Abstract -- This article describes the development of an unmanned monitoring system for the detection of hot spots inside a power substation. It uses an infrared camera connected to a robot which moves along the substation via a steel cable inside the substation. The robot is remotely controlled by a wireless system, operating at a frequency of 2.45 GHz (WiFi). The camera is dynamically directed to different substation components through a pan-tilt system. The whole structure is controlled by a microcomputer software located in a control room, around 200 m away from the robot. Aside of controlling the robot pan-tilt movements, the software also performs the data acquisition and analysis of thermographic images, thus detecting the referred hot spots.

Index Terms -- Thermography, robotic, wireless communication.

I. INTRODUCTION

The use of infrared cameras for fault detection is becoming a common practice in the maintenance routines of the different substation components [1], [2]. In an EHV substation, the reliability required from these components is critical. This was the main reason for the development of a system in which the infrared camera could be automatically moved inside the substation and positioned for collecting images of possible critical points.

Among the criteria adopted for developing this system, can be mentioned: the system robustness, so as to withstand the region’s high temperatures and air humidity (typical of the Brazilian Northern and Northeast regions) and its autonomy, so as to avoid the presence of a specialized professionals in situ. In [3]-[5], the application of automated systems for the inspection and some other specific tasks in transmission lines are described. The robot herein described has a different application as it deals with a real time monitoring system inside the substation aiming at safety during operation.

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II. BASIC DESCRIPTION OF THE SYSTEM

Several alternatives for the robot displacement along the substation were initially considered, such as: the over rail option, over the substation shield wires, and also carried over a special steel cable installed.

Despite the advantages offered by the rail option, such as its flexibility, size and better mechanical base for the robot and its related components, it was found to be very expensive in Brazil because an off the shelf product was investigated. This disadvantage appeared still in its design phase.

The use of the substation’s shield wires for the robot displacement could be considered in the future; although it would be necessary the development of a method for crossing the cables connection points in the substation. These were the main reasons for discarding this option.

The use of a steel cable (special installation in the edge of the substation) upon which the device moves (Figure 1) was found to be the best cost-benefit solution for this prototype. As the robot is suspended at a certain height, the interference with the maintenance vehicles is low. Also, it allows the infrared camera to be directed adequately with respect to the sun’s position, as it will be in a level above some critical points to be watched.

The choice on how to power the set composed by the robot, camera and others devices required another special attention. Due to the power required, a special type of battery was necessary which turned to be expensive. As for the lead-acid batteries option, a large quantity of them would be required making the robot too big.

Additionally, a system for recharging the battery in a scheduled and automatic way would have to be designed. However, in the future, the option for upgrading the battery and recharging system might be reconsidered in detail. The overall cost will also be evaluated and if reasonable the power cable option chosen will be replaced.

So, the power to feed the robot, as mentioned, was set to come from suspended cables at 220 V.
Figure 1. Robot propulsion system.

The robot moves itself using the steel cable as guide with two pulleys (one metallic and another made of polyurethane). The metallic pulley is responsible for the traction of the robot using an electric motor powered by a 12 V source inside the robot. The polyurethane pulley is connected to the mechanic odometer, aimed at positioning well the robot in the desired position. The power cable slides in the steel cable through a metallic rivet.

Inside the robot, a 220 V (AC), 12 V (DC) and 300 W converter is utilized to power the microprocessor and the motor. The robot’s traction motor power was chosen so as it can climb a sag of up to 6 m, carrying both the robot and the power cable.

Figure 2 shows a sketch of the robot, the guide and its position in relation to the control room. In this control room there will be a desktop with a control program installed. The communication between the robot and the control room is performed by a commercial WiFi System (IEEE 802.11g), operating at 2.45 GHz, supporting up to 54 MBPS.

III. DESCRIPTION OF THE ROBOT COMPONENTS

Figure 3 shows the main components of the proposed robot. Next, the main characteristics of such components will be described:

1. Camera: It is a FLIR A20 model camera with an Ethernet output. It is powered through a 12 V source and integrated with an IC LM35DZ aimed at monitoring the temperature of the substation components and to perform measuring corrections. It has a 12 mm telescope lens suitable for viewing the substation components at a distance up to 100 m. The spectral range of the camera is 7.5 to 13 µm (infrared wavelength), and the imaging is performed by a matrix of an uncooled microbolometer with a 160x120 dimension (approximately 19000 measuring points) which clearly defines the image resolution. The camera cover a temperature range of -20 to 250 °C, and it has both a video (PAL/NTSC) or digital (Ethernet 8bits) output.

It should be noted that the chosen camera is not a top one, mainly because at this time the image resolution was not a priority to be attained by the whole monitoring system but its performance.

The images are accessed either using the camera’s video output and monitor or via the Ethernet output where one can access the camera from the IP number of any regular browser. In order to protect the lenses and create a controlled temperature environment, a special glass window based on germanium alloy which is transparent to infrared light, with a transmission efficiency of 96% is used. The accuracy of the measured temperature is about ±2°C.

