a distributed, highly sensitive, strain and temperature sensor.

KEYWORDS

Distributed Strain and Temperature Sensing (DSTS), Brillouin Optical Time Domain Reflectometry (BOTDR), Strain, Optical Ground Wire (OPGW)

DISCLAIMER

In participating in this study, in writing of this paper and any subsequent technical work thereof, Hydro One Networks Inc., does not in any way endorse any product manufacturer or technology.

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1. Introduction

There has been interest in the use of Brillouin Optical Time Domain Analyzer (BOTDA) technology on fiber transmission media as a sensor to remotely measure both strain and temperature. A BOTDA is a system that uses frequency shifts due to Brillouin scattering of light at sample points. Analysis of reflected light for Brillouin frequency shift vs. optical pulse return time provides insight to physical properties such as temperature and strain at any location on the fiber. Distributed Strain and Temperature Sensing (DSTS) systems using BOTDA methods are an emerging technology with existing applications in monitoring of civil structures (e.g. bridges and tall buildings) and infrastructure (e.g. gas and oil pipelines). Application of this technology to overhead and underground fiber infrastructure is presently at its conception. A potential real-time monitoring application using Optical Ground Wire (OPGW) has been investigated here. OPGW cables, by the nature of their aerial installation, are subject to wind, ice buildup and temperature fluctuations. The ability to monitor the strain (absolute or relative) experienced by individual fibers (helically wound inside) over the entire length of the cable (67 km) and measure strain at short (10 m) intervals is valuable. If applied correctly, DSTS can provide enhanced capability to measure the dynamic response of OPGW fibers to environmental elements such as wind, temperature and ice, beyond what a typical OTDR can do. Additionally, DSTS can provide evidence of transverse loads on fiber at locations where marginal or incorrect attachment hardware are installed and the OPGW central core circularity may be compromised to the point of straining the fibers.

1.1 Optical Ground Wire (OPGW) Composition

Optical Ground Wire (OPGW) has been used in place of shield wire (or ground wire which is the highest conductor on the tower) on high voltage transmission lines since the early 1980's. The wide bandwidth and immunity from electromagnetic induction makes optical fibers (inside OPGW) an attractive choice for utility telecommunication needs. With some exceptions, almost all OPGW cables are grounded at every tower. The basic function of the cable is to provide lightning protection for the transmission line as well as to help dissipate fault currents which may be experienced by the components of the power system. The fiber optic strands inside OPGW are used for both power system protection and for commercial applications where bandwidth or dark fiber capacity is sold to commercial telecom operators.

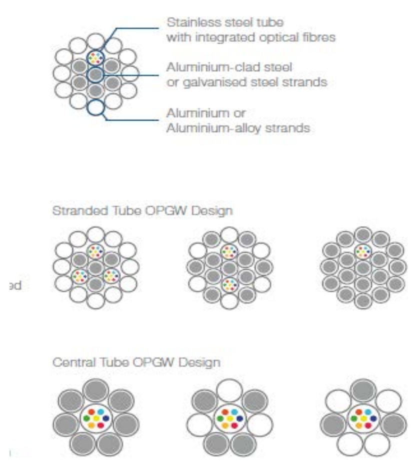

Figure 1: Typical OPGW cross-section (Source: NKT Cable OPGW)

Although OPGW cable comes in different compositions, in its most basic form the cable consists of a central aluminum core where fiber optics is located in bundles, wrapped by steel-reinforced aluminum strands. Although most manufactured cable today is not buffered, there are thousands of kilometers of tight-buffered cable (fibers are placed inside a tight plastic buffer and then in the core) already installed. Some older cables use a hexagonal aluminum spacer inside the core. A different construction of cable is called stranded tube design and is used for higher count OPGW (96 fiber or higher) cables. In this design, fibers are placed inside one of the strands which are wrapped around an aluminum-clad steel core. Each construction has its own set of advantages and disadvantages.

1.2 Distributed Strain and Temperature Sensing (DSTS) using BOTDA

DSTS uses a Brillouin sensor to measure strain vs. distance. Brillouin sensors measure Brillouin frequency shifts. Strain, temperature, or both strain and temperature are calculated as shown in equations (1) and (2) [1, 2].

$$\nu_B(T_0, \varepsilon) = C_\varepsilon(\varepsilon - \varepsilon_0) + \nu_{B0}(T_0, \varepsilon_0) \tag{1}$$

$$\nu_B(T, \varepsilon_0) = C_T(T - T_0) + \nu_{B0}(T_0, \varepsilon_0) \tag{2}$$

where C_ε and C_T are the strain and temperature coefficients, and ε_0 and T_0 are the strain and temperature corresponding to a reference Brillouin frequency ν_{B0}. From Eqs. (1) or (2), it is clear that Brillouin frequency shift is function of both strain and temperature. To get the strain value, the temperature value must be known and compensated.

Based on the measurements on fibers in the laboratory, the values of C_ε and C_T can be determined for both ITU G.652 (SMF-28) and ITU G.653 (DSF) fiber. For ITU G.652 (SMF-28), C_ε is measured to be 0.0529 MHz/με and C_T is measured to be 1.0241 MHz/degree C. For G.653 (DSF), C_ε = 0.0524 MHz/με and C_T = 1.0687 MHz/degree C, which is slightly different from the values in Reference [3].

