USING WIRELESS SENSORS IN THE REMOTE CONDITION MONITORING OF SECONDARY DISTRIBUTION SUBSTATIONS

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ABSTRACT

A solution for the condition monitoring and diagnosis of electric components in secondary (MV/LV) distribution substations (SDS) is presented, for the purpose of providing real-time monitoring, assessment, and remote communication of a number of status conditions, so as to improve maintenance criteria and operational control, yet at reduced costs. This system is based on a fully modular platform that encompasses a number of different, independent and self-contained smart devices which, being adequately located throughout a SDS – whether it is cabin-, vault-, or pole-type –, are locally integrated by a higher level unit over a wireless low-power, low-range network; a comprehensive functional integration may then be achieved over the Internet.

INTRODUCTION

Secondary (MV/LV) Distribution Substations (SDS) are relatively simple equipments that always exist in large numbers, spreading throughout the territory. Hence, they are typically dealt with as ‘abandoned’ infra-structures, whose maintenance, mostly in the hands of contractors, is often overlooked. In order to fight both the consequent rapid installation decay and the more recent wave of copper burglary that affects electrical utilities across the world, resorting to remote condition monitoring is a key solution, thus providing real-time monitoring, assessment, and remote communication of a number of status conditions, so as to improve maintenance criteria and operational control, yet at reduced costs.

In this line of approach, EDP Distribuição (EDP-D) – the main Distribution System Operator (DSO) in Portugal, where it operates over 60,000 SDS – firstly approached both the University of Coimbra and Eneida, SA, given their expertise and industrial background on smart sensors and the respective integration over both cabled and wireless communication networks, in order to devise, specify, and demonstrate an innovative systems platform for the overall condition monitoring of secondary distribution substations. This co-operative action led to that a former concept and design, dating from 2012 and still based on a Modbus RTU cabled network, was implemented in fourteen SDS of different types, within the framework of a successful pilot trial.

However, in a cost sensitive solution like this one, given its foreseeable scale of implementation, it soon became apparent that its feasibility would depend on gains arising from a wireless approach inside each SDS:

- Drastic cost reduction in both accessories and installation labour;
- Extreme system layout flexibility brought about by the lack of physical constraints;
- Enhanced modularity, granular in most cases, thus enabling all sorts of incremental growth as new devices and functions are easily added.

Thus, a completely new solution was developed from scratch which, by resorting to wireless technologies and the Internet in order to achieve comprehensive functional integration, matches the ‘Instrumentation Cloud’ approach, in line with the prospective vision of ‘The Internet of Things’ [1].

FUNCTIONAL SCOPE

Functionally, this system addresses the condition monitoring and diagnosis of electric components and, in accordance with the constructive type of SDS – whether it is cabin-, vault-, or pole-type –, the intrinsic safety evaluation and the prompt detection of impending security risks of the whole of SDS premises, as follows:

- Transformer: temperature and vibration pattern taken at the top lid, with a non-intrusive sensor, thus detecting both mechanical and thermal deviations from standard normal behaviour;
- Transformer: detection of partial discharges in the MV-input circuit (there comprising the automatic circuit breaker), with a non-intrusive ultra-sonic sensor (40 kHz);
- Switchboard: status information on all existing fuses, and real-time fuse blow-out detection;
- Switchboard: data acquisition of RMS current flowing at each and every output LV single-phase circuit, with an accuracy of ± 1% over the range of 1-400 A;
- Environmental safety: data acquisition of both temperature and relative humidity in the air, thus leading to abilities of both fire detection and ventilation malfunction diagnosis;
- Environmental safety: flood detection and water pump malfunction diagnosis and alarms;
- Intrusion alarm: prompt detection of intrusion through doors and ventilation grilles;
- Transformer attempted theft, in pole-type SDS: prompt detection of (i) pole climbing, (ii) non-authorized operation of the MV-input disconnect switch, and (iii) minor transformer displacement.

