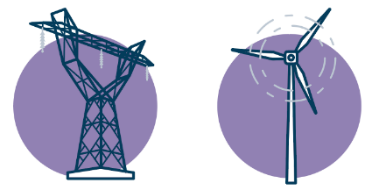
Cable Installation Considerations for Power Utilities

Introduction

Distributed fiber optic sensing (DFOS) techniques such as Distributed Temperature Sensing (DTS), Distributed Acoustic Sensing (DAS) and Distributed Strain Sensing (DSS) are powerful tools for monitoring of long, linear assets. Consequently, these approaches fit perfectly with specific requirements of the power industry, where they fulfill objectives in various areas:



- Monitoring the temperature of land and submarine power cables, overhead lines, generators, transformers and other assets
- Monitoring the sag of overhead lines
- Localizing faults in power cables
- Detecting ship movements and anchor events in proximity to submarine cables
- Detecting insufficient burial and unsupported spans of submarine cables
- Detecting activity along the cable route (work crews, trespassers, cable tampering)
- Monitoring mechanical load (tension, bending, torsion) during production, loading, transport, installation and operation of power cables

In each of these applications, distributed fiber optic sensing offers clear benefits in the ability to cover a wide area from a central monitoring point, often by taking advantage of spare fibers in existing buried cables and overhead lines.

Optimum performance for sensing objectives is dependent on cable type, installation method, cable position and the environmental conditions of the site. This applies to existing cables and those installed specifically for distributed fiber optic sensing.

This document provides guidance on best practice for the selection and installation of cables for fiber optic sensing in the power utilities domain. The most prevalent sensing technology for power utility applications is DTS which monitors temperatures related to the past and present electric current loads of power cables.

Cable Selection

General

Fiber optic cables should be selected according to their proposed use. For power transmission lines there are often multiple purposes of fiber optic sensing, communication, and Supervisory Control and Data Acquisition (SCADA) networks supporting the operational requirements of the power utility asset. The type of installation (e.g. integrated in or lashed to power cable, conductor or ground wire, direct buried or in conduit) and the environment / ground conditions may have an impact on the construction and level of protection / armor necessary to meet local regulations. Depending on various factors, the structure of the cable might affect the sensitivity and performance of the sensing system. Cable selection details should be discussed with your fiber sensing supplier or industry specialists before finalizing installation.

Fiber Selection by Application

Optical fibers should be single-mode or multimode with fiber selection tied directly to the method of interrogation. The following information provides general fiber selection guidance but is not exhaustive.

Multimode fibers for DTS applications should be selected that meet or exceed ITU-T G.651 C/D performance guidelines. Selection of multimode fiber that meets or exceeds this performance criteria will ensure that the attenuation of the fiber supports the desired range of the application, while the bandwidth of the fiber provides assurance that the desired spatial resolution of the DTS system can also be achieved.

For longer range sensing systems including DTS, DAS and DSS, single-mode optical fibers should be selected that meet or exceed the performance characteristics described in ITU-T G.652/654/655 (telecommunication grades) and G.657 (bend insensitive telecommunication grades).

Common Cable Configurations

Loose tube and tight buffered cables are the most common configurations used for organizing and protecting optical fibers inside the cable core. This helps to keep fiber attenuation low and ensures fiber reliability following installation.

Loose tube constructions allow the optical fibers within the cable subunits (tubes) to float freely, ensuring that the fibers contained within have minimal exposure to strain or compression induced by the cable materials. This leads to lowest optical attenuation. Commonly, DTS cables utilize this method of construction. Loose tube cables can be further categorized as gel-filled, or dry-blocked. Gel-filled cables utilize a thixotropic (hydrophobic) gel that surrounds the optical fibers and acts as a water-blocking agent. Alternate methods of water-blocking include the addition of super-absorbent polymer powders that swell into a gel when exposed to water, providing a water block with little to no effect on fiber attenuation.

Tight buffered cable constructions place individual fibers in cable subunits where the cable materials are in intimate contact with the individual fibers they protect. From a sensing standpoint, there may be advantage in this style of cable to aid in coupling from the environment to the fibers housed within the cable. This is an important consideration for strain (DSS) sensing applications.

When integrating sensing, like DTS, within larger electric power cables, it is common to use Fiber-In-Metal-Tube (FIMT) to ensure high tensile strength and excellent crush resistance. FIMT typically implies a loose-tube construction whereby the cable subunit is a welded metallic tube containing optical fibers. FIMT is commonly used as a component in subsea or buried electric power cables and in Optical Ground Wire (OPGW) applications and Optical Phase Conductor (OPCC).

