Power quality and electrical energy losses as a key drivers for smart grid platform development

ZORAN P. STAJIĆ
Faculty of Electronic Engineering
University of Niš
Aleksandra Medvedeva 14, 18000 Niš
SERBIA
zoran.stajic@alfatec.rs

ALEKSANDAR JANJIĆ
Dept. for renewable energy sources
R&D Center "Alfatec" Ltd.
Bul. Nikole Tesle 63/5,18000 Niš
SERBIA
aleksandar.janjic@alfatec.rs

ZORAN SIMENDIĆ
Electrical Utility Sombor
Apatinski put BB, 25000 Sombor
SERBIA
zoran.simendic@so.ev.rs

Abstract: - This paper presents how the problems of power quality and electrical energy losses in distribution systems led to the development of an interoperable smart grid platform being implemented in several electrical utilities in Serbia through various pilot projects. With practical examples of solving the problem of power quality and of locating the source of electrical losses in distribution network, using different types of Measuring Information Systems, evolution of smart grid development in Serbia is shown. Through the demands raised in the exploitation of these systems, it is presented how a flexible smart grid platform, enabling the use of all available information and communication technologies and interoperability with intelligent electronic devices and systems of different manufacturers, is developed. Beside the platform description, which allows the inclusion of all smart grid stakeholders, few examples of its practical use by different users are given. At the end, appropriate conclusions are drawn and directions for further research are clearly outlined.

Key-Words: power quality, electrical energy losses, smart grids, ICT, MV/LV substation automation

1 Introduction

In recent years, much attention has been paid to the development of Smart Grid, especially in technologically developed countries ([1]-[6]). A lot of effort is invested to the development of the area, especially in searching for business models that will be the fastest and most effective way to enable wider application of this concept in practice ([2]).

When analyzing the main causes that led to the development of smart grid, the most mentioned were: renewable energy sources ([1]-[4]), the need to reduce emissions of greenhouse gases ([1]-[4], and expected use of electric vehicles ([1]-[3]).

However, looking at the situation in Serbia, it can be concluded that none of these reasons influenced the research on smart grid, as far as the enormous amount of electricity losses in power distribution networks, and the need to localize sources of losses in every way, even using the latest technologies and modern equipment.

Searching for effective solutions in this area researchers recognized a transformer substation (TS) MV/LV as a very important node in which is necessary to monitor not only the parameters of voltage quality in distribution systems, but also all the relevant parameters of electrical energy consumption. For these purposes, a series of Measuring Information Systems (MIS) has been developed ([9], [10]). MIS proved to be a very effective tool for controlling parameters of voltage quality, and for closer localization of losses in low voltage (LV) distribution networks. For these reasons, they are accepted by most of the electrical utilities in Serbia. What is far more important, their design proved to be easily upgraded, without any restrictions regarding the manner of their mutual communication and communication with the superior centres. Furthermore, they can be combined with a variety of command and control modules, various sensors, detectors, intelligent electronic devices and systems, for the purpose of network supervision and control.

Several functionalities were recognized as crucial in designing these systems:

- the need to efficiently transfer large amounts of data from one place to another,
- the need to allow the system to have several superior centres with clear privileges,
- the possibility to enable remote configuration of system parameters or change control algorithms.

These requests and corresponding solutions offered by researchers led to the unique smart grid platform that can be applied as universal technical solution not only in the electrical utilities, but also in other distributed systems. The outlook of the platform is presented in this paper.

ISBN: 978-1-61804-023-7

2 Quality control of voltage and energy losses using MIS

Technology on which the smart grid platform is based, for the first time is applied in measuring information systems that were designed for recording the parameters of voltage quality and for closer localization of the source of losses in low voltage distribution networks in Serbia.

Very often, the electrical utilities in Serbia use MIS to test voltage after any remarks of customers (Fig. 1), or in cases when in the certain transformer regions different problems occur due to overload (Fig. 2).

Figure 1. *MIS-4S installed on pole TS 20/0.4 kV for checking the quality of power supply voltage*

Figure 2. *MIS-4S installed in TS 10/0.4 kV due to frequent overloads*

However, it turns out that in such situations, the causes often lie in the excessive unauthorized power consumption, and that results recorded during control can be very useful for understanding the type of consumption, the consumer habits, and the choice of adequate measures for the closer localization and removal of losses.

After discovering that electricity losses significantly exceed the expected technical losses in a TS MV/LV, closer localization of the sources of losses between a few hundred customers becomes a serious problem. In such situations, MIS can be used for simultaneous recording of consumption on a greater number of feeders, (Fig. 3). That way, distribution of losses between feeders can be obtained and problematic feeders with extremely increased losses can be identified.