There are two methods of measuring Brillouin Scattering. In a BOTDA, a probe light is attached to one end of the fiber and a pump is attached to the other end [4]. Loop back of the fiber at far-end achieves same result. The probe light is amplified by the pump light - travelling in the opposite direction - through Brillouin scattering. Distributed strain is measured along fiber length by analysis of the probe light in the time domain [4]. In a BOTDR, a pulsed light is launched at one end of the fiber and the Brillouin backscattered light generated by the pulsed light travels back and is analyzed using the principle of optical time domain reflectometry (OTDR). Similar to the OTDR, the width of the pulse in the BOTDR case determines the spatial resolution [4]. The strain resolution of BOTDR/BOTDA can be as fine as ±0.003%. Spatial resolution can be as low as 1 m in a long segment (tens of kilometers) of fiber. BOTDR combined with a fiber Bragg grating can have an accuracy of ±0.001 % with a spatial resolution as low as 1 cm [4].

Brillouin frequency shift associated with strain changes along a length of a cable need to be compensated for the ambient temperature. There are different methods of accomplishing this compensation. In the first method, the fiber (cable) temperature is measured in a controlled environment and is used for compensation. In the second method, the temperature is measured using a Raman OTDR, and the data is used to compensate the Brillouin sensor data [5]. A Raman OTDR, however, works on multimode fiber, hence additional fibers are required to be strung alongside the strained fiber, making this method highly impractical in the field. In the case of OPGW with a tight-buffer, measurement of the cable temperature doesn't give an accurate reading of the individual fiber temperature. The cable is designed to withstand high temperatures associated with lightning and/or high fault currents without raising the temperature of the optical unit significantly.

Temperature compensation of the measured data was carried out throughout the one-year monitoring experiment. Although these can be considered as sources of error, the overall effect is small.

2. Experimental Setup

The OPGW cable is installed in the Eastern Ontario, Canada. The cable distance between two stations (Station "A" in Ottawa and the other referred to here as Station "B") is 67 km, as shown in Figure 2. Starting from Station "A" (Ottawa area), the cable composition consists of a station cable fiber of approximately 1 km of Corning SMF-28 non-dispersion shifted fiber (NDSF) inside a dielectric jacket cable. The fibers are spliced to ITU G.652 (similar to Corning SMF-28 NDSF) fibers inside the central aluminum core of an OPGW cable. This is followed by 51 km of ITU G.653 dispersion-shifted fiber (DSF), also inside the central aluminum core of the OPGW. Finally, the route terminates in another 0.5 km of station cable at Station “B”, consisting of Corning SMF-28 NDSF inside dielectric jacket cable. It should be pointed out that not only the fiber types (ITU G.652 vs. G.653) are different for the 51 km and the 14 km segments, but also the construction/composition of the OPGW cables are different.

The BOTDA test equipment requires access at both ends of the fiber, so loopbacks were used at Station “B”. Thus, the total fiber length monitored by the Brillouin sensor [6] is close to 140 km. The BOTDA, located at Station “A” in Ottawa, was set to scan as often as once every 60 minutes, starting on June 12, 2012 and continuing to June 17, 2013. Much data was collected as part of this experiment. The data points correspond to running averages of strain experienced by the fiber at 10 m intervals along the 67 km length of OPGW.

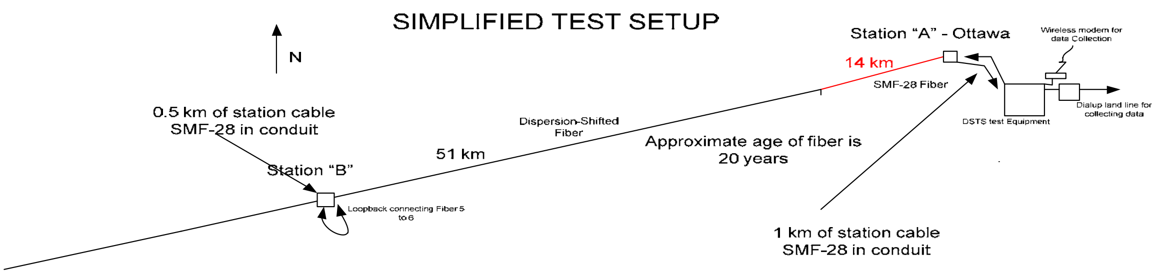

Figure 2. Experimental setup

3. Results and Discussion

3.1 Exact Fiber Length

Figure 3 displays the Brillouin frequency shifts over the length of the fiber. The loopback point is located at 66.6 km, where station “B” is located. The loopback distance corresponds exactly to the DSTS measured length. The analysis need only focus on the first 66.6 km to get strain distribution, and ignore the results after that.

The first ~14 km ITU G.652 (Corning SMF28) has Brillouin frequencies around 10920 MHz (Figures 4 (a) and (b)). Bare (acrylate coated) G. 652 fiber generates a Brillouin frequency shift (in lab environment) measured as 10878 MHz at 21 °C and zero strain [3]. Since the baseline values shown in Figure 3 were taken at 18 °C, then compensation corresponding to 3 °C (3 MHz) would be required. The difference between laboratory values and the baseline values on the installed OPGW shows 45 MHz difference in Brillouin center frequency, corresponding to approximately +900 $\mu\varepsilon$. This indicates that the bare, but acrylate-coated, fiber strand likely experiences approximately +900 $\mu\varepsilon$ tension in the process of manufacturing of the OPGW cable and in the actual installation of the cable overhead. This “pre-tension” value is only valid for the first 14 km of fiber where the ITU G.652 fiber exists.

