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Distributed Temperature Sensing in Secondary Networks

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SUMMARY

The increase of manhole events in the Indianapolis Power and Light Company's (IPL) underground secondary network necessitated the need to be more proactive in minimizing and mitigating manhole events. After conducting Root Cause Analyses, it was determined that a major contributing factor to manhole events was from IPL's underground infrastructure being exposed to high temperature steam anomalies from the steam distribution system. To help monitor IPL's downtown distribution network for steam anomalies, a Distributed Temperature Sensing (DTS) monitoring system was installed. A DTS system is an optoelectronic device that measures temperatures by means of optical fibers functioning as linear sensors.[1] The DTS system helps mitigate and minimize manhole events by identifying extreme heat conditions and cable exposed to excessive heat. With this information, Engineering and Operations can proactively work with the steam company to evaluate the steam anomalies, take corrective action, and replace the affected cables, thus reducing the potential for manhole events.

In addition to monitoring the underground network system for steam anomalies, the DTS system can also detect secondary network fires which allow Operations to address a situation in a more efficient, timely manner. Other benefits to installing the DTS monitoring system is the fiber optic cable that is used as the sensor can also be used for Supervisory Control and Data Acquisition applications. This option provides IPL the ability to retrieve additional data from the field through unused fibers.

KEYWORDS

- Distributed Temperature Sensing
- Fiber Optic Cable
- Cable Degradation
- Thermal Decomposition
- Combustible Gasses
- Minimize and Mitigate Manhole Fires
- Minimize and Mitigate Manhole Over-Pressurization Events
- Dislodged Manhole Covers
- Raman Effect
- Stokes and Anti-Stokes

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INTRODUCTION

Underground secondary networks are very reliable and robust systems in which customers rarely experience interruptions or power outages. With the added robustness, come more complex mitigating issues such as preventing manhole events. Manhole events are typically comprised of manhole fires and on rarer occasions, over-pressurization events. All of which can pose a public safety risk, but the latter poses the greatest risk to public safety due to dislodged manhole covers.

Most manhole events can be attributed to low voltage cable faults due to damage to the cable's outer jacket and insulation. The damage, along with contributing factors such as; salt water, excessive loading, and external thermal sources, accelerates the thermal aging of the cable's outer jacket and insulation. The thermal aging causes the cable's insulation to become brittle and crack as shown in Figure 1 below. Once this has occurred, salt water from de-icing roads for instance, will aid in a cable fault, resulting in the thermal decomposition of the outer jacket and insulation. Combustible gasses created during the thermal decomposition of the cable start to build up in the duct line and manhole system, creating the perfect storm for an over-pressurization event. With this in mind, it is imperative for electrical utilities to minimize and mitigate the potential of such events from occurring.

Figure 1: Cable Damaged by Elevated Temperatures Caused by Steam. Cable had been in Service for Only 2 Years.

One method to help mitigate and minimize potential events is the use of a Distributed Temperature Sensing monitoring system, hereinafter referred to as a DTS system. A DTS system is comprised of a DTS controller and standard fiber optic cable used as a linear sensor. The DTS system eliminates the need to install and maintain thousands of sensors. In essence, the DTS controller measures the temperature profile of the entire length of the fiber optic cable in 1 meter increments with an accuracy of ± 1.00°C. The fiber optic cable can be installed in a separate conduit or along with primary and secondary cables. Once installed, the DTS system is able to monitor the secondary network for either gradual or sudden rises in temperature and alert the appropriate personnel depending on the situation. In addition, unused fibers in the fiber optic cable can be used for other purposes, e.g. SCADA (Supervisory Control and Data Acquisition), to provide additional system information to the Energy Control System.

In the Indianapolis Power and Light Company's (IPL) underground secondary network for example, one of the major contributing factors to cable degradation is elevated temperatures from the steam distribution system, which are gradual in nature. With the DTS system, IPL is able to monitor the ambient temperature of IPL's infrastructure and detect hotspots created by a steam distribution issue. Once the DTS system detects a steam anomaly, written or verbal notification is initiated with the steam company who in-turn investigates and coordinates corrective measures to reduce the elevated temperatures. With the assistance of the steam company, IPL is able to address steam anomalies in a timely manner and proactively reduce the potential for manhole events by replacing affected cables, if necessary. Monitoring for steam anomalies also has the added benefit of using the DTS system to detect manhole fires and allowing Operations to pinpoint and address these types of events sooner.