Figure 3. *MIS-8 installed in TS 10/0.4 kV for closer localization of loss sources in the LV network*

2.1 Examples of voltage quality control

Typical examples of using of MIS for voltage quality control in the electricity networks are presented in this section.

A case of extreme voltage drops appeared on one of the LV feeders of TS 10/0.4 kV "V. Jovanovic", located in Niska Banja, is shown in Fig. 4, and the LV feeder topology is given in Fig. 5.

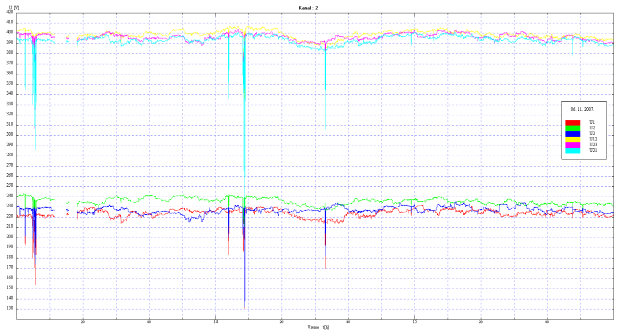

Figure 4. *Phase and line voltages recorded on a pole of LV feeder of TS 10/0.4 kV "V. Jovanovic" - 06.11.2007.*

The time period shown in Figure 4 refers to the 3-hours period (between 14:00 and 17:00). Image shows that the voltage drops at the moment of fault occurrence even exceeded 40% of nominal voltage. Even though the fault currents were high, due to relatively short duration of the phenomenon, there was no reaction of any protection system or any fuse failure, and the voltage drops repeated many times per day. This caused a very negative impact on all electrical equipment connected to the electrical network by this feeder. Obviously, the faults appeared completely aperiodically and Electrical Utility teams could not discover the cause with common control methods and common measurement techniques.

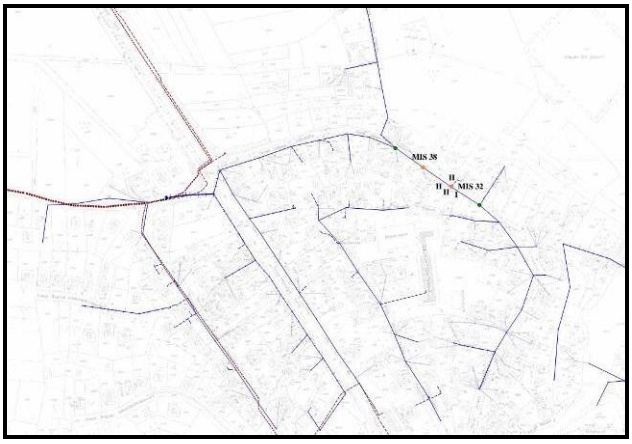

Figure 5. *Topology of LV feeder with the described fault*

For this reason, several MIS are used for a closer localization of the fault source in the feeder. Three hours were enough to found the source. It was a cable used for temporary site connection (Fig. 6).

Figure 6. *Problematic cable used for temporary connection of a site*

The next example (Fig. 7) demonstrate excessive voltage drops in a LV feeder, too. This time they were not caused by faults, but by excessive unauthorized power consumption. The diagrams were recorded at December of 2010 in one pole of LV network belonging to TS "Nikola Tesla 2" - Electrical Utility Nis.

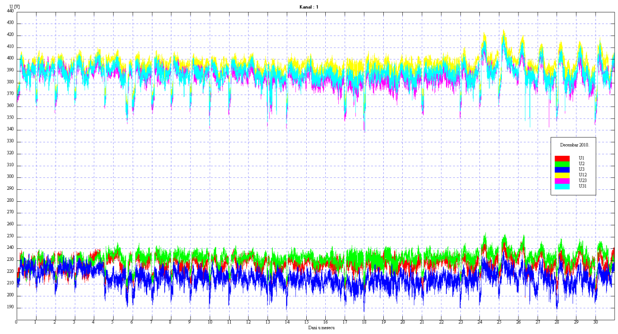

Figure 7. *Phase and line voltages recorded on a pole of TS 10/0.4 kV "N. Tesla 2" LV feeder - December 2010.*

One can notice that voltage drops in this situation reach 15% of rated voltage. Increased voltage asymmetry is also evident in this case (Fig. 8).