Specific Cable Considerations for DTS

Loose tube fiber with appropriate excess fiber length (EFL) should be used to minimize micro-bending and fiber strain when the cable is under tension or when the temperature varies in operation. Thermal coupling inside the fiber optic cable is in general no issue because its response is often much faster than that of the asset it is monitoring.

DTS works using one (or two) single-mode or multimode fiber(s) depending on the type of interrogator. Multimode fibers shall have a graded index design with enough bandwidth*length product to achieve desirable spatial resolution over great distances.

Depending on the type of DTS interrogation equipment, sensing systems work in either a single-ended or dual-ended measurement method.

In single-ended use the interrogator couples laser energy into the fiber at the proximal end of the system, relying on backscattered light to determine event magnitude and location.

Dual-ended interrogation systems utilize a loop-back method whereby two optical fibers run in parallel along an asset being monitored. These fibers are joined at the distal end of the system to create a continuous optical path such that the ends of the optical fiber are accessible at the proximal end of the system.

Single and dual-ended configurations for both Raman and Brillouin based DTS systems are available and the choice between the measurements is dependent on the application and required performance.

Specific Cable Considerations for DAS

DAS works in one single-mode fiber and requires effective acoustic coupling between the fiber, the cable and the environment in which acoustic (vibrational) events are to be detected.

So far good experiences have been made with standard single-mode fiber cables which are used for telecommunication and work with wavelengths between 1530 – 1560 nanometers. The preferred cable specification for DAS is:

- Single-mode
- Tight buffered or gel-filled loose tube
- Single jacket
- Unarmored or single armor
- Spare dark fiber cores (generally one for every 50 km monitored)

DAS

This type of cable has proven its capabilities in many different installation scenarios and ranges of 70km or more. Heavily armored cables with loose buffering or powder fill should be avoided if possible, as this type of construction may result in damping of vibrations and a reduction of system sensitivity. This could cause difficulty in detecting low energy events such as walking or digging near the end of the fiber.

While most installations to date have made use of existing cables, it is expected that in the future cables optimized to enhance acoustic sensitivity will become prevalent.

Specific Cable Considerations for DSS

For DSS tight buffered fiber must be used to ensure mechanical coupling to the environment. Fibers showing a single Brillouin peak are in general better suited for DSS at large distance than multipeak fibers.

DSS

Cable Deployment Methodology

General

The methods used to deploy and protect the cable near a power utility will depend on local geography, environmental conditions and regulations. These will generally be focused on protecting the cable from weather and accidental or malicious damage but may also affect system sensing performance.

Cable Deployment for DTS

DTS

For DTS it is essential to have good thermal coupling to the asset for accurate monitoring. Best thermal coupling is achieved by any deployment where the fiber optic cable is integrated into the asset. If the fiber optic cable is lashed to the asset being monitored, it is important to optimize contact between cable and asset and to minimize air gaps. If a fiber optic cable is lashed to a power cable it should not hang between cable binders on the lower side but should lay on top of the power cable and industrial tape should be used in addition to cable binders to improve physical contact.

Cable Deployment for DAS

For DAS the key is finding an installation method that places the cable close to the signal of interest and protects the cable both from damage and unwanted noises without unduly reducing sensitivity. Best acoustic coupling is achieved when the fiber optic is integrated into the asset to be monitored i.e. a FIMT within the power cable to be monitored.

DAS

Buried cables should be embedded in the soil, backfilled with the same soil type, and compacted for best acoustic coupling results.

Cable Deployment for DSS

For DSS it is essential to have good mechanical coupling with the asset being monitored. Initial cable strain should not be too high to allow for a wide measurement range for strain and to ensure a long shelf life of the fiber. However, some initial cable strain may be useful to measure compression should the asset being measured shrink rather than elongate. It also helps to minimize strain variations caused by the fiber deployment, e.g. the fiber should be installed with uniform and low strain.

DSS

Cable Positioning

General

There are many possibilities for how new or existing cables could be installed, and these can significantly affect performance depending on application, as explained in the following sections.