Figure 4(c) shows the Brillouin spectrum for the remaining DSF (ITU G.653) fiber. The center frequency of the main peak is around 10512 MHz. The individual-peak spectrum of the DSF shown has a distinct four peak signature which is very similar to that of Large Effective Area non-zero dispersion shifted Fiber (LEAF) from Corning. The actual value attributed to DSF (ITU G.653) bare fiber is shown in [7] to be 10517 MHz at 23 °C for the main peak.

In these tests, the relative strain experienced by the OPGW (relative to the strain on the reference day of June 12, 2012 at 14:30 EDT, outside temp. of 19 °C) is stored and analyzed. In any test, if the bare fiber strands are provided *a priori*, then absolute values of the strain experienced by a fiber can be recorded. This data takes into account the strain experienced by each fiber in the manufacturing process plus the strain due to installation. Alternatively, a spare (one that has not been installed) reel can be used to establish the baseline strain and measure the additional strain due to installation and weather phenomena. At low temperatures, negative strain values show up in the results. Since relative strain values are measured, negative strain means the optical fiber releases tension or is under compression as compared to measured values on June 12, 2012 at 14:30 pm.

Figure 3. Brillouin Frequency shifts along the fiber, loop back point located at 66.6 km

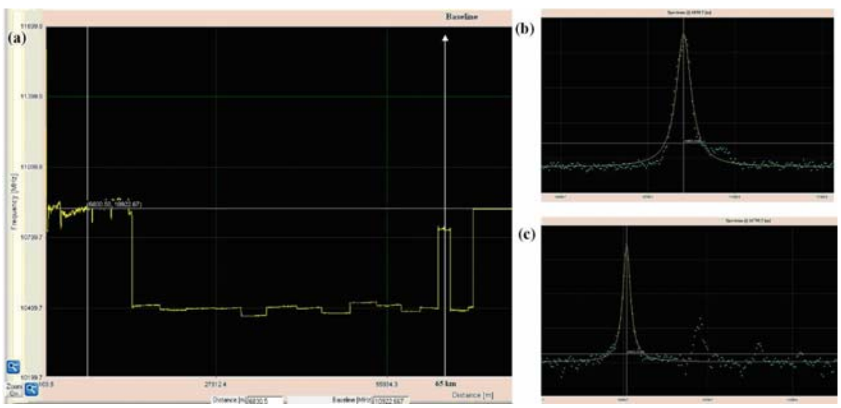

Figure 4. (a) Baseline Brillouin frequency distribution along the cable. (b) Brillouin spectrum at 6830.5 m of ITU G.652 (SMF-28) fiber. (c) Brillouin spectrum at 16790.5 m (DSF or ITU G.653 fiber).

3.2 Strain after Temperature Compensation:

Temperature compensation is important in order to get real strain values according to Eqs. 1 and 2. If we consider temperature compensation, the true relative strain values compared to the baseline can be obtained. It is possible to use the same DSTS equipment which measures strain along the length of fiber (OPGW) to measure temperature along the looped back portion of the loose buffered fiber. These temperature measurements can then be used to compensate for the DSTS strain measurements. It should be noted that loose buffered (or loose) fiber gives temperature information whereas tight-buffered fiber can provide both temperature and strain information. Temperature measurement from loose buffered fiber can be used for temperature compensation of the strain from tight-buffered fibers. Temperature compensation in this experiment utilized the following linear relationship:

Temp. Corrected Strain =

Measured (uncorrected strain) – [(Local Temp (today) – Ref. Temp) * 1.024 * 18.915 $\mu\varepsilon$]

Ref. Temp is the temperature on June 12, 2012 at 14:30 EDT of 18 °C. The value of 18.915 $\mu\varepsilon$ corresponds to $1/ C_{\varepsilon}$. The value of 1.024 MHz corresponds to C_T. During the test period of 365 days (a year), the temperature variations experienced in the region were large. These were from –30 °C to 30 °C. This 60 °C temperature swing can introduce about a 60 MHz Brillouin frequency change corresponding to a variation of approximately 1200 με (0.12 %). It is recognized here that if the temperature value is not accurate, it will introduce errors to the strain measurement.

3.3 Change in Cable Strain due to Daylight Heating

Variations of strain on the fiber during the warm days and in transition hours from day to nighttime can be observed with the DSTS. During the day as the OPGW cable heats up, the cable expands and the fiber inside the cable experiences strain (despite having a helical winding). At night, the cable cools down and the OPGW contracts, thus relaxing the strain on the actual fiber inside the cable. This pattern can be observed clearly with DSTS. In Figure 5 the strain on the fiber strand at 3:58 PM on a June 11 (a sunny day) is much higher than early morning hours at 3:59 AM or 6:59 AM when the ambient temperature and subsequently the OPGW cable surface temperature is much cooler.