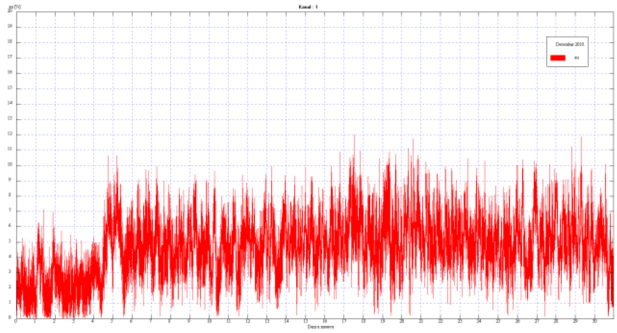

Figure 8. *Voltage asymmetry*

Figure 9 shows phase and line voltage diagrams recorded in a TS 20/0.4 kV in August of 2010 in Electrical Utility Sombor. Even though electricity networks in the region of Vojvodina are in much better condition in comparison to the rest of Serbia, very interesting forms of voltage changes, caused by operation of a transformer on-line tap changer on higher voltage level, can be observed, too.

Figure 9. *Phase and line voltages recorded in a TS 20/0.4 kV, Electrical Utility Sombor - August 2010.*

2.2 An example of localizing the source of losses

Although the abuse and theft of electricity also occurs in the developed countries ([7], [8]), electricity losses are one of the major problems

ISBN: 978-1-61804-023-7

faced by electrical utilities in Serbia. Because of numerous and various cases of abuse and theft of electricity, Electrical Power Industry suffered huge financial damage.

Recognizing the problem of energy losses as a very serious, one of the biggest Electrical Utility in southern Serbia – ED Nis, made the first step in 2005 and began with the application of modern MIS for the localization of energy losses with the aim to reduce financial losses.

The following example shows a process of closer localization of sources of losses in the region of a TS 10/0.4 kV. Recording electricity consumption in the TS and comparing it with the total energy delivered to customers, it was found that the difference between actually spent and delivered energy is over 25%. Analysing the electrical energy consumption per LV feeders, it is concluded that the losses are significantly increased on feeder 6, where they even exceed the level of 60%. The network topology of this LV feeder, taken from the GIS of Electrical Utility Nis, is shown in Fig. 10.

Figure 10. *The network topology on LV feeder 6*

Figure 11 shows the curves of active, reactive and apparent power of the observed feeder that have been recorded using the MIS-8. From these curves, on/off characteristic of small industrial consumer which is supplied through this feeder are identified.

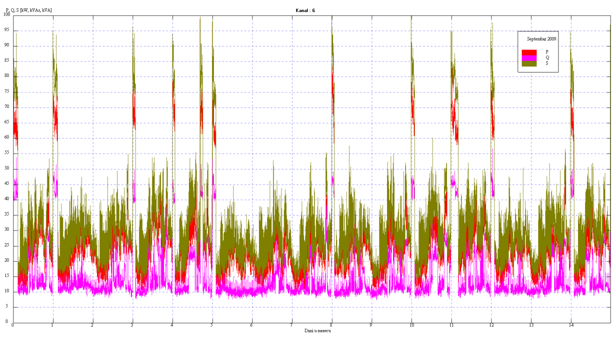

Figure 11. *Curves P, Q and S on feeder 6 obtained in TS 10/0.4 kV*

Calculating the time of using of this facility and the average change of active power at each turn, it is estimated that electricity consumed by this facility is unregistered consumption. It is significant to note that the facility is not active in regular working hours, and usually works at night. For this reason, it is practically impossible to detect this consumption in the regular inspections performed by mobile crews, that take place during working time.

Knowing the type of customers and the usual time of use of energy, the possibility of detecting such abuses for mobile inspection crews is significantly increased. In case the information recorded in the TS 10/0.4 kV is not sufficient, for a closer localization of the sources of losses, additional MIS can be set downstream, even on the low voltage network poles. For the demonstration of such possibilities, one type of MIS (MIS-2S) is installed on the 0.4 kV pole marked in Fig. 10. One of the channels recorded its consumption in the direction of the line 6 (Fig. 12), and the other one of the lateral line (Fig. 13). It is noticeable that in this case the source of losses is detected on the lateral.

Figure 12. *Curves P, Q and S recorded by MIS-2S being installed on 0.4 kV pole - channel 1*

Figure 13. *Curves P, Q and S recorded by MIS-2S being installed on 0.4 kV pole - channel 2*

3 Smart Grid platform development

The problem of energy losses in power distribution networks turned out to be the main driving factor for the development of smart grid platform in Serbia.

