THERMAL DIAGNOSIS OF MV SWITCHBOARDS: A COST-EFFECTIVE, DEPENDABLE SOLUTION BASED ON AN OPTICAL SENSOR

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ABSTRACT

Thermal monitoring of conductors in MV substations is the best means of early detection of conduction faults that are liable to lead to thermal runaway and disruptive dielectric discharges. The system presented is based on the use of an optical temperature sensor. The physical principle used is the determination of the fluorescence time of a material when excited by a light pulse conveyed by optical fibers. This time is a known function of temperature. A cubicle may be equipped with twelve sensors which are totally insulated and therefore do not modify the dielectric withstand of the equipment. The sensors are entirely passive, which gives them a level of reliability and a service life compatible with those of switchgear. The device presented has the particularity of offering, for the first time, all the answers to facilities managers' needs since it provides reliable continuous installation monitoring at a cost which is compatible with the service rendered.

INTRODUCTION

Conduction faults are relatively rare in medium voltage switchboards, but the consequences of such faults are serious enough to justify a search for diagnosis systems to protect facilities managers from the risks involved.
Conduction problems are due to either loose connections or the deterioration of contact surfaces. They result in local temperature rise, and the greater the current, the greater the rise, which contributes itself to the downgrading of contact quality... This leads to thermal runaway which, when the temperature becomes excessive, deteriorates the insulating material and ends up causing disruptive dielectric discharges, which are a disaster for the MV substation.
The quest for greater safety and availability explains facilities managers' concern to use thermal monitoring in their installations, a concern which is shared by insurance companies which, more and more, are making this function compulsory in invitations to tender.

PREVIOUS SOLUTIONS

Periodic maintenance

To date, the solution most commonly used to protect against conduction faults consists of periodically carrying out maintenance operations. Typically, at the time of annual servicing, a complete inspection is made of the electrical installation, during which all the connections are checked, bolts tightened, etc. Those operations are costly on two accounts since they call for substantial labour as well as a lengthy shutdown of the substation, which runs counter to the growing need for availability.

Infrared thermal analysis

Another technique is gaining ground: infrared thermal analysis. It consists of periodically inspecting the installation by means of an infrared camera, with the aim of detecting thermal faults liable to reveal a conduction fault.
In order to have visual access to the conductors, it is necessary to adapt MV substations. Openings may be made in the metal plates of MV cubicles but this downgrades the degree of protection and hence operating safety. The solution therefore often consists of installing inspection ports made of quartz - the only material transparent to infrared rays - the cost of which is prohibitive. And despite these adaptations, there are still points to which visual access is impossible.
In addition, the infrared measurement principle is not very accurate since it only allows the emissivity of the radiating bodies to be measured, and not the temperature.
To detect a fault by means of infrared thermal analysis, several conditions must be met at the same time: it is necessary to have a substantial fault, a strong current to reveal it and an expert eye trained to detect differences in emissivity between phases.
The periodic nature of inspection is the main limiting factor with this practice. A fault which appears on the day after the yearly visit will only be detected a year later... if it does not degenerate into thermal runaway in the meantime.

Electronic temperature sensors

A short while ago, MV cubicle monitoring systems appeared, based on the use of electronic temperature sensors installed at the critical points. This solution offers the advantage of ensuring continuous monitoring of the installation and, as a result, detecting thermal faults very early.
Unfortunately, the galvanic barrier necessary for measurements on MV conductors leads to a complex electronic sensor architecture. Each sensor must draw its energy from the mains current and transmit digital data via an infrared or optical fiber link. Such complexity leads to a high cost for each measurement point.
However, the stumbling block with these solutions is that they require the installation, at medium voltage potential, of devices whose level of reliability and service life are incompatible with the associated switchgear and the function to be performed. A diagnosis system must be much more reliable than the equipment that it is monitoring, especially if, as it is the case here, it is not maintainable without a shutdown of the substation.

OPTICAL TEMPERATURE SENSOR

The key of the diagnosis system presented in this article is an optical temperature sensor which, as in solution above, allows continuous monitoring of the critical points of MV cubicles.
This sensor is based on a principle that has been known for a long time [1], but which, up to now, had been reserved for very specialized applications, of the instrumentation type, characterized by wide measurement ranges, high accuracy and also a very high price. What is original about the approach which led to the solution being presented is that the sensor developed is just sufficient for the diagnosis application: measurement of 0°C to 130°C, accuracy of ±2°C and very low cost.

Principle of the sensor

The sensitive component of the sensor is a material which has the property of transmitting a fluorescent signal, the decrease time of which depends strongly on the temperature at which it is carried.
Practically speaking, the material is placed at the ends of two plastic optical fibers (figure 1).