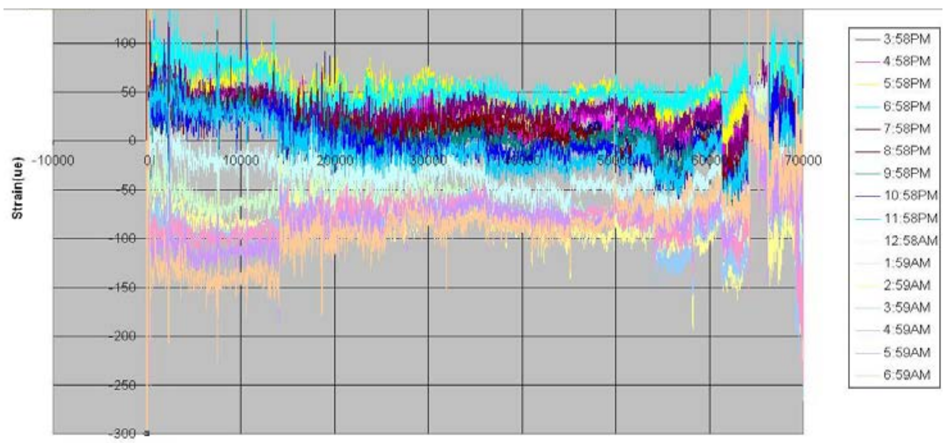

Figure 5. Variation of Strain from June 11 (Day) to June 12, 2012 (Night), Typical behavior

3.4 Change in Strain due to Cable Construction

The behavior of the first 14 km of fiber (starting from Ottawa) is different from that of the rest of the fiber due to the fiber type and cable composition. This cable has SMF-28 or ITU G.652 equivalent single-mode, non-dispersion shifted fiber. The rest of the cable (excluding station cables) has dispersion-compensated (ITU G.653) fiber. ITU G.652 and G.653 fibers have different core geometries and the difference can be seen at the transition splice location, 14 km away from Ottawa, in a sharp down or upslope change (depending on temperature). These are shown on the OTDR and DSTS traces in Figures 6 and 7.

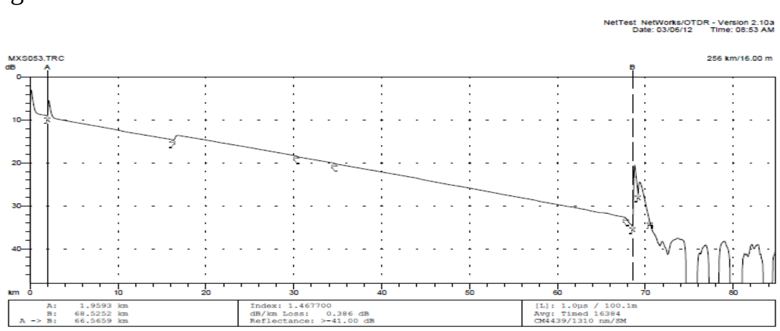

Figure 6. OTDR result on the Fiber under test

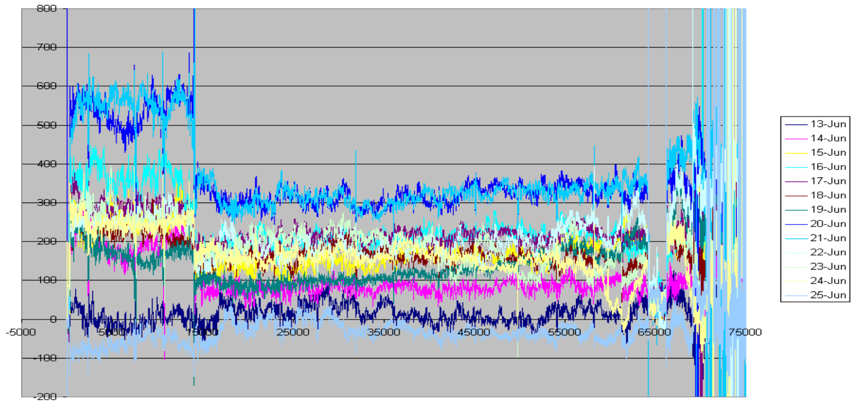

Figure 7. Measured Strain values along 67 km of OPGW show the higher values for the first 14 km (Summer time behavior)

In Figure 8, the first ~14 km of the cable shows negative relative strain values compared to the baseline. The measurements here are relative measurements comparing the current cable status against previously known values taken under conditions where no rain or ice was present. The differences in strain behavior at two different positive and negative temperatures are shown.

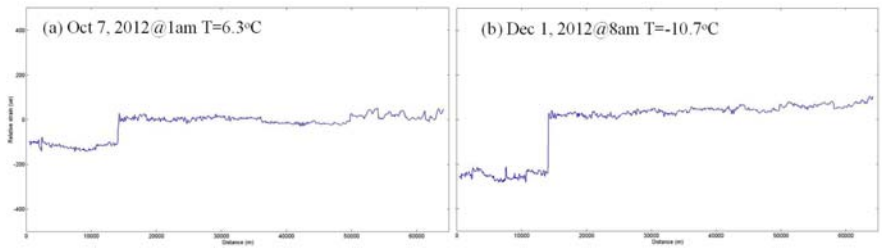

Figure 8. Comparison of strain change with outside temp. in the first 14 km (Cold Weather)

The aforementioned OPGW (with ITU G.652 fiber) has a central core and an aluminum spacer inside the core as shown in Figure 9. The fibers ride in the grooves of the aluminum spacer. Through the use of DSTS, it is observed that this OPGW experiences higher (positive) relative strain in the summer and lower (negative) relative strain in the winter. Comparison of the strain values shown in Figures 7 and 8 show this behavior.

