Utilizing Visual and Thermal Video Analytics to enhance Operational Efficiency

I. Introduction

Automated video systems provide utilities with real-time visualization of the substation allowing them to make key decisions designed to prevent outages, save time and reduce costs. Substation video systems use sophisticated multifunctional sensors and provide real-time information and analysis for input into substation maintenance and operations programs. Using the latest technology in video automation, these systems monitor key points in the substation providing visual and thermal imaging that ties into the utility SCADA system. Operators are provided real-time visualization of the substation assets and are automatically notified when normal operating conditions are not being met.

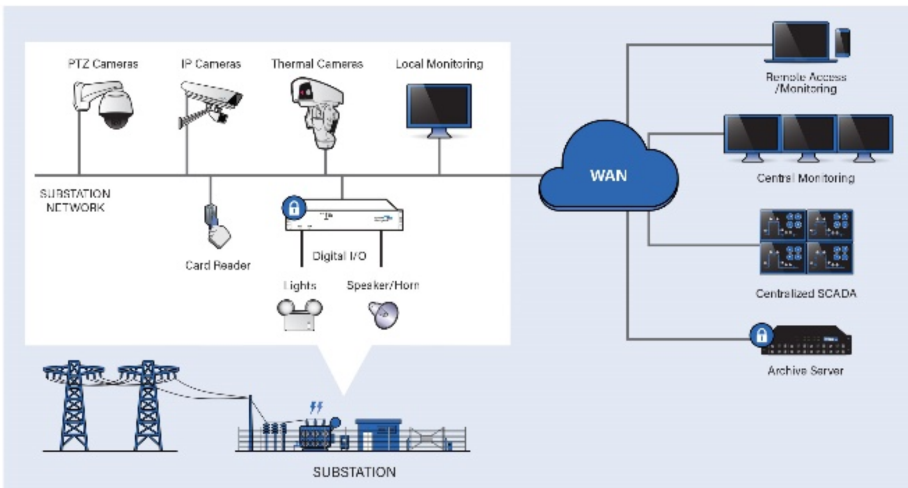

Figure 1: Video System Architecture on an IP Network

Modern Industrial Video Monitoring Systems use digital technology to send images over an Internet Protocol (IP) network. An IP network is commonly used for Internet connections and corporate LANs making it a very common, easy to use and deploy technology that can be used to connect and tie together separate systems to make more powerful and useful solutions. Use of IP technology allows video systems to be connected to existing corporate networks and to be managed by existing personnel and policies minimizing installation costs and training. IP networking techniques allow the video system to be secured and segregated from the Internet and from the corporate LAN but still connected to the control center and the SCADA network. As an example, video systems from several substations can be accessed for viewing from the control center, connected to the energy SCADA system and connected to a remote archive server, all over an IP network (Figure 1).

II. Visual and Thermal Monitoring on Industrial Process Networks

IP networks are commonly deployed in substations and other industrial applications to connect Intelligent Electronic Devices, (IEDs), Remote Terminal Units, (RTUs), and other protection and control equipment to each other and to the SCADA system [1,2]. Substation automation networks are industrial, process based networks that run critical applications to keep substation equipment and the power system protected and running safely [3]. Process based communications is machine to machine so uninterrupted and timely delivery of data is critical to keep processes running correctly. Process based networks must therefore be kept isolated from the Internet and other corporate traffic to ensure that the data flow is secure and free of losses. In an IP network, technologies such as Virtual Private Networks, (VPNs), subnets and firewalls are used to keep the substation network isolated from the rest of the corporate LAN [4].

The video monitoring system is connected on the substation network so it can communicate with the SCADA system at the control center with alarms, messages, visual and thermal information of the operating conditions at the substation. The information can be fed into the control system for automated responses or for operators to make decisions and take actions. Since the substation network requires access privileges, the video and SCADA systems are not accessible to personnel without proper authorization.

III. Visual and Thermal Monitoring Systems for Substation Automation

Substation monitoring systems differ from conventional video systems in function and application. A substation monitoring system is designed to give utilities a real-time view of the operational status of high value assets at remote substations from both the visual and thermal perspective. This differs from the conventional video system that is focussed on physical security. A substation monitoring system can provide both operational and security functions [5].

Figure 2: Embedded Video Snapshot

The data obtained from the video and thermal sensors is processed by an analytics engine in a server at the substation that monitors the conditions at the site and determines if an alert should be sent to the operations and control center. A typical substation can have several video and thermal sensors deployed and it is not possible for operators to constantly monitor them all, especially if there are multiple substations involved. The video and thermal analytics automate the monitoring process and provide the alerts directly to the utility SCADA system when further action is required. Operators can open the alert message to view a video snap-shot of the event and open a real-time video feed from the substation to view the live scene (Figure 2). All the video and alerts are recorded at the substation for review and archiving.

