INTEGRATED MONITORING SYSTEM FOR DISTRIBUTION SUBSTATIONS

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ABSTRACT

EDP Distribuição is testing and implementing solutions to perform online monitoring of a wide set of variables coming from scattered physical assets. EDP Distribuição as a DSO has significant number of unattended HV/MV substations that require inspections and maintenance operations in order to maintain their operational capabilities. Due to this large number of HV/MV substations, currently near 400, scheduling and performing maintenance and inspections activities is a very time intensive process which can lead to the detection of defects in an advanced state. In electrical installations hot spots and insulation breakage are key aspects in for predictive maintenance, since the evolution of these defects can lead to service interruptions in the worst case, degrading the quality of service. This paper presents an autonomous integrated inspection system to be installed in substations, including thermal and corona inspection, as well as intrusion detection. The development of this system came from the market absence of a solution that could integrate all of the components, considering the DSO requirements: low cost, autonomous and with minimal intervention from the operator.

INTRODUCTION

Currently EDP Distribuição performs thermography on an annual basis and occasional corona discharge inspections in order to identify hot spots and insulation breakage in substations. The ability to detect in real time hot spots and insulation breakage in substation abnormal situations enables predictive maintenance, preventing future component failures. In terms of corona discharge analyses the inspections are performed using specialized and quite expensive UV cameras. Facing an eventual replacement of ceramic based insulators by polymer based ones, corona discharge importance ramped up, due to the production of corrosive chemicals: ozone, nitrogen oxides which in presence of water vapor yield nitric acid. These corrosive materials shorten the life span of high voltage polymer based insulators leading to insulation breakage. Theft is also a concern, due to the unattended nature of substations, causing equipment damage that could cost millions of euros. Thus, EDP Distribuição uses stand-alone intrusion detection system in a small number of substations.

INTEGRATED MONITORING SYSTEM

EDP Distribuição has a pilot project with Institute of Systems and Robotics from Faculty of Sciences and Technology-University of Coimbra that comprises an innovative, low-cost and integrated solution for corona discharge and thermography inspection and surveillance in real time.

SYSTEM ARCHITECTURE

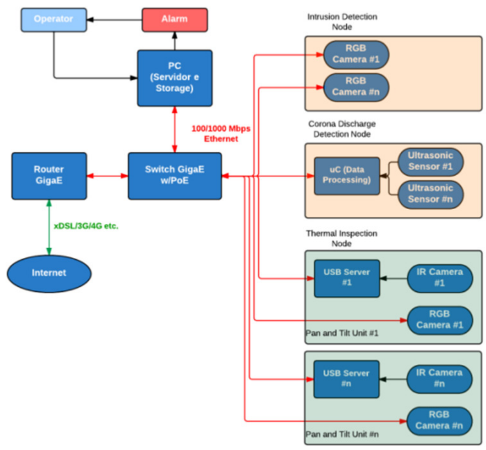

Figure 1 – Global system architecture for the monitoring system

The system is divided in three main sub-systems: Thermal Monitoring, Corona Discharge Detection and Intrusion Detection, that work independently from each other but share some hardware and computing capabilities (Figure 1). Due to the intensive computing requirement of the some nodes, such as the intrusion detection and the thermal monitoring sub-systems, their main application runs in one or more computers connected to the network, while the corona discharge detection nodes have local processing capabilities.

The system management and data visualization is performed through a website that aggregates the information provided by all the sub-systems. Via the website is possible to have access to the system information in real time, if alarm events have occurred and the evolution of the sampled variables by the platform.

The integrated system was developed taking into account the cost of the solution, aiming to be as low as possible and using readily available components, low installation complexity, high bandwidth for local access, low bandwidth requirements for external access and ease of integration of new components. Taking into account these requirements the infrastructure was implemented on a Gigabit Ethernet backbone, which allows the integration of the system in the substation or Distribution System Operator IT infrastructure. This architecture also allows a more versatile distribution of the computing nodes since they are not required to be in the same network or substation. The end nodes are connected to a switch with Power over Ethernet capability to minimize the cables required and simplify the equipment installation (the sensor nodes communicate and are powered through a single cable). The Internet connectivity is provided through a Gigabit router.

When an abnormal condition is detected, a specific alarm is triggered for the appropriate maintenance procedure to be performed. This system was validated in a distribution substation where the system performed with very good results.

CORONA DISCHARGE

Corona discharge creates corrosive materials, such as ozone and nitrogen oxides, which in presence of water vapor yield nitric acid. These corrosive materials shorten the life span of high voltage lines and substations components, especially non-ceramic insulators [1].