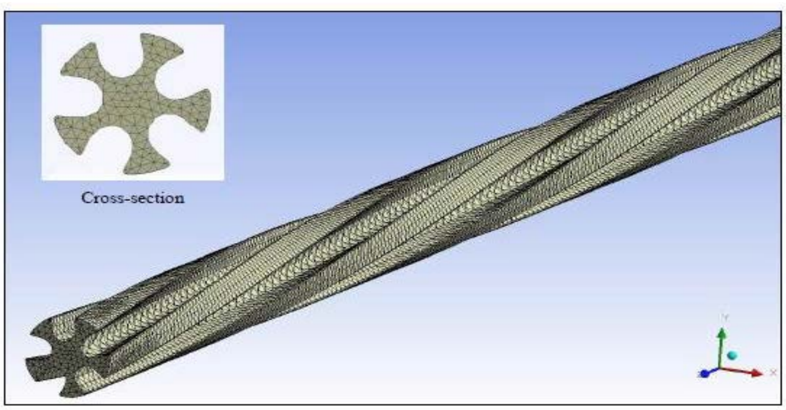

Figure 9. OPGW composition of the first 14 km (G.652) cable with Al. spacer in the Core [8]

The OPGW used in the next 51 km of the cable has a central aluminum core, but without the aluminum spacer. The material thermal expansion coefficient of aluminum is 2.3 x 10^{-5} /^{o}C which is equivalent to a change of 23 $\mu\varepsilon$/^{o}C. By comparison, the thermal expansion coefficient of silica - the main component in fiber - is much smaller at 5x 10^{-7} /^{o}C [10].

Given that aluminum has a different coefficient of expansion than silica, when the aluminum spacer is heated up (in the first 14 km), it expands at a different rate than fiber, thus producing additional strain on the actual fibers. This may explain the negative strain values of the first 14 km of fiber (NDSF) when the temperature drops. The reverse happens in warm weather, as seen in Figure 7.

The variations in strain are noticeable in these tests, and the measurements are consistent in this regard. One conclusion/recommendation could warn against use of this design on fibers intended for installation in extremely cold climates. Pronounced variation in strain and repeated changes due to warm/cold temperature cycles could lead to fatigue in the fibers.

3.5 Analysis of Weather Phenomena experienced by OPGW

On July 23, 2012, at 15:31 PM EDT (Ottawa), a sudden drop in strain was observed approx. 28-34 km away from the Ottawa test start location. Shock cooling of OPGW cable due to thunderstorm rain could be the cause, but it is just a speculation. It needs to have further investigation.

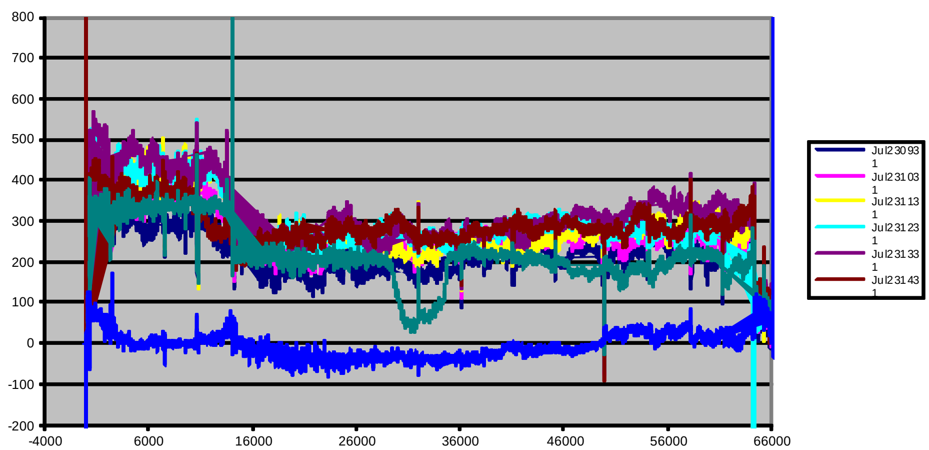

Figure 10. Strain measurements prior, during and after the thunderstorm

Further investigation of weather at the Ottawa International Airport (CYOW) - 5 km away from the Station “A” in Ottawa where the BOTDA was located - shows that a severe thunderstorm with associated rain and gusting wind was present in this area at that exact same time. Furthermore, a large change in wind direction was noted at about the same time as shown in Figure 11. It appears that the correlation between thunderstorm effects (due to cold front crossing) matches the event shown on the DSTS graph on July 23, 2012 @ 15:31. The lower strain experienced following the event and measured at 16:31 PM corresponds to the cooling of the air (and the cable) due to a cold front. A temperature drop from 30 °C to 22-21 °C is noted in weather details.