DTS SYSTEM

A DTS system is comprised of two components, a DTS controller like the one shown below in Figure 2 and standard fiber optic cables with lengths up to 30km+ each. The fiber optic cables can either be installed radially or looped to add robustness to the system.

Figure 2: LIOS Distributed Temperature Sensing Controller

RAMAN EFFECT

The DTS system operates on the principle of the Raman Effect. Essentially as the fiber optic cable is heated up, the molecules in the cable begin to vibrate. The vibration causes a lattice effect in the cable causing a backscatter of light towards the DTS controller. The DTS controller then interprets the backscatter of light focusing on two components of the backscatter, Stokes (independent of temperature) and Anti-Stokes (temperature dependent) as shown below in Figure 3 below. It is the relationship between the two components that allow the DTS controller to measure the temperature at 1m increments, thus turning the fiber optic cable into a linear sensor.

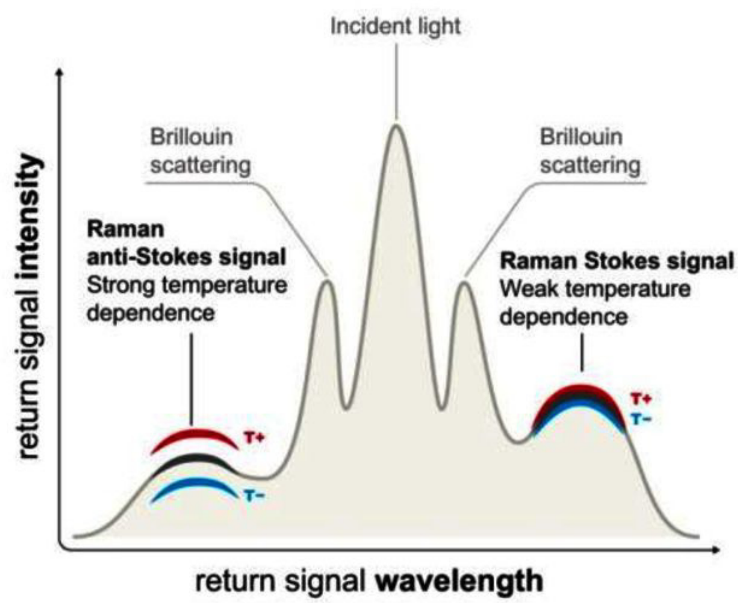

Figure 3: Raman Effect

THE SEARCH FOR A SOLUTION

Downtown Indianapolis has the 2nd largest steam system in the United States. Often times the steam system is in close proximity to the IPL underground secondary network. Efforts were made to detect steam leaks during routine inspections with varying results. Often, the cable threats from steam anomalies occur deep in a duct bank where inspections would be impractical and may not be noticed by field personnel during inspections. In an effort to detect these types of threats, field personnel used snake thermal sensors on fiberglass rods to detect steam anomalies. This method proved to be impractical and time consuming. In addition, any steam anomalies occurring after an inspection would not be detected until the next inspection cycle.

Each manhole or over-pressurization event potentially costs IPL several hundred thousand dollars in repair and restoration. IPL engineers actively searched for a more practical solution and partnered with Fiber Optic Pipeline Solutions (FiOPS). IPL and FiOPS created an innovative solution to address the steam anomalies. The DTS system provides IPL with a cost-effective and reliable underground secondary network monitoring system to detect thermal events resulting from steam and cable failures.

CONSTRUCTION AND COMMISIONING

Initially in June of 2016, IPL and FiOPS installed a 2.07km (6,800ft) pilot route for testing along with one DTS controller. The 2.07km pilot route affectively monitors approximately 15.24km (50,000ft) of primary and secondary cables for thermal issues. The pilot route was divided into 81 temperatures zones consisting of manholes, vaults, and the duct lines between manholes. The zones allow those monitoring the system to know if the thermal event is in a vault, manhole or between two manholes. Within the first couple of weeks the DTS was providing real world results.

One example shown below in Figures 4 and 5 illustrates the temperature trace of a steam anomaly that started at the beginning of July 2016. The temperature increase was gradual over a period of 30 days indicating it was a steam issue. The steam leak was 9 meters (30ft) from manhole K13-21. After further investigation with the steam company it was determined that an abandoned steam line running perpendicular to the IPL duct bank had not been properly capped off and was allowing a steam leak from the steam line on the opposite side of the street to travel towards the IPL duct bank. Due to the promising results from the pilot DTS installation, IPL management approved installing three additional routes and an additional DTS controller.