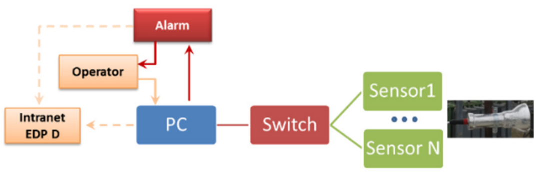

Figure 2 - Ultrasonic sensor system architecture.

The corona discharge detection sub-systems (Figure 2) is based on an ultrasonic detector, able to capture the ultrasound emitted by a corona discharge and measure in real time the existence and evolution of the corona defect on the installed equipment [2]. Depending on the signal emitted by the corona discharge, the software classifies its severity. When compared with UV cameras based inspection, ultrasonic technology is a low cost and effective technology.

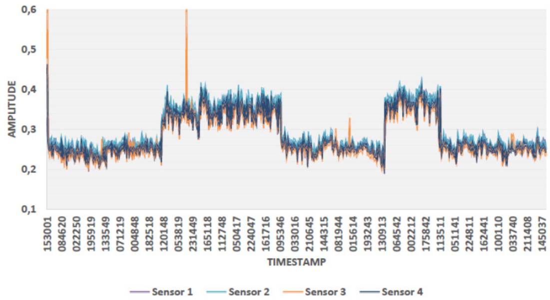

Figure 3 - Corona discharge overview

A data log in the main system shows the daily evolution of the corona effect which can help to estimate component failure, which in this case is associated with isolation breakdown (Figure 3).

This solution is cheaper, can operate in all-weather conditions 24/7 and in an fully autonomous way, allowing the operator to track the evolution of the corona effect under a significant number of conditions (such as weather and system load).

Each sensor node is composed by multiple sensors and a processing unit that acquires samples from each sensor at a predetermined period of time for analysis. The signal is normalized to eliminate the distance effect in the signal attenuation, followed by a peak and amplitude detection, to verify if they occur in a periodic fashion. If the peaks are periodic, then they are averaged and the amount of these peaks above a given threshold (for instance 25%) are determined. The number of peaks above this preset threshold is indexed to the severity of the corona effect detected. A Fast Fourier Transform (FFT) analysis is also performed to check if a 50/60 Hz frequency component is present. The presence of this component indicates that the defect is from an electrical source.

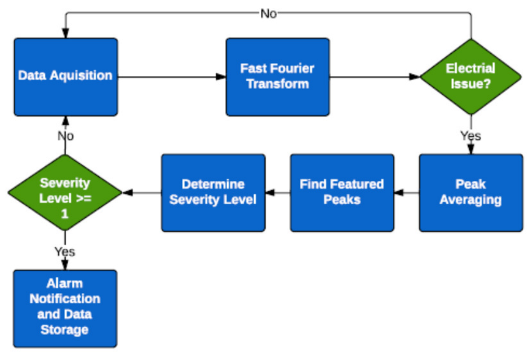

Figure 4 - Corona effect classification algorithm

The severity classification is based on the featured peaks percentage, 25% higher than the average (positive and negative):

$$Peaks(\%) = (N\_featured\_peaks = N\_hcycles) \times 100 \quad (1)$$

Since the corona effect occurs on the peaks, both negative and positive ones, of the sinusoidal wave, the number of half cycles, for a given signal sample and considering the frequency of the grid, is given by:

$$N\_hcycles = (Tsample \times Fgrid \times 2) \quad (2)$$

Based on the amount of peaks above the peak average, the severity is quantified by (using Equation 2):

1. High - Percentage of peaks above 1%;
2. Medium - Percentage of peaks between 0.5-1%;
3. Low - Percentage of peaks between 0-0.5%;
4. Quiet - Percentage of peaks equal to 0%;

If the classification of the sampled signal meets one of the above criteria, a notification is sent to system operator for further analysis. And data is stored for future evolution analysis. The quiet cases are not synonyms that there is no corona effect. There may be corona present, just not at a degree of severity required to emit crackles.

The sensor is able to detect in real time the corona effect on the equipment installed on a substation. This system classifies and triggers an alarm when a corona evidence is detected and also allows to track the evolution of the corona effect in a substation over the time, helping to predict a possible equipment failure. Based on tests performed to the sensor on a live substation environment, the setup was able to detect the features of the corona with high reliability for distances up to fifteen meters.

THERMOGRAPHY

Heat rising in electrical components can be due to various reasons, namely contact problems, unbalanced loads, insulation breakdown, defective components, etc. that will eventually lead to a component failure. Due to the large number of components to inspect spread over an extensive area in a substation a contact monitoring solution is not viable, being developed a solution based on two types of node a based on remote sensing technologies. A multi-spectral node, composed by an infrared camera and an RGB camera mounted on a pan and tilt unit, to provide orientation capabilities for the cameras, and infrared spot sensors that are used to cover blind spots for the infrared camera. Both the infrared camera and spot sensors are sensible to wavelengths between 8-13 μm (Long Wave Infrared), the useful part of the spectrum for thermal inspection [3-4]. In Figure 5 is represented the architecture of the thermal monitoring system. It should be noted that the network equipment and PC is shared with the other sub-systems.