The information gathered at each and every SDS is intended to immediately serve both operational and maintenance purposes and, ultimately, also materials resource planning. This implies that data are to be selectively made available to the respective management tools, in contents and, especially, in timing: (i) dispatch, which, being typically overwhelmed with information, requires that this system behaves as an alarm centre, with timely, bold messages drawing attention to events, (ii) maintenance, which requires historic information to be amassed in order to support predictive decision, and (iii) resource planning, handling long time-series of information relevant to continuously evaluate the expected lifetime of assets, and to recommend investment opportunities. Such disparate requirements and constraints commanded a strategy of decentralised data processing, for each SDS based on a local machine acting as data concentrator, applications-dependent processor, and message handler.

Our approach to the architecture and some of the underlying technologies of a highly distributed systems platform is presented next, which, having the capability to integrate a number of deeply embedded devices that pass information among themselves and act as a single system, allow people in charge to intelligently and timely react to both trends and events found in those pieces of equipment under observation [2].

ARCHITECTURE AND DEPLOYMENT

In a SDS, the present solution consists of a fully modular platform that encompasses a number of different, independent and self-contained smart devices which, being adequately located throughout that SDS, are functionally integrated by a higher level unit over a wireless network. This single controller unit in a substation – a mix of a PLC-type machine, Web server, and telecommunication node of a WAN-IP network (over GPRS or LTE) – acts primarily as data collector and integrator from a number of sensors representing the status and condition of different devices.

As depicted in Figure 1, besides acting as node of a low-power, short-range wireless network (WPAN), this integrating unit has a role as gateway to the upper levels in the overall information system, for database maintenance, condition assessment, and alarm issuing.

Integration of data collected from a number of SDS is carried out by a central station – the co-ordinator centre –, which supports a common remote database based on Microsoft SQL Server, as well as web-services concerning the appropriate data handling and presentation for status assessment and diagnosis – according to the SCADA paradigm –, from virtually anywhere in the world; remote communication is carried out over the Internet, with recourse to a ‘mobile’ public network, and human interaction needs no more than light terminals, as thin clients.

Communication amongst smart devices in a SDS relies on a wireless network (WPAN) of either technology: (i) the ISM (Industrial, Scientific, and Medical) sub-GHz radiofrequency (RF) band (433 MHz), given its superior EMC and radio-range in environments hostile to RF signal-propagation, duly complemented by an efficient proprietary protocol, and (ii) ZigBee operating in the ISM 2.4 GHz band, mainly for the sake of worldwide compatibility.

Powering the smart sensors in a SDS was carried out according to the specific limitations concerning both the respective operational factors and environmental conditions; in particular, resorting to batteries was rejected whenever practical, so as to avoid the typical pitfalls in case they may have to endure high temperatures and the consequent maintenance costs. Thus, only three types of smart sensors run on internal battery, given their very low working duty cycles, as much as issues concerning their typical locations: (i) combined temperature and relative humidity in the air, (ii) water detection, and (iii) intrusion.