IV. Visual Monitoring and Analytics

Visual monitoring has multiple operational, maintenance and safety applications in a substation that can be done without sending a crew to the site:

Operational/Maintenance:

- Automated detection of events such as arc flash and switch arm movement
- Confirmation of remote controlled operations such as switch opening/closing
- Detection of animals around lines, switches, transformers

Safety:

- Ensuring safe conditions for the public and work crews at remote sites
- Witness and record that proper operational procedures are followed
- Intrusion detection, tampering, vandalism

To use the input from all video cameras installed in all substations for the tasks mentioned above, a constant monitoring is required. However, monitoring simultaneously the video channels from all substation is an impossible task for one operator. Here is where the use of video analytics becomes crucial.

Video analytics have been used for security video system for years. Most of them use algorithms that subtract the picture background from a video feed and analyze the shape and behaviour of the objects left on the foreground. All these techniques have been mostly used to create video analytics routines for security purposes (e.g. motion detection, virtual tripwires, loitering alarms, etc.) [6], however, using the same concepts and algorithms, analytics can be manipulated to perform functions that are specific to electric power applications. As an example, if the analytic is fine tuned to a specific area and type of movement, the analytics can determine the position of a disconnect switch arm and if it has moved. Similarly, analytics can be tuned and focussed on the switch contacts to detect an arc flash event that can provide an operator information about an unintentional event or operation.

V. Thermal Monitoring and Analytics

For several years, Infrared thermographic inspection has played a key role in maintenance plans in electrical utilities due to its non-invasiveness, safety and relatively low-cost approach [7]. This technology detects and measures infrared (IR) radiation coming from objects in the field of view of the thermal camera and turns it into a visual image that represents the temperature of the objects. Traditionally, IR thermographic inspections are done by technical experts using handheld thermal imaging cameras targeting specific components in a substation like transformers, breakers, capacitor banks, control cabinets, cable joints and insulation, etc. Due to the manual nature of the inspection, it cannot be done continuously and it is very common to have several months passed between two consecutive thermal inspections at a same site. Even though it is still a helpful tool to locate potential issues with components in a substation, the prolonged period between manual thermal inspections makes it impractical for real preventive and predictive maintenance. Furthermore, issues can arise very quickly in an electrical substation causing considerable damage before an scheduled inspection takes place. A fully automated thermal monitoring system that can run continuously in a substation would be the adequate tool for a proper preventive and predictive maintenance plan.

Every component or equipment in a substation has a normal temperature of operation. Components in the path of an electric current will dissipate power in the form of heat proportional to its resistance to the current. Electromagnetic induction generates heat in the core of transformers which is usually dissipated with radiator fins. Insulators on the other hand are not in the path of current, so they should be at ambient temperature if they are in good condition. Understanding the temperature behaviour of critical components in the substation is crucial to establish the targets for an automated thermal system: It is not always about finding the hot spot, but also the not-hot spot.

Here are some examples of situations with critical components in a substation that can be detected using thermal cameras:

a. Transformers

Electromagnetic induction generates heat in the core of a transformer so a working temperature higher than ambient is usually expected, however, defects in the structure will create hot spots in unusual places around the body of the transformer. Other components that can have unusual temperature behaviour are:

- *Primary and secondary bushing connections:* Loose or dirty connections, unbalance and overloading problems can cause overheating in the connections (Figure 3). The connection with the problem will be hotter than the connections of other phases.

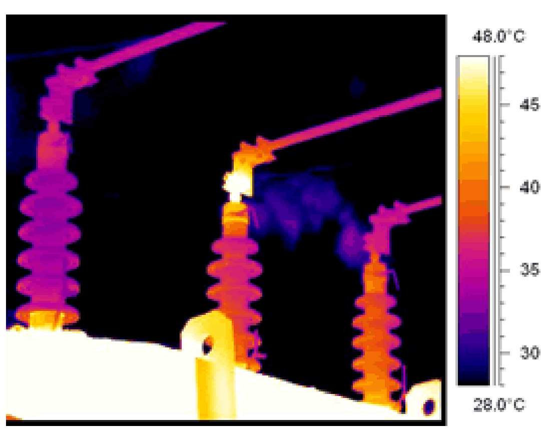

Figure 3. Transformer showing center primary side bushing with external connection problem [8]

- *Cooling fins:* Cooling fins normally appear warm as they dissipate the heat generated in the core and windings of a transformer. If it is seen that one or more fins have lower temperature than the other fins (Figure 4.), then it can be concluded that the circulation of oil is being limited in those fins, probably due to low oil level, flow obstruction, a closed valve, or perhaps the apparatus is out of level [9,10]. An automated thermal system can detect an increment of the delta temperature between fins and report it to an SCADA system.