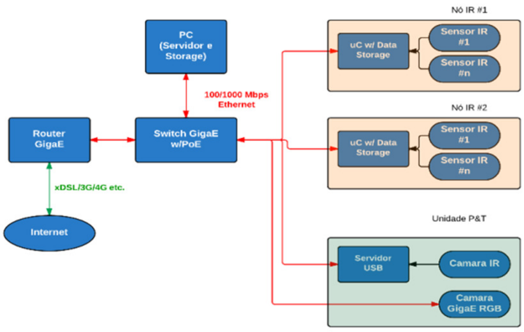

Figure 5 - Thermal monitoring sub-system architecture.

The thermography sub-system monitors in real time the substation environment using infrared cameras installed in pan and tilt units. The thermal monitoring communication infra-structure is based on Gigabit Ethernet and all the sensors node support the IEEE 802.3f standard, which describes the Power over Ethernet standard. The nodes are connected to a Gigabit switch that can supply up to 30 Watts. The multi-spectral unit is presented in Figure 6.

Figure 6 - Thermal monitoring multi-spectral unit.

The multi-spectral unit is autonomous in is normal mode of operation, however this mode can be override and be manually controlled, by using a graphical or a command line interface (Figure 7).

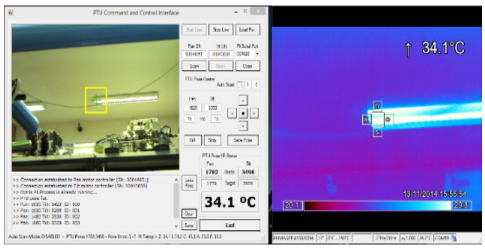

Figure 7 – Control interface of the thermal monitoring system

Using a thermal camera, thermal profiles of electrical equipment and connectors are captured, consisting in a thermal image with an associated temperature scale. Since the position of each component to inspect in the substation is known, the temperature measured is then associated with a given component. Components are also grouped in groups of three (3 phase system) which facilitates the detection of a possible faulty component by software, since it is hardly likely that all components fail at the same time.

For each scan the system stores the timestamp of the reading, the component ID, pan and tilt pose and associated error (based on position target and feedback), component, ambient and camera temperature. The scan duration depends on the number of components to analyze, however a full system scan per hour is easily achievable.

The software gives feedback of the temperature in the region of interest and unit pose and allows manual or autonomous operation. In the manual mode allows the user to operate a pan and tilt unit while in the autonomous mode the system scans all the components registered on the system. Each component is identified by their pan and tilt angles associated to a given multi-spectral unit. In case of abnormal temperature situation an alarm is raised and an email is sent with a snapshot of the region where the abnormal temperature is detected and respective coordinates.

The IR spot sensors (Figure 8) are used to monitor components that are in the blind spot of the multi-spectral unit. These sensors have an IP66 protection index and allow temperature readings in the range of -40 to 1030 C with an accuracy of ±1.5 ºC or ±1.5%.

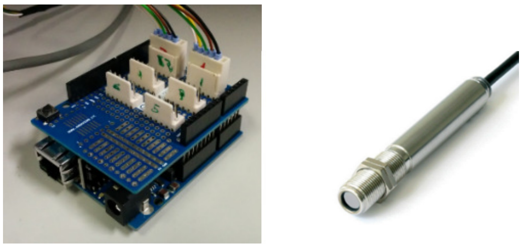

Figure 8 - IR spot sensor node (left) and detail of the Optris CS LT15 IR sensor (right) used.

Each node is composed by up to six IR sensors, a processing unit and an Ethernet network interface. The node also provides local data storage through the use of a memory card and also runs a local telnet server that is used for the node configuration and remote data access. The system is configured to perform temperature readings from all the IR sensors at a 1Hz data rate. Temperature data for each sensor is averaged using a 60 seconds window a stored in a log file with the respective timestamps and sensor ID. An alarm situation is raised when a 20% temperature rising is identified in a minute or the temperature of a given component is off by 10ºC when compared with similar components.

The system developed and installed on-site for thermal monitoring have proved effective in covering the points of interest and detecting situations likely to generate alarms. The monitoring system based on IR spot sensors also proved effective and robust in the detection of hotspots, as in the previous system, a warning is generated with the area, temperature, date and time information.