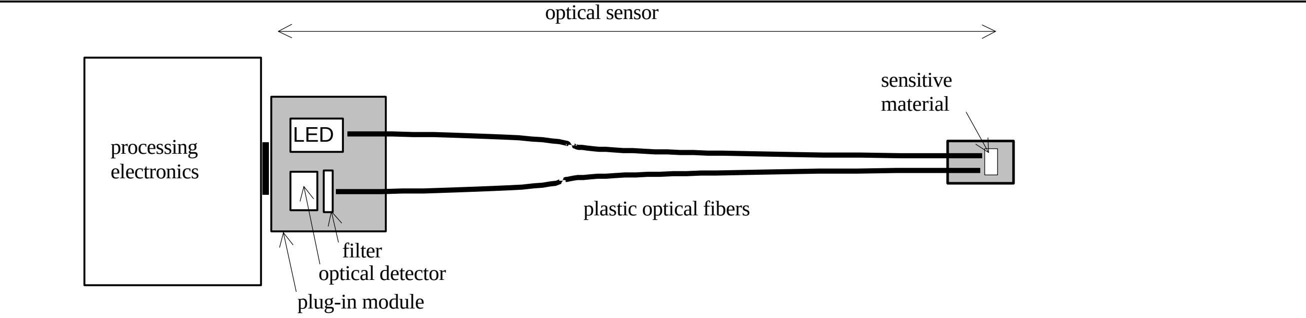

Figure 1: sensor architecture

A pulsed light beam from a light emitting diode is injected in the so-called rising fiber and conveys it to the transducer. The incident pulsed beam excites the sensitive material which transmits a fluorescent signal with an exponential-shaped fall (figure 2). A part of the fluorescent signal is collected by a second so-called descending fiber and is conveyed to an optical detector (Si photodiode). The optical filter inserted between the descending fiber and the optical detector eliminates any residual pump signal. The optical signal, now become electrical, is analyzed by processing electronics which measures the decrease time and converts it into "temperature" data by means of a conversion table which is stored in the memory.

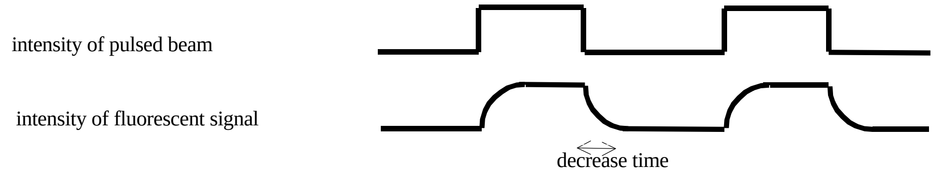

figure 2: shape of optical signals

It is interesting to observe that the time constant is in the range of a millisecond, which does not call for very fast and expensive detection electronics.

The average measurement sensitivity is in the range of 5 to 10µs/°C according to the temperature zone. A typical example of a temperature/decrease time conversion curve is given in figure 3.

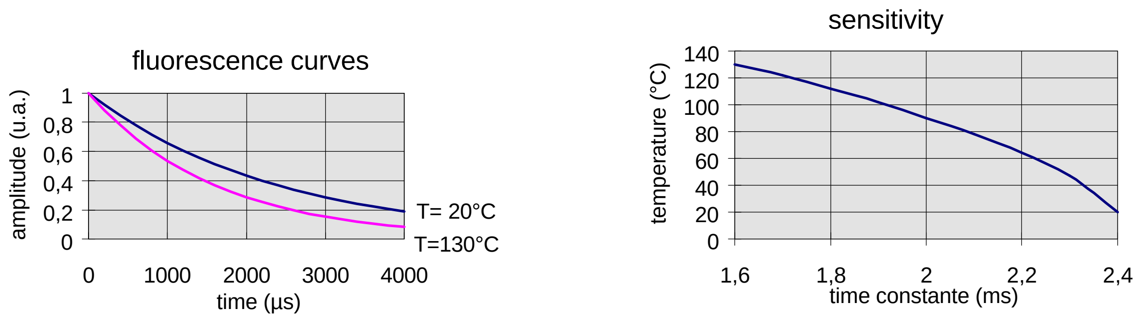

Figure 3: fluorescence curves and sensitivity curves

The choice of each component gives priority to the use of standard mass marketed components: LED used in traffic lights, optical detector from the automobile market, plastic optical fiber, polycarbonate molded light guides.
In addition, the sensor has been designed to give the user electrical type connectors which are much better suited to on-site handling than optical connectors are.
Two patents cover the innovations contained in the sensor.

Integration in the MV cubicle

In a MV cubicle, it is useful to monitor the temperature at 12 points i.e. 4 per phase: the busbar connection, the two plug-in contacts for the circuit breaker and the cable connections. Photo 1 below shows the MCset withdrawable metalclad MV cubicle equipped with the thermal diagnosis device. Figure 4 shows the position of the temperature sensors.