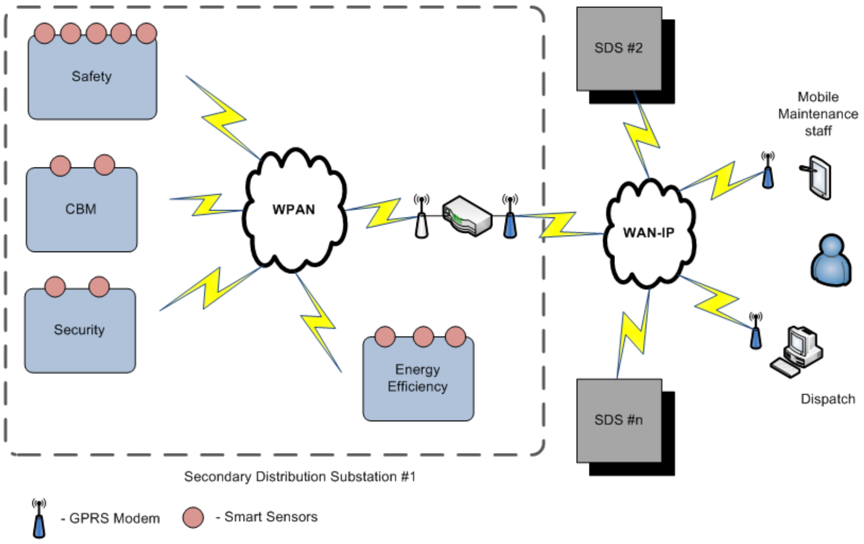

Figure 1 – Overall system architecture

Particularly, sensors for electric variables – fuse status detection and current measurement – are powered from the very circuits they monitor, the former by the ac voltage of the single phase circuit it watches over, and the latter using a split-core current transformer to obtain current there induced by the same current flow it measures. Other devices could be powered from a mains outlet, duly backed-up by a battery-inverter set, given their location and ascribed functions.

DATA HANDLING

As referred to above, information services provided by this systems platform are very disparate according to the served departments in a utility:

- Short messages and/or colour changing icons representing warning and alarm situations issued to a <u>dispatch</u> centre and to mobile terminals that equip teams on the ground, of contractors in an increasing number of cases;
- Data strings of analogue variables that are relevant to embody long time-series that are required to define behavioural profiles of equipments, namely transformers, and determine <u>maintenance</u> actions to be taken in case of verified deviation from a programmed standard profile, in either criteria of amplitude or time variation rate;
- Data strings of analogue variables used to assist the resource <u>planning</u> decision process, especially in what concerns reasoning on the economic and technical feasibility of life extension of transformers *vs.* buying replacements.

To note that the data concentrator located at each SDS is currently programmed to cross-correlate data gathered from different devices in the SDS, so that a complete ‘picture’ can be provided to final users, including diagnosis and recommended action.

As an example, the partial discharge detector provides information on the average frequency of discharges in a determined time period as well as their magnitudes (actually the measured magnitudes of the respective sound blasts); this is then correlated with both humidity and temperature data, in order to quantify the impending risk and, therefore, originate the warning/alarm message of the appropriate level. Given the absence of discharge events in our small scale pilot trial – despite the high levels of humidity verified across the past winter (2013/14) – we have no actual results to show.

In another example, measured temperature inside a cabin is compared against the overall SDS load – as depicted in Figure 2 –, thus recommending actions leading to load balancing or limitation; also, by correlating temperatures, humidity and load, it is possible for that unit to find out emerging fire situations or simple ventilation malfunction.

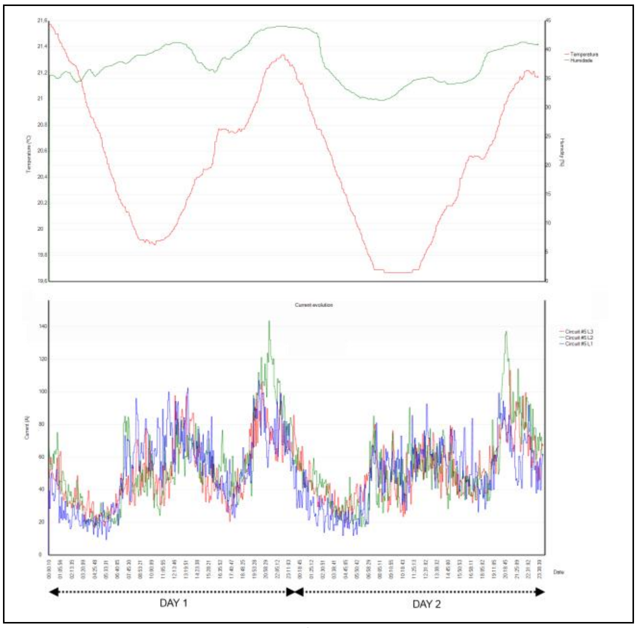

Figure 2 – Load diagram of a three-phase circuit (lower) synchronized with evolving temperature and humidity in the SDS (upper), for a 48 hour time-period

Figures 3-5 show the single-phase load diagrams that are superimposed in Figure 2, thus allowing an interactive fine analysis to take place.