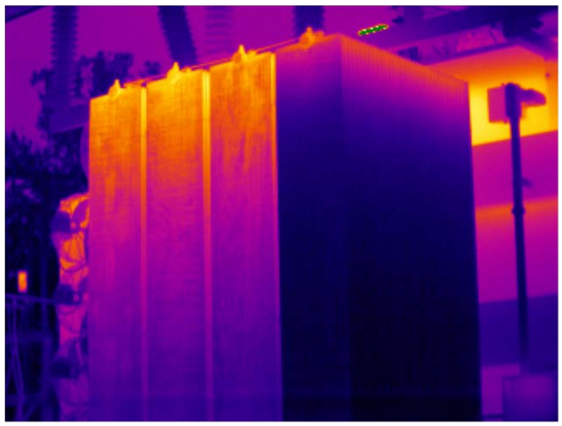

Figure 4. Transformer showing a problem with a cooling fin. [10]

- *Internal problems in bushings:* A study found that, out of the problems a transformer can have, bushing failures are the ones that most often lead to fire in a substation [11]. Thermal imaging can show internal defects or connection problems in the bushing (Figure 5). It is important to remember that the temperature inside the bushing will be much higher than surface temperature detected by the camera.

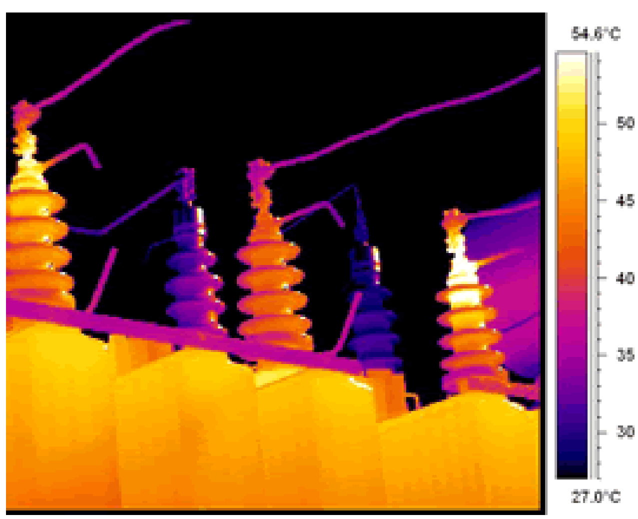

Figure 5. Transformer showing left and right primary side bushings with internal problems [8].

b. ***Circuit breakers:*** Several different problems with circuit breakers can be detected by using thermography (Figure 6). Like transformers, a faulty or dirty connection between bushing and conductor cable or a bushing with structural damages will overheat during operation, which can be detected with a thermal camera.

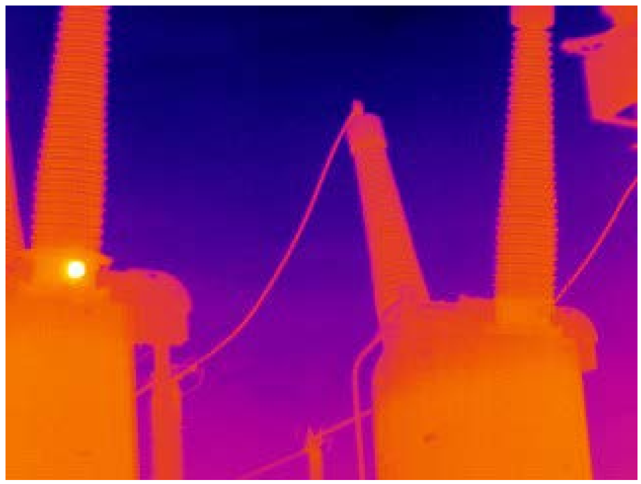

Figure 6. Circuit breaker with a problem on the test tap cone [12].

VI. Types of Thermal Cameras

Up until a few years ago, most thermography systems used in commercial and military applications were based on photon detectors. This technology has both perfect signal-to-noise performance and a very fast response (as low as 50us). But to achieve this, photon detectors require cryogenic cooling, which made thermal cameras based on this technology bulky, heavy, expensive and inconvenient to use.