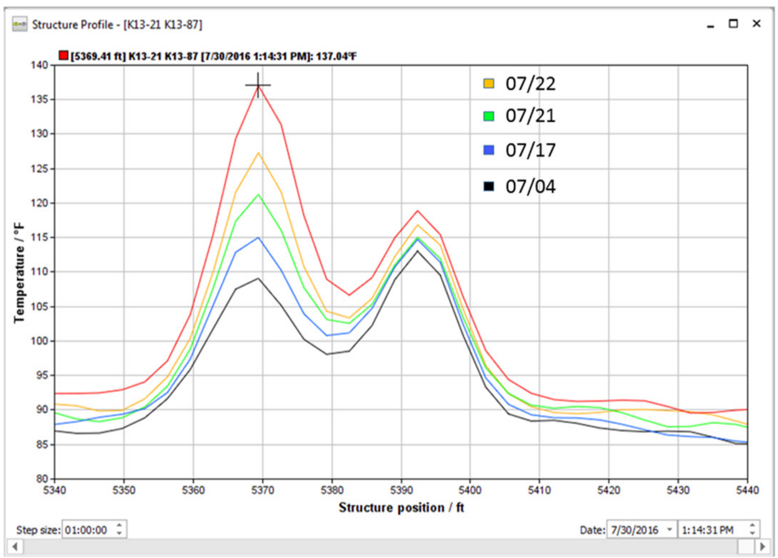

Figure 4: Steam Anomaly that Occurred in July 2016 Shortly after the IPL DTS System was installed.

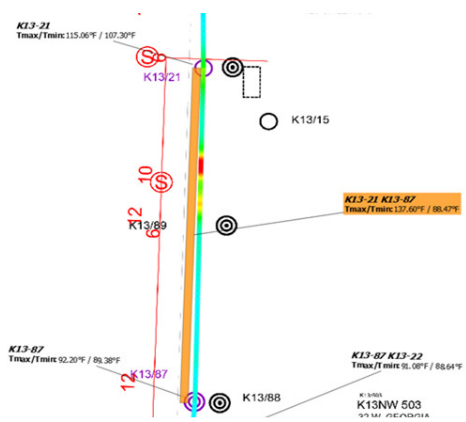

Figure 5: Enhanced View of Steam Anomaly that Occurred in July 2016

CURRENT STATE OF THE IPL DTS SYSTEM

Currently IPL has installed two DTS controllers at separate locations with four routes of fiber optic cable covering approximately 11.3km (37,000ft). To achieve the same amount of coverage of the DTS system, we would have needed to install and maintain approximately 11,300 sensors. The temperature traces of all four routes are updated every 90 seconds. The DTS system has detected several steam anomalies as well as cable fires in two manholes. Below in Figure 6 is a screenshot of the Charon 4 software with the temperature trace, the "Enhanced View", and Figure 7 showing zone data of Route 3.

Figure 6: Charon 4 Software, Temperature Trace and "Enhanced View" of Route 3

Status	Tmax / °F	Tavg / °F	Tmin / °F	Controller	Fibre	Name	Index	Start / ft	End / ft	Alarm	Pre-alarm	Fault
192	91.23	81.30	78.91	4424	Route 3	ICC Sub Floor	192	32.81	154.20	-	-	-
193	95.14	93.60	91.23	4424	Route 3	IPL Vault	193	154.20	200.13	-	-	-
194	95.08	92.87	90.82	4424	Route 3	IPL Vault V11-96	194	200.13	216.54	-	-	-
195	91.91	90.10	88.17	4424	Route 3	V11-96	195	216.54	265.75	-	-	-
196	100.62	94.61	89.62	4424	Route 3	V11-96 K11-02	196	265.75	301.84	-	-	-
197	96.81	95.35	94.25	4424	Route 3	K11-02	197	301.84	318.24	-	-	-
198	95.01	90.86	88.11	4424	Route 3	K11-02 K11-21	198	318.24	364.17	-	-	-
199	91.58	91.02	90.69	4424	Route 3	K11-21	199	364.17	370.73	-	-	-
200	92.13	90.87	89.43	4424	Route 3	K11-21 K11-01	200	370.73	423.23	-	-	-
201	91.99	90.86	89.23	4424	Route 3	K11-01	201	423.23	485.56	-	-	-
202	97.78	94.54	87.36	4424	Route 3	K11-01 V11-01	202	485.56	659.45	-	-	-
203	92.87	91.34	89.89	4424	Route 3	V11-01	203	659.45	695.54	-	-	-
204	102.30	98.93	91.83	4424	Route 3	V11-01 M11-04	204	695.54	862.86	-	-	-
205	100.24	98.15	96.71	4424	Route 3	M11-04	205	862.86	908.79	-	-	-
206	101.90	98.59	95.52	4424	Route 3	M11-04 M11-03	206	908.79	1059.71	-	-	-