The use of BOTDA DSTS provided a window on the effect of a thunderstorm on the cable. The hypothesis is that a large (approx. 6 km) thunderstorm front crossed the transmission line at this time, affecting the OPGW cable and the fiber strands inside the OPGW. It is possible that cooling of the OPGW strands due to cold rain from the thunderstorm (as it passed through a segment of the line) contracted the cable, reducing its sag which reduced strain on the fiber by almost 150 $\mu\varepsilon$. If validated, this could lead to interesting applications for monitoring of sag (and tension) on cables. Other applications in the metrology may also be possible. The validation, however, requires further research in a controlled laboratory environment.

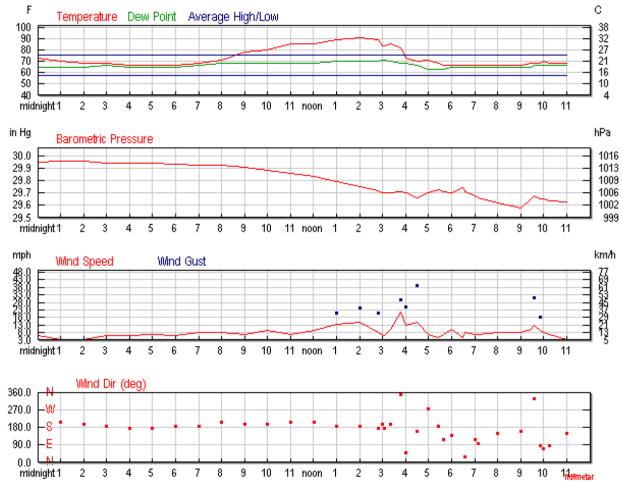

Figure 11. Temperature/Humidity/Wind at Ottawa, Ontario, Canada on July 23, 2012 [9]

3.6 Strain Distribution due to Possible Ice Accumulation

On April 12, 2013, a snowstorm occurred in the Ottawa area in the early-morning hours and continued through the day with a mix of ice pellets, freezing rain, snow and rain. While April snow flurries happen from time to time in the Ottawa area, the characteristics of this storm, with temperatures and dew points hovering around 0 °C, resulted in icy conditions which paralyzed the region quickly.

These measurements clearly show that strain increases with time from 05:42 to 19:42 which can be correlated with possible ice accumulation on the OPGW cable. The strain increase on the NDSF fiber (first 14 km) is shown in Figure 14. The maximum strain change (relative strain) on the fibers inside the OPGW (on the first 14 km) is around 60 με, (from -20 με to +40 με).

A Brillouin sensor measures Brillouin frequency shift due to strain/temperature change, and then calculates strain/temperature based on the following formulas:

$$\Delta\varepsilon = \Delta\nu_B / C_\varepsilon \qquad (3)$$

$$\Delta T = \Delta\nu_B / C_T \qquad (4)$$

Since it is impossible to calibrate the strain coefficient C_ε of the OPGW, we use the strain coefficient of bare fiber, $C_\varepsilon = 18.915\mu\varepsilon/\mathrm{MHz}$. The outer layer of the OPGW is made from aluminum clad steel reinforced wires wound around a central tube made from aluminum, aluminum clad steel, or stainless steel, depending on manufacturer. These layers work as buffers between the bare fiber and the environment, therefore bare fiber experiences strain only when the outer layer of the OPGW experiences a bigger change of strain. Material properties of various components of an OPGW similar to the one used in the first 14 km of the link (from Ottawa towards west) are shown in Table 1 [8]:

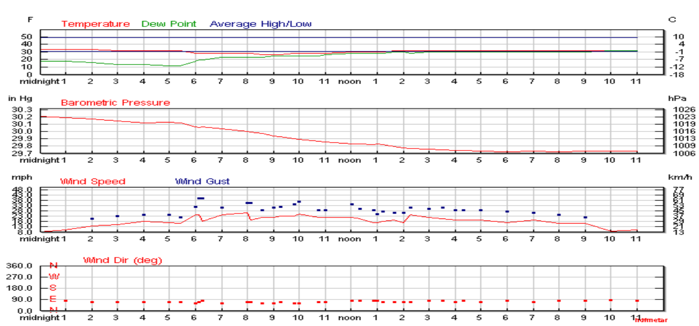

Figure 12. Temperature, Dew Point, Pressure and Wind in the Ottawa area on April 12, 2013[9]

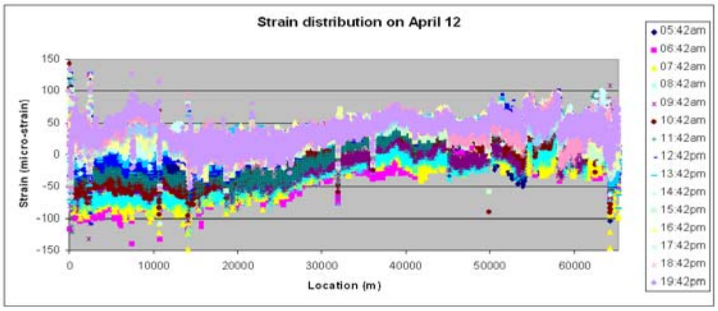

Figure 13. Strain Measurements on the fiber corresponding to the Ottawa area on April 12, 2013

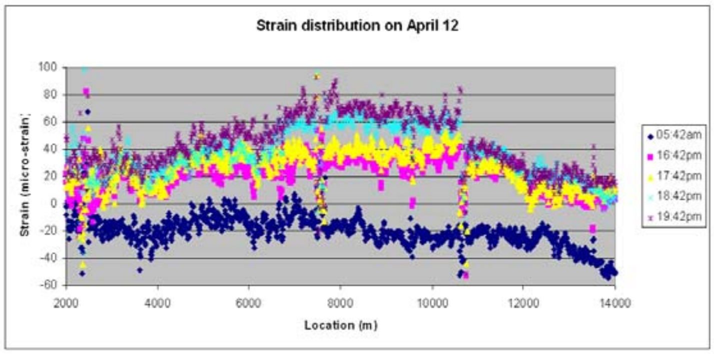

Figure 14. Strain distribution on April 12 on the first 14 km of Fiber.