2. DC Motor: Due to its robustness and cost-efficiency, a 12V DC, 300 W motor (the same used in automobiles) is here used.

3. Motor Controller: Constituted by a circuit board with a PIC microcontroller that receives signals from a RS232 port and which controls the motor speed through a PWM converter. By using this circuit, it is possible to change the speed and to reverse the rotation direction. The circuit board is also responsible for receiving signals from the odometer, connected to one of the robot pulleys and establishing accurately the robot position.

4. RS232 – Ethernet converter, RS 232 – 485 converter and hub communication interfaces. This communication architecture was chosen because the images will be transmitted to the control room and System Operation Center (far from the substation).

5. Pan tilt: Included for moving the camera in a three dimension space. The system is controlled via commands sent by the RS485 interface. The range of the “pan” movement is 360° (around the horizontal axis), and the “tilt” movement ranges 180° in the vertical axis. Figure 4 shows both the types of movements as well as the components included in the robot.

6. Access Point: Receives the hub signals and transmits them through a wireless channel. It operates at a frequency of 2.45 GHz (IEEE 802.11g) and transmits a 10 dBm power.
7. Patch Antenna: Its aim is to provide a good signal coverage with a reasonable gain, small size as well as to offer a good mechanical resistance. A micro-line patch antenna with these characteristics was designed and installed in the robot. As micro-line antennas of this kind have a narrow operation band and because for the present application a band of approximately 100 MHz was necessary, it was proposed a patch antenna having an intermediate air layer. This is done in order to increase the operation band. The RF power is provided by a standard coaxial cable.

Figure 4. Overview of all components included in the robot.

IV. CONTROL ROOM EQUIPMENT DESCRIPTION

Within the control room there is a desktop with a WiFi PCI communication board and its respective software responsible for the management of the global system.

The software processes the thermographic images of the substation components limited only by the camera lens and the robot guide cable.

When an over-temperature is detected (automatic mode), the system sends a message to the control room and to the Utility Operating Center with the time and the image that triggered the alarm.

The system has the ability to stop the robot in strategic positions, in this way certain substation components can be better imaged and analyzed. It was the case of some disconnection switches’ main contacts that caused many faults due to improper contact closing.

This halt (stop) mechanism uses a pulse counter from the encoder. Therefore, there is a synchronism among the system elements. Briefly, the operation of the robot can be described as follows:

1. Once arriving to the targeted substation component the robot stops.
2. The pan-tilt is pointed towards the targeted component. This is done according to the coordinates stored in the control room’s desktop.
3. The image is taken and sent to the control room.
4. The robot goes on scanning until it finds the next stop signal.

Prior to stopping (once located the substation component to be imaged) the propulsion system reduces the robot speed to finally stop smoothly. This process is performed by a motor control (encoder). The positions in which these braking and stopping actions occur are stored in a table. The position in which the system stops is then sent to the control room’s computer which in turn sends such coordinates to the pan-tilt system for taking the desired position. Once the pan-tilt system is positioned, a message is sent to the desktop from where a command for taking the image is sent to the camera.

The software has also a manual adjusting module. Through this module similar commands for controlling the robot and the pan-tilt positions can be sent by an operator. The objective of this module is to define the position of the substation components whose thermal analyses would be of interest during the system commissioning stage. These position records (pan-tilt and robot position) can be loaded to the software for future automatic operation of the scanning system. Another function of this module is the manual access from the control room. In this way, the operator can get the thermographic image of any component not included in the automatic monitoring mode.

V. EXPERIMENTAL RESULTS

During the steel cable installation phase and also the first tests of the system wireless connectivity, it was noticed that care should be taken while aligning the patch antenna of both the transmitter and receiver as well as while leveling the poles so as to set the steel cable as horizontally as possible. In this way, additional stresses upon the robot’s motor can be avoided.

Figure 5. Main screen of the computational system of the robot control.
Initially, the substation was segmented in 10 sections. The camera’s inclination and the robot position in the steel cable for each section were stored in the system. The automatic procedure divided the task into 5 ‘go and return’ records from the initial monitoring point.

The thermal image records confirmed the expected performance. The system was capable to register a number of observations according to the monitoring needs of the system. The maximum temperature recorded was 55°C at 16:35 (local time) in surfaces exposed to the sun (Figure 7).

For a 256 colors palette (gray scale) the dark colors indicate low temperatures whereas the bright colors represent highest temperatures. This monitoring system is not affected by the degree of luminosity, thus, it can also be used at night, without the solar radiation influence.

VI. CONCLUSIONS

The hot spot monitoring system presented in this paper can be an efficient tool for fault detection and its subsequent prevention during the operation of a substation. In order to perform periodic examinations of thermal behavior in strategic points, it was developed a system that records thermal images from an infrared camera. The use of an automatic system for receiving such information, in which the operator can configure all the parameters, may help in the detection of faults at their initial stages. This can be an important tool for strategic sectors such as the case of transmission systems, to the extent that the thermal-image technology allows.

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IX. BIOGRAPHIES

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