The need for constant monitoring of the TS MV/LV where problems can occur, in order to rapidly respond to the possible occurrence of losses, the comfort in working with large amounts of data that provided the accompanying software and financial savings that utilities have accomplished by reducing energy losses, promoted MIS as the standard equipment in many TS MV/LV in Serbia. Further development of Smart Grid was a logical upgrade of this platform, because following requirements emerged in many electrical utilities:

- centralized data collection from remote MIS,
- management of switching elements in the TS,
- integration with the systems of remote control of switching equipment in medium voltage distribution networks,
- detection of unauthorized entry into a TS facility,
- video surveillance in TS facility,
- remote access systems with prior authorization in order to be able to remotely configure systems and to monitor their operation,
- electricity consumption forecasting,
- ability to exchange information with a number of superior centres, and authorized users.

As the information section of MIS was based on the latest embedded computers, with many communication ports, expanding this system was possible, like the Lego bricks building. The above requirements are implemented step by step. With this approach, electrical utilities are allowed to have one unified system that will integrate many functions and will be interoperable with existing intelligent electronic devices and systems. In terms of hardware that can meet the previous requirements, the configuration in Fig. 14 is used.

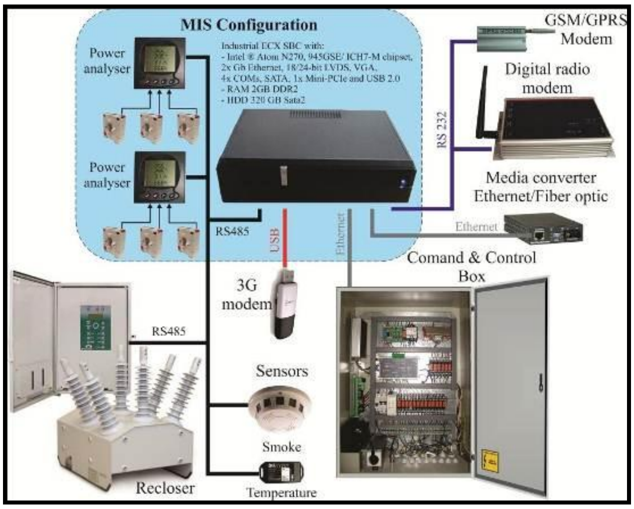

Figure 14. *Hardware configuration for TS MV/LV as a part of the smart grid platform*

4 Application of the smart grid platform by other users

With the similar requirements as they were arising from other users in Serbia (measurement, remote monitoring and control, protection of buildings and equipment), the developed smart grid platform was used in different applications: water supply systems, industrial consumers, small power plants, municipal systems, buildings and residential facilities. In terms of communication technologies that were used, almost all available communication services have been tested (digital radio modems, GSM/GPRS, 3G, dial-up ISDN, ADSL modems, fiberoptics, etc..) as well as their combinations. Protocols were developed to enable systems to use different communication channels with automatic choice of optimal one, without interruption in the communication. Interoperability of systems integration is demonstrated with the equipment of a large number of domestic and foreign manufacturers, whether it took place at the remote terminal units, or at the level of control centres (SCADA).

All these systems are independent autonomous entities, accessed only by authorized system users. Since these systems basically use the same platform, the exchange of useful information between them becomes a matter of time and the adoption of appropriate regulation. The research team working on the project [11] has permission to access all of these systems for study, and for further development of new technologies that may offer adequate benefits to all stakeholders who are expected to participate in the smart grid projects in the future.

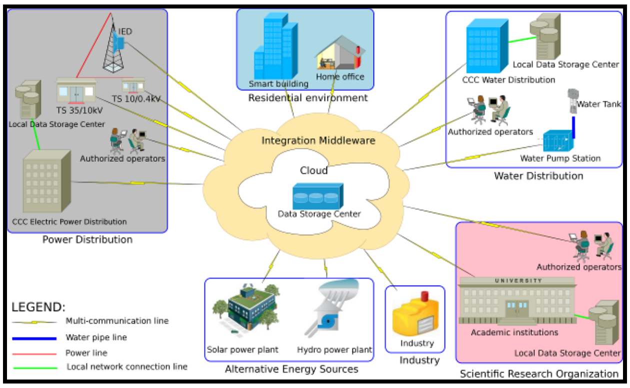

Figure 15. *Smart grid platform as a service for different users*

The latest researches conducted within the framework of the project [11], realized by the 34 scientific and research organizations from Serbia, aimed at developing a decentralized distributed

ISBN: 978-1-61804-023-7

system (DDS), which represents a significant improvement of the smart grid platform. The new DDS technology should provide intelligent linking of all individual computers belonging to the smart grid into a unique system, allowing optimal use of all available computer resources. Special attention in its developing is paid to the transparent system and user services.