SURVEILLANCE

The surveillance sub-system is able to perform intelligent motion and intrusion detection, being able to monitor the substation area with the implementation of virtual barriers and trigger an alarm notification depending on the detected intrusion. Moreover, there is the capability of tracking the intruding body in the image element and between several cameras.

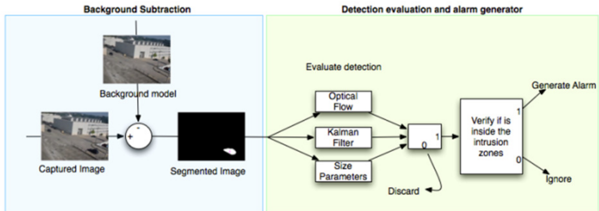

Figure 9 – Surveillance System Architecture

Figure 2 shows the surveillance system architecture which comprises two main stages: i) Event detection by means of robust foreground/background segmentation, and ii) Event tracking and validation where detected events are spatially and temporarily validated [5-6].
For the purpose of event detection, a dynamic eigen-backgrounds solution was adopted providing robustness against illumination variations, whereas for the events validation a Kalman filter tracker was used to extract image objects trajectories and temporarily validate the detected events [7]. In order to enhance the performance of the system, several features (HOG & Optical flow) are extracted from the tracked objects, which are used by a Support Vector Machine classification system to recognize pedestrians against other types of events that may trigger events within the field of view of the camera.
The intruder detection system is supported on a set of virtual barriers (figure 3), triggering an intrusion alarm each time an intrusion is detected and confirmed has been triggered by a pedestrian crossing a virtual barrier. The virtual barriers are user defined, allowing the definition of different types of barriers organized on a hierarchical structure.

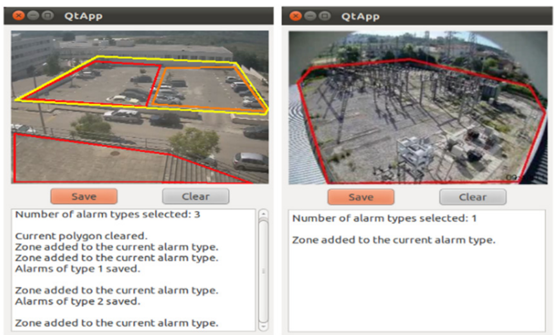

Figure 10 – Hierarchical Virtual Barrier User Interface

Depending on the distribution substation under surveillance, multiple surveillance nodes (cameras) can be incorporated to the system, providing total scalability to the video surveillance system. Each node acts on a stand-alone fashion, incorporation in-node processing capabilities, distributing intrusion detections to the other nodes of the system, increasing system robustness and reducing false positive detections level.

Figure 4 - Intrusions detected in a substation. Top, L-R: a) pedestrian, b) semi-occluded person, c) pedestrians at a large distance. Bottom, L-R: d) pedestrians, e) truck, f) cat.

Figure 4 shows several intrusion events detections, where the source of intrusion was successfully recognized by the intruder classification system.

For remote surveillance purpose, the system incorporates a web remote monitoring platform, which enables real-time video streaming from surveillance cameras and also intrusion retrieving by logging on the list of intrusion detections locally stored. Events statistical data is displayed to the user using hourly/daily/monthly charts

CONCLUSIONS

So far, the evolution of Smart Grids has been mostly driven by objectives of both energy efficiency and operational flexibility, especially pursuing the ability to manage over energy flows across networks with smart metering and several automation mechanisms and tools. In this process of distributing intelligence throughout the infra-structure, the logical 'counterpoint' to such operational goals consists in the ability to manage the relevant capabilities of scattered physical assets, with criteria and tools of the Asset Management scope, from investment decision support and, thereafter, throughout the entire life cycle exploitation.

The recent significant advances in different technological areas – sensors, microsystems, wireless networks, and web service programming has made it feasible to bring industrial maintenance to higher levels, by bringing together maintenance, operation and engineering, through the whole life cycle of assets. The key to this policy lies in the ability to monitor, in real-time, a number of variables that describe the operating status and condition of equipment that being critical to the respective process operation, should be subject to more sophisticated maintenance criteria: Condition-Based Maintenance (CBM) and, in the long-term, other forms of predictive maintenance based on Risk Management criteria, are now being preferred by most utilities.

This system provides both alarm and warning messages to staff in charge, corresponding to instant detection of appliance failures, as single events, as much as early warning of probable future malfunctions, from trend analysis of slow varying analogue data. Thus, allowing faster and more reliable condition diagnosis of Distribution HV/MV Substations and, therefore, accurate and timely responses whenever required, the present solution is part of a broader sophisticated framework of asset management, which provides gains in operation efficiency, power availability and overall quality of service. The cost to deploy a monitoring platform like this can vary typically, depending on the area and number of components to inspect in a substation.

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