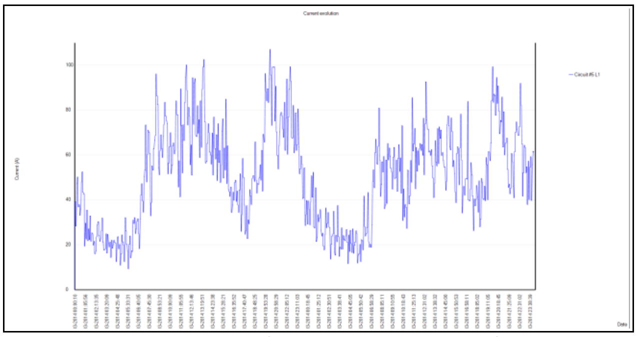

Figure 3 – Load diagram of single phase circuit L1, for a 48 hour time-period

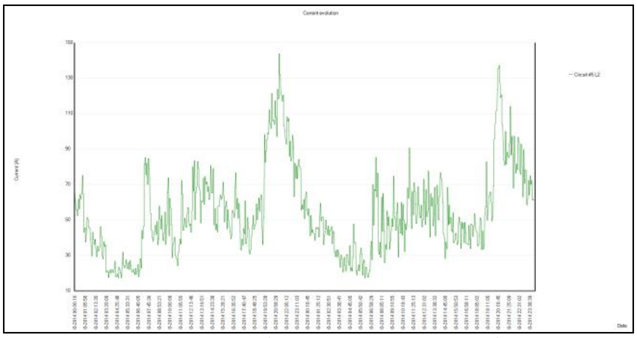

Figure 4 – Load diagram of single phase circuit L2, for a 48 hour time-period

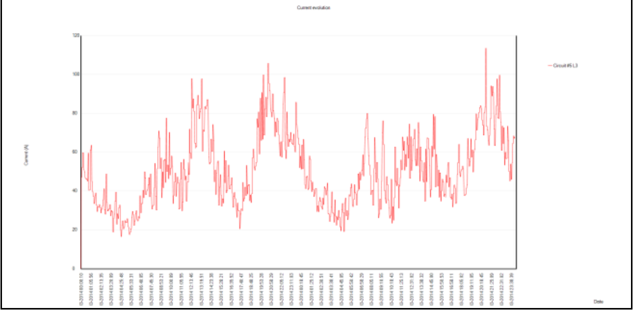

Figure 5 – Load diagram of single phase circuit L3, for a 48 hour time-period

CONCLUSION

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 future malfunctions that are likely to occur, from trends analysis of slow varying analogue data. Thus, allowing faster and more reliable condition diagnosis of Secondary Distribution Substations in a grid and, therefore, accurate and timely responses whenever required, the present solution is part of a broader sophisticated framework of asset management, with gains in operation efficiency, power availability and overall quality of service.

And indeed, it is from such capabilities of gathering, analysing, and supporting human decisions – while it does not start sending out worksheets on its own – that systems like this one represent valuable tools for the purpose of high-level asset management and, by increasing the amount of intelligence dispersed throughout electricity grids, these better deserve being designated as smart [3].

ACKNOWLEDMENTS

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REFERENCES

[1] ITU – International Telecommunication Union, 2005, *The Internet of Things*, ITU, Genève.

[2] F.J.A. Cardoso, and B.J.F. Ribeiro, 2001, “Remote Applications Programming in CANopen-Based Distributed Embedded Systems”, *Proc. ITM 2001 – 1st International Conference on Information Technology in Mechatronics*, Istanbul, 268-272.

[3] A. Ipakchi, and F. Albuyeh, 2009, “Grid of the Future”, *IEEE Power Energy Magazine*, March-April 2009, 52-62.