Figure 7: Charon 4 Software, Zone Data for Route 3

MANHOLE FIRE – JUNE 2017

On June 22, 2017 at approximately 12:59 pm the DTS system detected a manhole fire in manhole I14-00. The DTS system recorded the ambient temperature of 35.19°C at 12:57:56pm. The temperature rose to over 165.87°C over a span of 7min and 30 seconds. The temperature traces in Figure 8 through Figure 10 shown below and on the following page illustrates the rise in temperature.

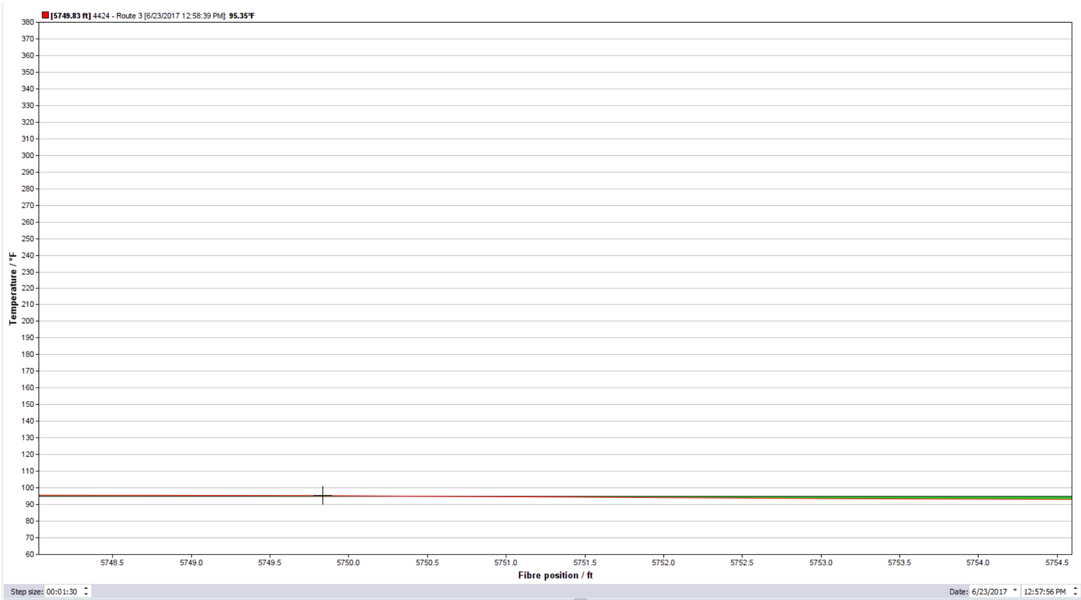

Figure 8: Manhole Fire 6/22/2017at 12:57:56 pm
Temperature: 35.19°C or 95.35°F

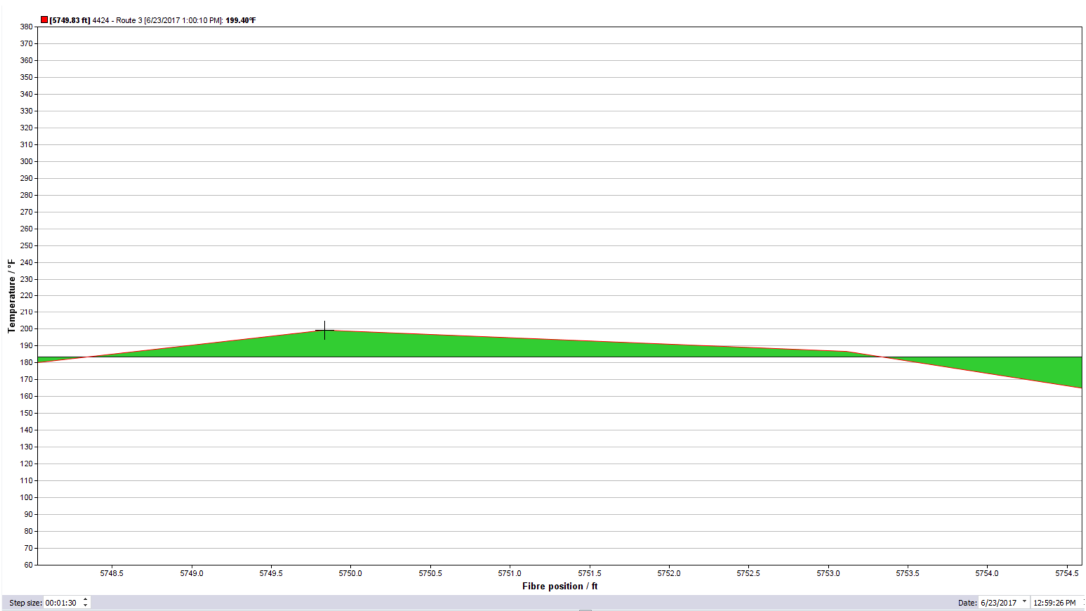

Figure 9: Manhole Fire 6/22/2017 at 12:59:26 pm
Temperature: 93.00°C or 199.40°F

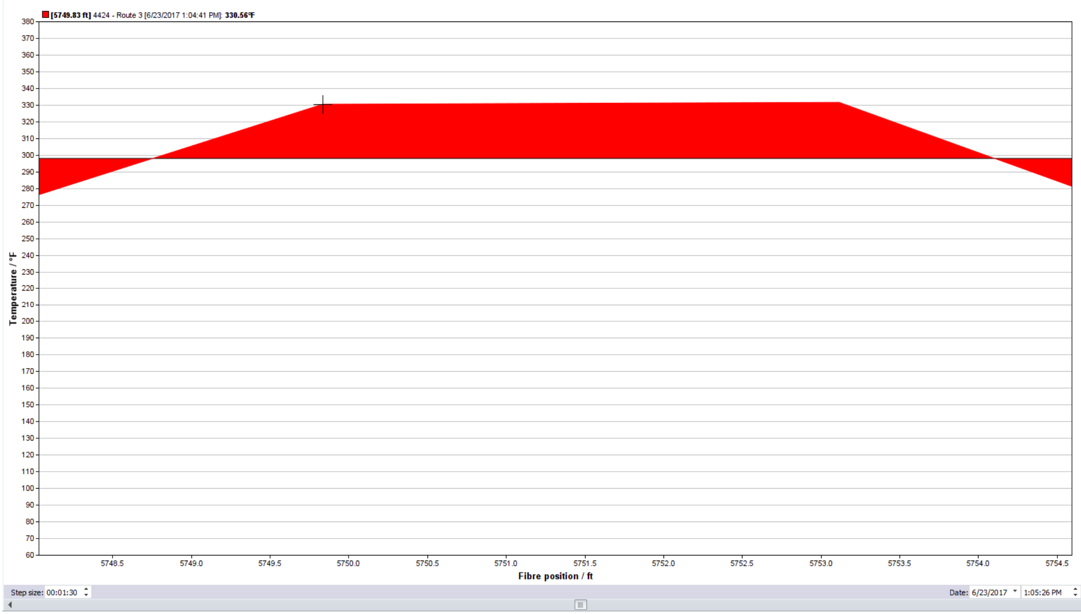

Figure 10: Manhole Fire 6/22/2017 at 1:05:26 pm
Temperature: 165.87°C or 330.56°F)

FUTURE PLANS

Starting in 2018 through 2019, IPL plans to install 4 to 6 more routes of fiber optic cable to cover the rest of IPL's infrastructure in the downtown network that is vulnerable to steam issues. Once this is accomplished IPL and FiOPS will begin engineering and testing Distributed Acoustic Sensing (DAS) technology utilizing the same fiber optic cable as the DTS system. The DAS system will enable IPL to monitor infrastructure for damage caused by other companies working in close proximity to IPL facilities. In addition, IPL is working on being able to detect the noise signatures of a cable arcing to allow for even more efficient mitigation of secondary cable fires. IPL also plans to develop a process using the DAS system to locate primary cable faults. This would allow field crews to eliminate the need to perform a DC Hipot test or "thumping the cable" to locate faults. Over time, DC Hipot tests degrade the primary cable creating potential failures.

CONCLUSION

The DTS system has proven to be a very promising technology for use in secondary networks. With the fiber optic cable being used as a linear sensor, it eliminates the need for installing and maintaining thousands of sensors. In addition, the remaining fibers of the fiber optic cable can be used for other applications such as SCADA and DAS. Due to this innovation, IPL customers and employees will enjoy a safer, more reliable secondary network as a result.[1]

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