Table 1: Material Properties of the Components of an Optical Ground Wire [8]

Component	Material	Properties	Characteristic	Comments
Outer Wires	Aluminum Alloy	E= 63.77 GPa v=0.33 Y=204.5 MPa UTS= 336 MPa	Linear elastic Large kinematics Small strain	
Inner Wires	Aluminum-Clad Steel	E= 162 GPa v=0.33 Y=1250 MPa UTS= 1474 MPa	Linear elastic Large kinematics Small strain	Main load-carrying component in the OPGW
Central Tube	Aluminium	E= 61.8 GPa v=0.33 Y=123.61 MPa UTS= 146 MPa	Linear elastic to multi-linear plastic Large kinematics Large strain	
Spacer	Aluminum Alloy	E= 63.77 GPa v=0.33 Y=204.05 MPa UTS= 272 MPa	Linear elastic to multi-linear plastic Large kinematics Large strain	

Table2: Material Properties of Fiber [10]

Component	Material	Properties	Characteristic	Comments
Fiber (Singlemode)	Silica	E=70.3 GPa v=0.16 UTS=700 MPa	Linear Elastic Large Strain	Maximum UTS tested per ITU standard (Corning). Thermal Expansion Coefficient: 5x $10^{-7}/^{o}C$

E is Young's modulus of elasticity in GPa, Y is the Yield Strength (MPa). Y is the value of force applied at which the material starts to become elastic. UTS is the Ultimate Tensile Strength (also in Mpa). v is Poisson's ratio, - a measure of the elastic properties of a material. Steel has v =0.33.

Theoretical strength of fiber (based on silicon bonds) is 14 GPa (2000 kpsi). In practice fibers can only handle 4.9 GPa (700 kpsi), due to impurities in the material. The fiber coating has much lower

Young's modulus than silica. The outer coating has a strength of 800 MPa while the inner coating has 1-5 MPa [10]. Fiber strength tests today are carried out to 0.7 GPa (100 kpsi) applied stress and a safe operating design tension of 20 % is established. This corresponds to 0.14 GPa (20 kpsi) which corresponds to 2000 $\mu\varepsilon$ (or 0.2 %) of absolute strain.

3.7 Presentation of Fiber Strain vs. Distance over Time

Plots of relative strain vs. distance over time (Figure 15 and 16) can provide beneficial trending information. Orange and red correspond to higher relative strain, correlated to weather phenomena.

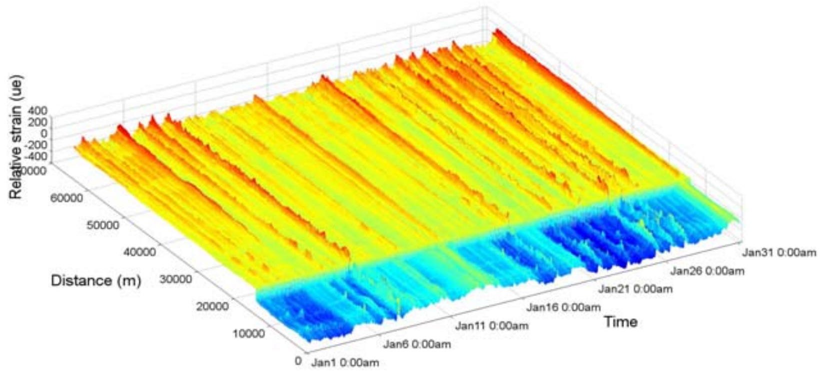

Figure 15. 3D plot of relative strain over the Month of January 2013.

3.8 DSTS as a Long-term Trend Monitoring Tool:

The results of one year of monitoring of strain in this experiment are documented in Figure 16.

