Monitoring Your Underground System Investment

Utilities invest large amounts when it comes to underground distribution or transmission lines. Installation of underground distribution lines and infrastructure can cost between three to ten times more than overhead lines[1] and for transmission lines it can be up to fifteen times as much[2]. For most utilities it's not only the initial investment to consider but also the life expectancy and cost of maintaining the system; high voltage overhead lines can have a life expectancy of 80+ years while an underground system is roughly half of that[2]. If a utility chooses to go with an underground system, they may also consider investing extra to protect their investment in the system as well as for the safety of the public and workers that maintain it. There are many recorded incidences of underground vault fires and explosions that not only cause extended outages but put the public and utility workers at risk. Most existing underground monitoring methods are used to detect faults, disconnect loads and restore power as quickly as possible to unaffected areas. These methods can be effective at isolating faults and restoring power however they are not able to prevent the failure. Thermal monitoring offers a method to detect potential problems before the faults can occur and in an underground system this is key to preventing more extensive and hazardous failures before they happen.

Advantages of an Underground System

Utilities consider a number of things when installing lines; underground systems can provide a number of advantages:

- Reliability – underground systems do not face outages due to falling vegetation, downed poles (due to storms, rot, fire, collisions), lightning, animal problems etc.

Fig 1. Vault Fire in California (FogCityJournal.com)

- Routing – in some urban areas it is not possible to go overhead and underground always looks better
- Safety – no exposure to downed lines and less poles to drive into

Underground Systems Are More Expensive

In almost all cases underground systems are more expensive due to:

Fig 2. Underground and overhead cable (Georgia Transmission Corp)

1. Overhead and Underground Trends in Utility Lines, EC Mag July 2015
2. Overhead vs Underground Fact Sheet, XCEL Energy, May 2015

- Cost to trench the cable and restoration of property afterwards
- Insulated cable not only costs more but up to two times more is required because it runs at a higher temperature than uninsulated, air cooled overhead cable[3]
- Concrete splice vaults are required every 600m (2000ft) or more
- Restoration time and costs – its harder to find faults and replace buried cable

Fig 3. Underground vault (Xcel Energy)

Underground Systems Have a Shorter Life Span

The main factors that shorten the life span of an underground system are 1) the breakdown of insulation and 2) degradation and failure of splices[4]. Overhead systems do not suffer the same problems since cables are generally air insulated while underground cables are completely insulated and shielded. Underground systems are more exposed to contaminated water that washes into vaults from the street that is made particularly worse by the application of road salt. Water and contaminants accelerate the aging process of the insulation.

Any impurities or defects in the insulation can lead to partial discharge, (PD), the leakage of current through the insulation phase to ground or phase to phase. Breakdown of the insulation is accelerated due to the higher temperature and the presence of moisture that is never possible to completely eliminate in an underground system. High fault current in the system also increases heat and vibration on the cable that further accelerates the breakdown of the insulation. If undetected, partial discharge will lead to complete insulation failure.

Fig 4. Cable joint failure (Cablejoints.co.uk)

Degradation of splices has a similar effect of prematurely aging the system. A poorly executed or defective splice will have increased resistance over time that will increase heat and accelerate breakdown of the insulation. This again can lead to partial discharge and eventually complete failure of the insulation.

Effects of Insulation Failure

As the insulation surrounding the cable or splice breaks down combustible gases are produced and due to the enclosed space of the vault, venting of these gases is very limited. When the insulation fails completely, a phase to ground or phase to phase arc occurs that can release a large

3. Underground Transmission Lines, Altalink, Winter/Spring 2012
4. [4] Electric Energy Online - Finding the root cause of power cable failures, Vern Buchholz, 2004

amount of heat and pressure inside the vault. The heat can vaporize the cable insulation resulting in more combustible gases being released and even worse situation. A resulting explosion and fire can blow the cover off vault and the fire can spillover. If a transformer is involved and it ruptures and spills the combustible insulating oil the situation can get much worse[5]. Early detection of failing insulation is one of the keys to preventing this type of situation.

Visual and Thermal Monitoring in the Underground Vault

Monitoring inside of a vault can be done for a number of reasons and it can be done safely by being both automated and remote. Underground systems may have hundreds or thousands of vaults so manually inspecting each vault does not scale; automated monitoring is the only feasible method to inspect a large number of vaults simultaneously. Video analytics that are programmed to detect various events are key to the automated monitoring process so operators do not have to visually monitor each site. Triggered analytics can send alerts directly to the utility SCADA system or by email to operations personnel.