Cable Positioning for DTS

The fiber optic cable should be installed as close as possible to the location where the temperature needs to be known, e.g. the conductor core of a power cable. Since the fiber often cannot be installed inside or attached to the conductor core, thermal simulation software may be required to calculate the temperature of the core. Such software, often referred to as real-time thermal rating (RTTR) or dynamic cable rating (DCR), works best if the thermal properties of all materials between the fiber and the conductor core are precisely known. This is the case for all materials inside the power cable, and consequently, all fiber positions inside or attached to the power cable can accurately record

DTS

temperature. Thermal properties of soil may vary with moisture. Therefore, the presence of soil in between the fiber and the power cable should be avoided as much as possible.

Cable Positioning for DAS

A major factor in the coupling of acoustic or vibrational signal transmitted to the sensing fiber is the location and installation method of the cable. Distance from the fiber to the sound source must also be considered. The influence of noise (undesirable vibrations) to the DAS system should also be considered, for example vehicles passing or people walking. Care should be taken to route the cable away from these areas to optimize the DAS system's ability to detect and classify signals of interest.

High energy sources such as large ships can be detected at a greater distance than low energy patterns like human digging or walking. In addition to distance, the type of medium (water, soil, etc.) through which acoustic energy needs to travel will affect the level of vibration applied to the fiber – for example, a cable buried in loose sand will be less sensitive than one buried in firm sand , clay or loam since the loose media will absorb some of the signal.

Cable Positioning for DSS

The fiber must be installed at a location on or along the asset to be monitored where strain appears. This is normally inside or attached to the asset to be monitored. For tension, it is enough to use one fiber (and maybe a loop back for certain types of interrogators). For bending or torsion, multiple fibers at different locations within the asset may be required. It is sometimes of interest to look for variations of the ground around a cable as a means of preventing damage. In this use case the placement of the sensing cable may be burial near the power cable.

Considerations Around Cable Joints

General

When joints are installed on power cables there is often a restriction of space meaning that the sensor cable cannot be installed inside the joint with the power cable. Usually the sensor cable must travel away from the power cable and then re-join the power cable once it has passed the joint.

Sensor Installation Around Power Cable Joints for DTS

Due to the short length of power cable joints in comparison to the minimum spatial resolution settings of many DTS instruments (1 m); the temperature changes of the joints are usually not precisely reflected in the DTS measurement results.

Power cable joints cannot easily be modelled thermally to calculate the conductor temperature. To obtain an indication of the joint surface temperature, several meters of sensing cable are recommended to be affixed in a loop or s-shape to the joint with minimum space in between the fiber and joint as possible. Several meters are recommended so that the spatial resolution of the system can be accommodated for.

The spatial resolution setting of the DTS depends on the total length of the monitored circuit, therefore the length of the fiber length monitoring the joint also depends on the total length of the monitored circuit. The coil should be at least two times the spatial resolution on each joint per phase. To assist with mapping, it is essential that the fiber start and stop position at the joints are known and recorded during installation.

For spliced locations of the sensing cable it is therefore recommended that they are accessible for reference temperature measurements and calibration during DTS system commissioning.

It is also recommended to have all joint pits consistent in design, including labeling all incoming and outgoing cables.

Sensor Installation Around Power Cable Joints for DAS

As mentioned above, usually the sensor cable must separate from the power cable at power cable joints. This is particularly true with joint bays. In these cases, it is important to position the sensor cable as close to the joint as possible for fault detection because joints are where faults are most likely to occur.

Looping the sensor cable multiple times around the cable joint will ensure that signals are being detected from the joint itself as this signal should repeat with each wrap of sensing cable around the joint.

Exact and calibrated positioning of the sensor cable to the power cable is extremely important in locating cable faults. Best practice is to perform tap testing along the asset during DAS system commissioning to accurately record sensor cable position.

Figure 1: Example of cable joints in a joint pit for three separate phases

Sensor Installation Around Power Cable Joints for DSS

At the joint, access to fiber for jointing results in a loss of strain coupling. To maintain strain coupling, the sensing cable should remain attached as close as possible to the joint before exiting loosely to a junction box. The sensing cable for the next section should come back from the junction box to the cable whilst overlapping the previous section. As such, the sensing cable makes a circle with the contact point to the power cable being both the exit and the entrance of the two sensing sections.

If the strain sensing coupling is used for ground movement measurement, the same installation can be used to ensure continuity of the measurement.

DSS

If the strain sensing cable is inside the power cable, then strain measurement will be lost within the junction box.

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Please visit www.fiberopticsensing.org for further information on the application of fiber optic sensing.