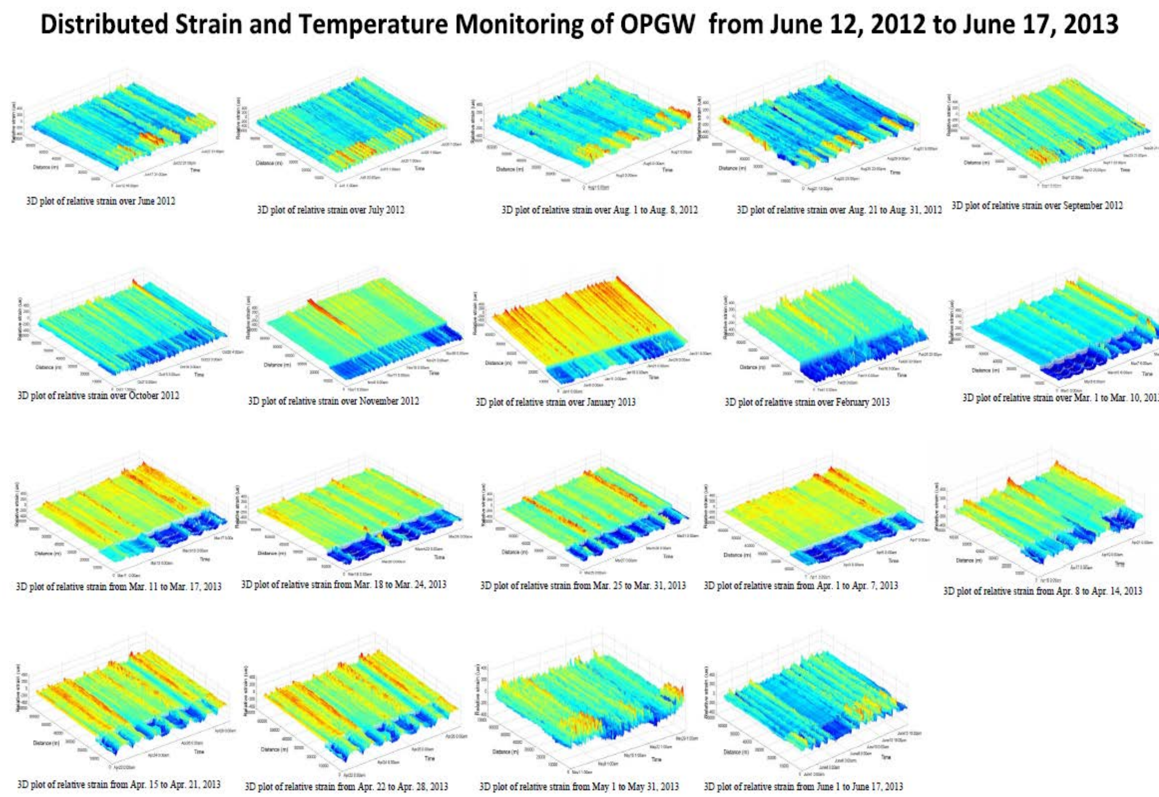

Figure 16: Typical strain distribution along cable within 12 months from June 2012 to June 2013
(The results for December 2012 were incomplete due to data acquisition issues, hence not included)

The use of DSTS to measure absolute strain on the fiber must begin with the establishment of the Brillouin center frequency of a loose strand of fiber similar to the one installed in the cable. Comparison of this number to the center frequency of a jacketed – but not installed - fiber (in the case of tight buffer cables) inside the OPGW shows how much additional strain the fiber encounters in the manufacturing process. These two measurements can serve as a benchmark to find the absolute strain on the fiber "at rest" prior to installation.

Strain measurement for the length of installed cable immediately after installation, similar to the OTDR tests, can potentially reveal installation issues. Long term monitoring of the absolute strain of an individual fiber along the length of installed aerial cable can provide clues as to where this fiber and (by association) cable may experience momentary or periodic abnormal strains.

Abnormal strain in this context can be defined as anything above the long-term fiber design strain of 0.2 % (corresponding to 2000 $\mu\varepsilon$ and design tension of 0.14 GPa (20 kpsi)). Higher strain levels on the individual fiber are correlated with higher probability of failure over a long time of 25 years [10].

4. Conclusions

The application of BOTDA based distributed strain and temperature monitoring of aerial cables – of which OPGW is a subset – has become an area of active research. These fibers are subject to weather extremes. Their performance as communication medium (both for line protections and as commercial products) and means of lightning protection are of utmost importance. The use of BOTDA/BOTDR-based DSTS on aerially-installed fiber cable would allow such cables to serve as long (many kilometers), highly sensitive, strain and temperature gauges with accurate spatial resolution. The conclusions drawn from the long term monitoring experiment here are as follows:

1. Distributed strain and temperature sensing by using a Brillouin Optical Time Domain Analysis (BOTDA) on OPGW fiber strands is presented. DSTS provided hourly field monitoring of strain changes of a particular single mode fiber at every 10 m along a 67 km OPGW cable for one year.

2. The use of DSTS can point out potential installation issues at local areas of high strain. This capability could not be demonstrated in this investigation and should be further researched.

3. The effect of a weather phenomenon such as a thunderstorm or snowstorm on aerial cable (e.g. OPGW in this case) can be identified by monitoring relative strain on the OPGW.

4. Variations of strain on the fiber during warm days and going from day to night can be observed; Combined with temperature data from BOTDA, useful information on cable surface temperature may be extrapolated. This application should be studied further in a research laboratory.

BOTDA-based DSTS used on aerial cables in general and OPGW, ADSS and helically applied fiber in particular should benefit immensely from further research and tests at reputable laboratories. Strain changes on the fiber inside an OPGW as the cable is subjected to different weather phenomena are more pronounced than what an OTDR generally records. This is particularly true if an event has immobilized or constricted movement of fiber strands in the OPGW cable, leading to increased strain. Application of DSTS can be two-fold: 1) High resolution monitoring with high spatial resolution (+/- 10 cm) of a short segment of cable, or 2) Lower resolution monitoring with spatial resolution in the order of 1 - 10 m of a long (50-80 km) length of cable.

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