Another technology of IR detectors is known as thermal detectors. They are not as sensitive as photon detectors and their response is not as fast (as low as 200ms), but they are cheaper and easier to use than photon sensors, and they can work at room temperature. In recent years, development in this technology compensated the moderate sensitivity of thermal detectors using large arrays of them [13]. This improvement made possible the use of this type of detectors in real life applications that didn't need a time resolution lower than 200ms, like in an electrical substation. A common misconception is that thermal security cameras, which are based on thermal detectors technology, can be also used to monitor the temperature of components in a substation. These security cameras usually have a simple array of thermal detectors which does not have enough sensitivity for accurate thermal readings, and the ones that are sensitive enough do not have embedded software tools to provide thermal readings, instead they rely on external software applications that analyzes the thermal images offline which is impractical for real time monitoring. A thermal image from a thermal security camera will show, for example, that the bushing connections of a transformer are hot but will not provide enough information about the actual temperature of those connections or if there is a delta temperature between two of them. This is information that is crucial for real substation automation purposes and for preventive/predictive maintenance.

VII. Methods of Thermal Measurement

There are two common ways to assess the thermal condition of components in a substation. One is quantitative, where the objective is to get a fairly accurate temperature of the equipment. The other way is qualitative, where the goal is to find difference in temperature between two components that should have a similar temperature, which can be understood as a hot or cold spot [7]. Each technique has pros and cons, and should be used depending on the type of automation process that is required. A good thermal camera system should provide tools to use both methods.

a- Quantitative method

In this method, the temperature readings from the IR camera are used as the real temperature of the component. This temperature reading can then be compared to a threshold set by the component manufacturer for normal operation, and trigger alarms when the temperature passes that threshold. It can also be used to create models that can help to predict when a component may break.

The problem with this method is the factors intrinsic to the component in which temperature is being measured (i.e. emissivity, size and distance from the camera), as well as environmental (i.e. ambient temperature, humidity, rain, wind, velocity and solar radiation), that affect the IR light reaching the camera [14]. All these factors should be taken into account when the temperature reading is calculated to have a valid useful temperature value. Factors related to the component can be provided by the manufacturer or measured directly in the substation. Some electrical substations have weather stations that can be used to provide the required environmental inputs to the thermal system. However most of the times these factors are unknown. This is when the qualitative method is used.

b- Qualitative method

In this method the temperature readings from two components, whose difference in temperature or delta temperature (ΔT) is known, are compared. If the ΔT obtained from the measurements is different than the expected ΔT then an alarm is triggered. For this method to work, the components that are being compared should be made of the same material and be at a similar distance from the IR camera. As both components are affected by the same factors, those factors can be ignored from the calculations and still obtain a fairly accurate measurement of the ΔT between the two components.

This method can easily detect problems in the substation, however it cannot be used for modeling and failure prediction as it does not guarantee an accurate reading of the temperature of the component.

VIII. Visualization in SCADA

Representation of an electric power system traditionally consists of a one line diagram that shows essential information such as current and voltage levels, switch status etc. in a two-dimensional map. The information is real time and shown on the Human Machine Interface, (HMI), of the utility SCADA system. Integrating a video system with SCADA adds another dimension of real time visualization that is critical in making operational decisions and providing trending analysis input to prevent outages and prolong the life of high value assets.

While a SCADA or OMS/DMS system can provide critical information on the status of the system such as a breaker trip and power outage, visual and thermal video information can provide confirmation of the cause of the event and create real time situational awareness. Visualization may be able to provide clues as to why the breaker tripped and what is happening now at the remote site? Is a power line down? Is there a fire or leakage? With this information, the utility can safely and securely reduce the outage time by having knowledge of the problem before rolling the truck and sending personnel into the area.

More importantly, video information can reveal system inefficiencies by finding temperature hotspots in the system so the utility can make repairs before the failure occurs. Transformer losses, voltage drops and load imbalances can be caused by leakage current in insulators or high resistance connections in power system components. These components will often show increased heat buildup that can be detected by monitoring with thermal cameras. Continuous monitoring will provide alerts and trending data as the system goes through load cycles allowing the utility to perform condition based maintenance on the system before failures and outages occur.

IX. Conclusion

Utilities are faced with the challenge of maintaining/improving service reliability without increasing costs. Video automation can remotely predict failures before they happen and detect and diagnose problems when they do. Video analytics automate the monitoring process to minimize the workload on operators and provide visual confirmation of the conditions at the substation. A visual monitoring system can make the operations more efficient in two ways: 1) automated remote inspections that reduce the number of trips to remote sites and 2) thermal monitoring that measures and analyzes the operating temperature of components in the power system that can be used to track the condition of the equipment and schedule when preventive maintenance should be performed.

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