DDS is designed to be fault-tolerant, self-balancing, self-maintaining, self-supervising, modular and easily scalable system, independent of computing platforms and the type of communication services. It enables maximum utilization of network resources, secure communication over insecure channels, and can be used in different services: grid, utility, and cloud computing, web hosting, data storing and data processing, etc.

Appropriate pilot projects are in testing phase.

5 Conclusion

In this paper, unique and very flexible smart grid platform, being implemented in several electrical utilities in Serbia through various pilot projects, is presented. It is shown that the problem of energy losses in power distribution networks was "driving factor" that contributed to the development of this platform in Serbia, which is completely different from the developed countries of the world, where the motives for the development of smart grid electricity networks are completely different (integration of renewable electricity sources in electric power systems, environmental problems, the expected expansion of electric vehicles).

The main advantage of presented platform is its flexibility. It is demonstrated that implemented hardware solution enables simple expanding of the system, similar to the "Lego bricks building".

Besides the application in many electrical utilities, the same smart grid platform is successfully implemented in different applications: water supply systems, industrial consumers, small power plants, municipal systems, buildings and residential facilities, etc. In all these applications, possibility of using of almost all available communication services is demonstrated, as well as possibility of integration with the equipment of a large number of domestic and foreign manufacturers (the system interoperability).

Exchange of useful information between these, up to now independent autonomous systems, that will be surely important stakeholders in the future smart grids, becomes a matter of time and the adoption of appropriate law regulation.

Acknowledgement:

The work presented here was supported by the Serbian Ministry of Education and Science (project III44006).

References:

[1] *Strategic Deployment Document for Europe's Electricity Networks of the Future European Technology Platform*, European Commission, April 2010.

[2] “GEODE Position Paper on Smart Grids”, GEODE Working Group Smart Grids, Oct. 2010, paper 240.

[3] H. Späck, B. Schüpferling, J. Riemenschneider, M. Schelte, “Intelligent Transformer Substations in Modern Medium Voltage Networks as Part of SMART GRID”, *7th Mediterranean Conference and Exhibition on Power Generation, Transmission, Distribution and Energy Conversion*, Nov. 2010.

[4] Jürgen Heckel, “Smart substation and feeder automation for a SMART distribution grid”, *20th Int. Conference and Exhibition on Electricity Distribution, CIRED*, June, 2009, paper 0722.

[5] Josco C. P. Kester, Peter J. M. Heskes, J. J. Kaandorp, J. F. G. Cobben, Gerard Schoonenberg, Dmytro Malyna, Erik C. W. De Jong, Ben J. Wargers, A. J. F. Dalmeijer, “A Smart MV/LV-station that improves power quality, reliability and substation load profile”, *20th Int. Conference and Exhibition on Electricity Distribution - CIRED*, June 2009, paper 0776.

[6] Hak-Man Kim, Jong-Joo Lee, Dong-Joo Kang, “A Platform for Smart Substations”, *FGCN '07 Proceedings of the Future Generation Communication and Networking*, Vol. 1, pp. 579-582, 2007.

[7] P. Kadurek, J. Blom, J. F. G. Cobben, W. L. Kling, “Theft detection and smart metering practices and expectations in the Netherlalnds”, *Innovative Smart Grid Technologies Conference Europe (ISGT Europe), IEEE PES*, 2010.

[8] J. Nagi, A. M. Mohammad, K. S. Yap, S. K. Tiong, S. K. Ahmed, “Non-Technical Loss Analysis for Detection of Electricity Theft using Support Vector Mechines”, *2nd IEEE Int. Conference on Power and Energy (PECon 08)*, Dec. 2008, pp. 907-912.

[9] *"Development of Measuring Information Systems for monitoring and analysis of electrical energy consumption of distributive transformer substations"*, Project funded by Serbian Ministry of Science for the period 01.05.2005.-30.04.2007, record No: 222001.

[10] *"Improving performance of measuring information systems (MIS) by introducing supervising, control and remote management functions"*, Project funded by Serbian Ministry of Science and Technological Development for the period 01.11.2008. -31.10.2009, record No: 401-00-00144/2008-01-IP.

[11] *"Development of new Information & Communication Technologies, using advanced mathematical methods, with application in medicine, energetics, telecommunications, e-government, and protection of National Heritage"*, Project funded by Serbian Ministry of Education and Science for the period 01.01.2011.-31.12.2014, record No: 44006.