Reasons for Vault Monitoring:

Security

- detection of unauthorized vault access

Safety

- visual observations of the conditions inside the vault before entering
- Confirmation that procedures are being followed

Operations

- Visual inspection of equipment
- Thermal monitoring around joints and splices inside the vault

Infrared (IR) imaging is a suitable technology to “detect excessive heat generated by failing components, such as a splice in a vault.”[6] Thermal (IR) imaging has been widely used by utilities for periodic spot checking temperatures on insulators, bushings, arrestors, transformers etc. to quickly find impending problems. Although very valuable as a tool, spot checking may miss problems that occur under load conditions or weather conditions that make it challenging for IR to work most effectively.

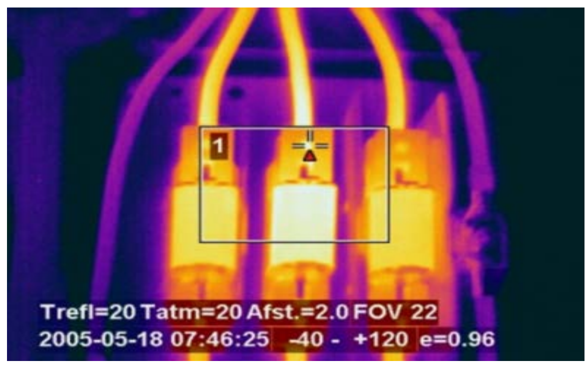

Fig 5. Thermal imaging insulators

About Thermal Technology

Thermal technology is based on the detection and measurement of the thermal radiation emitted by an object. Thermal radiation from very hot objects may be visible (as light) or invisible as infrared in the EM spectrum beyond what a human eye can see. Infrared radiation can be captured by a specialized sensor and converted to usable information in a visible color coded representation and/or converted to temperature. Infrared sensors can work in any light conditions (as in a darkened closed vault)

5. Mitigating Blast Effects, Robert E. Snodgrass, 2005

6. EPRI – Underground Roadmap, S. Eckroad, 2009

since they are measuring beyond the visible spectrum. Emissivity is an object's ability to emit thermal radiation and it can vary between objects of different material composition or color. When making measurements emissivity may have to be taken into consideration and in some cases comparative measurements may be more effective than absolute temperature measurements. Specialized cameras will have temperature 'zones' within the field of view that allow several measurements to be made from each camera position. Analytics can then be run separately on each zone allowing several points or splices to be monitored inside a vault at the same time from the same camera. Some cameras also have programmable pan/tilt positioning that allows several different views from a single camera. Thermal analytics provide processing of temperatures that compare between maximum and minimum thresholds and the rate of temperature change within each temperature zone. Temperatures exceeding preset thresholds will automatically send an alert to the operator through the SCADA system or through email.

Continuous vs. Periodic Thermal Monitoring

Heat dissipation is a sign of increased resistance in a splice and the resulting energy is calculated using I^2R. A joint or splice may not show a significant increase in temperature until the system is under load and increased current is flowing through the splice. The temperature in the splice may peak at certain times of the day that will be caught with a continuous monitoring system where a periodic observation may miss it. Automated thermal analytics can notify operations when temperatures are trending out of range and can be monitored on the utility SCADA HMI. Continuous monitoring also allows for trending analysis to see how the overall conditions of equipment and splices in the vault are changing over time.

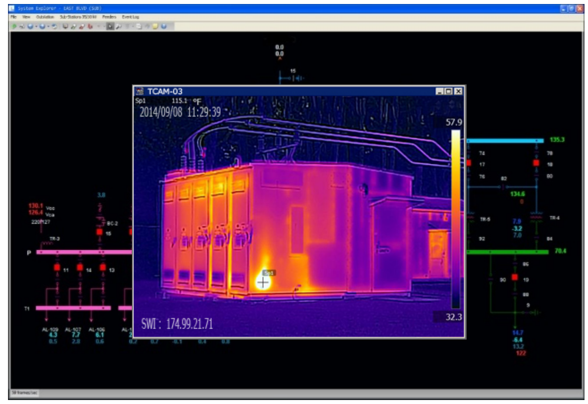

Fig 6. SCADA integrated visual monitoring

Conclusions

Underground cabling is a significant investment for a utility that is expensive both to install and repair so considerations should be taken to monitor and protect it from premature destruction. Its not only the cost of repair that needs to be considered but also the time that customers will be out of service. There are several effective methods for testing the conditions of joints and splices, i.e. resistance measuring, thumping, sectionalizing and periodic IR monitoring but these are time consuming, labor intensive and in some cases destructive. Continuous video monitoring offers a remote, non-invasive, multifunctional, visual assessment that provides an early warning that further testing or maintenance is required. Once a potential problem is detected a more detailed analysis can be carried out to determine what type of repair will be required to improve the reliability of the system.