photo 1: Merlin Gerin MCset withdrawable metalclad MV cubicle

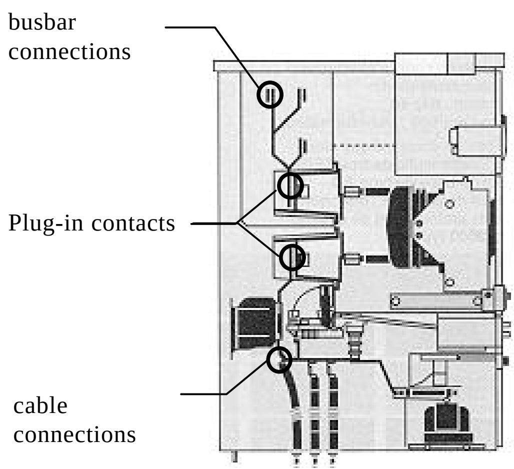

figure 4 : position of the sensors in MCset

The 12 temperature sensors (photo 2) are factory mounted on the cubicle conductors so as to guarantee installation quality. They are totally insulated and tests show that they do not downgrade the dielectric performance of the equipment.
They are connected to the Sepam protection unit (photo 3), installed in the low voltage compartment of the cubicle.

Sepam is a digital device which performs protection, metering, automation and communication functions. The integration of the board which processes the optical signals derived from the temperature waves enhances it with the thermal diagnosis function.

photo 2: temperature sensor

photo 3: Sepam protection unit

THERMAL DIAGNOSIS

Thermal diagnosis is split into two separate, complementary functions in Sepam:

- an early conduction fault detection function, the output of which is an alarm
- a thermal runaway detection function, the output of which is designed to open the circuit breaker and which is therefore more like a protection.

Early fault detection

Early fault detection improves availability and permits predictive maintenance.
Conduction downgrading phenomena are generally slow and progressive. Detection of them right from the start has the advantage of allowing the facilities manager to schedule a maintenance operation at the time which creates the least disturbance of the process and preserves the installation, mainly the contacts and insulating materials, since the thermal phenomena are still weak.
Early detection is necessarily fine-tuned protection since it analyzes small changes in temperature measurements. Several algorithms are being assessed, each of which has advantages (relevance, robustness) and drawbacks (processing quantity, storage resources). However, a few principles which give good results may be retained:

- exploitation of the comparison of the three phases;
- use of known cubicle thermal models.
- taking into account of current and ambient temperature measurements,

A compromise must be found in the determination of detection sensitivity. Since the phenomena are rare and slow, priority is given to the robustness of the algorithm in order to absolutely avoid all nuisance alarms. Therefore, any MV network fault situation (strong phase unbalance, short-circuit) or any temperature measurement fault (noise, incoherence) temporarily inhibits the function.
In the event of a conduction fault and therefore an alarm; the facilities manager is given the precise location in order to facilitate and shorten maintenance operations.

Thermal runaway detection

Detection and interruption of thermal runaway resulting from a conduction fault increase safety.
In the event of a failure to detect a conduction fault early or late maintenance operations, it is necessary to have a very simple function to save the installation.
Thermal runaway detection is a temperature setting function which, when it observes a measurement greater than a set point value, sets an output designed to control the opening of the circuit breaker.
Sepam offers substantial flexibility with respect to set points and the switching of outputs. Two different set points may be associated with each sensor, one to set an alarm and the other to trip the circuit breaker.

Operating dependability of the device

This type of diagnosis facility only serves a purpose in an electrical installation if it is reliable.
Used to detect faults which seldom occur, it should not give false alarms or even worse, cause nuisance tripping of the circuit breaker.
All the design choices have been made to promote dependability. The FMEA (Failure Mode and Effect Analysis) has been applied for the definition of the sensor electronics and software. It has led to the integration of a number of self-tests. A temperature measurement is only considered to be exploitable if it meets stringent coherence criteria. For example, all measurements with noise are rejected.
As we have seen above, the measurement processing algorithm also gives priority to robustness in the choices made. The slowness of the observed phenomena allows good results to be obtained without sacrificing sensitivity.
Installed on equipment with a long service life, at points that are not accessible with the power on, the sensors must have a very high MTTF and service life. This is the requirement that makes optical technology a must for temperature measurement since, in this case, the components at the potential level are totally passive.

CONCLUSION

The optical sensor described in this article is the result of the convergence of an already old optical technology with a need for switchgear safety that was previously poorly met. The advantage of the sensor lies in its full suitability for the target application, which allows it to reach a cost that is compatible with the service rendered.
Its existence opens up interesting prospects in the field of thermal diagnosis, beyond its application in MV cubicles: diagnosis of medium or even low voltage conductors, diagnosis of high current rating MV circuit breakers [2], monitoring and protection of power transformers, etc.
These applications will contribute to improving distribution network reliability and also to optimizing network operation. The temporary electricity consumption overloads with which facilities managers are commonly confronted will, in the future, take place under thermal control.
Reliable and inexpensive, the diagnosis function presented contributes strongly to making electrical installations safe and optimizing operating costs.

REFERENCES

[1] K.A. Wickersheim and R.V. Alves, "Recent Advances in Optical Temperature Measurement", Industrial Research Development, p. 82, (1979)

[2] J.Y. Blanc. "Generator circuit-breaker: maximum availability thanks to self-expansion progress", CEPSI 1998.