Utilization of the Monitoring System for MV/LV Transformers in Smart Grid Application

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***Abstract*—Continuous development of the power grid infrastructure in the area of distribution and legal regulations concerning the reliability of the powering consumers of electricity is a challenge for systems used for power system protection. This requires continuous improvement of an existing solutions and development of new methods for fast and reliable identification and location of the disturbances and failures occurring in the network. The application possibilities offered by modern digital devices go far beyond what was the primal purpose, and allows the creation of "intelligent" electric networks.**

This article presents the equipment used by Polish electricity distributors for monitoring load of the low voltage transformers, describes analyzes carried out in the range of functionality and measurements and mentions capabilities of the data acquisition systems for other purposes. In this paper also considered are the possibilities of usage of existing metering systems and obtained data from them in automation systems supporting the operation of the medium and low voltage networks.

Keywords—Smart Grid, smart metering, power protection automation

I. INTRODUCTION

Dynamic expansion of modern technologies into all areas of human activity is the reason of the continuous development in electrical power industry. All early existing systems and devices used for protection of the power grid have changed their rules of operation. Old electromechanical devices were replaced by the devices based on analogue technology, which were superseded by a systems based on digital electronics. After the information science took control over all electronic devices developed in last decades, the time for gathering the data at a global level has come. The supervisory systems used for operation of the power grid are able to compute data obtained from wide area network, using the PMU (Phasor Measurement Unit) telemetry units. At the beginning the data was mostly collected at high and medium voltage levels, due to high costs of data transmission systems. The situation has changed with the global communication era presence. Prices of data transmission in the communication networks drastically went down giving a chance for expansion of cheap and effective telemetry equipment that can be installed and used now by everyone for any purpose.

Abilities offered by modern remote sensor appliance are widely used by providers of all types of media, such as: water, gas, electrical energy. Area of application of those systems is still increasing, giving much more detailed information about all aspects of the operation of the media distribution system. The ability to obtain data from different sources has the particular importance for the companies involved in electrical power transmission and distribution. The information about electrical energy utilization gathered from many locations in power system can be processed together in the same place and time. The conjunction of the data coming from power generation, transformer substations and consumers gives the whole picture of the power system operating condition, that results in increased reliability and safety in the electrical energy supply. Systems developed in a past few years, such as Automatic Meter Reading (AMR) or especially its newer counterpart AMI (Advanced Metering Infrastructure), perfectly match the requirements for the Smart Grid application [1], [2]].

II. SMART METER DEVICE

The AMI smart meter devices are produced by many power automation manufacturers. Despite of differences in firmware and control software all devices offer the similar basic functionality, other functions are dependent on measurements implemented by producer and user needs. Common device functions include measurements (voltage, current, power), communication, control ports. Typical application of the AMI meter type S650 in LV substation is shown in Fig. 1.

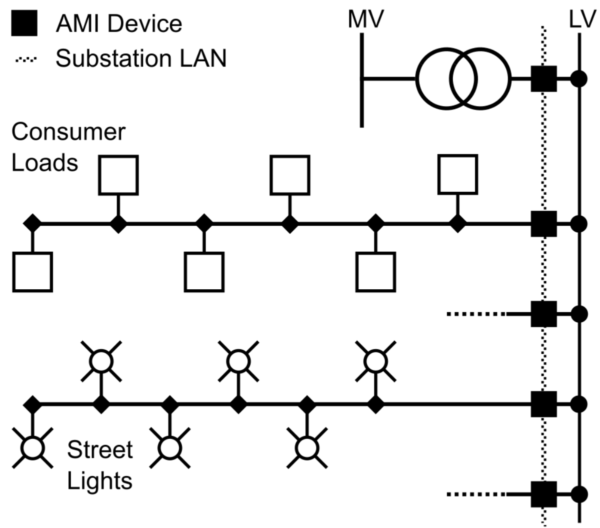

Fig. 1. Scheme of typical application of AMI system in LV network

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The AMI device for electrical energy distribution sector in Poland was chosen in result of successful completion of the tender procedure. The polish distribution companies purchased the smart energy meters type S650 from Landis+Gyr. The price of the basic order was about 23 million PLN (6 million USD - depends on the current exchange rate) for over 36,000 smart energy meters. It means that basic price per unit is about 640 PLN (170 USD) what is a very low price for this type of device. Standardization of installed in power grid AMI meters gives an excellent opportunity to develop an unified system for all electrical energy distributors.

The number of devices purchased by the individual companies amounts to:

- Tauron Distribution – 18050 pcs.
- PGE Distribution – 9200 pcs.
- Enea Operator – 7000 pcs.
- RWE Stoen Operator – 2000 pcs.

Specification of selected functions and measurements realized by S650 meter device taken from documentation available from vendor are presented in tables I and II. The comparison is limited to AMI meter s650 mark SMA 400 and SFA 400. Full technical specification of described AMI device is available in product datasheet provided by manufacturer [3].

TABLE I. COMPARISON OF THE AMI METERS MEASUREMENTS ABILITIES

	SMA 400	SFA 400
Instantaneous values		
Phase to ground voltage	L_{12}, L_{23}, L_{31}	-
Phase to phase voltage	U_{L12}, U_{L23}, U_{L31}	L_{12}, L_{23}
Current	I_{L1}, I_{L2}, I_{L3}, I_N	I_{L1}, I_{L3}
Frequency	▼	▼
Phase angles	▼	-
Current/voltage asymmetry	▼	-
Active power	all phases, total	total
Reactive power	all phases, total	total
Power factor	all phases, total	total
Power factor (no harmonics)	all phases, total	-
Current/voltage THD (abs.)	L_1, L_2, L_3	L_1, L_3
Current/voltage THD [%]	total	total
Active energy THD	total	total
Threshold Measurements for event logs		
Overcurrent	▼	▼
Current/voltage asymmetry	▼	-
Over & under voltage		
Phase to ground	▼	-
Phase to phase	▼	▼
Event logs		
Number of entries (max.) [a]	500	
Special event log with a snapshot		
Number of entries (max.) [a]	3x30	
Extended SMS alerts		
Alert on digital inputs	3÷7	
Alert detail	▼	
Event alerts (SMS)	▼	
Other functions		
Primary or secondary values	▼	
Astronomical clock	▼	
Calendar clock	▼	

a. Ttime stamped

TABLE II. AMI METER REGISTRATION ABILITIES

	SMA 400 & SFA 400
Measured quantities	
Energy	17
Sum of channels (digital & virtual inputs)	2
Losses OLA, NLA	2
Losses I^2 & U^2	2
Active power harmonic distortion	2
Direction of field rotation	▼
Power and energy registers	
Energy in zones	32
Total energy	37
Power in zones	24
Power factor	2
Current power and last avr. value	2x10
Other registers	
Operating time register	8
Diagnostic register	41
Tariff module	
Season tables	12
Week tables	12
Daily tables	12
Special days	100
Tariff control signals	16
Emergency settings	▼
Active and inactive tariff sets	▼

The S650 device is a successor of the E650 meter platform which was the successful company product [4]. Four typical areas of application of AMI S650 smart grid terminal according to manufacturer data are:

- Energy balancing.
- MV/LV transformer and LV network monitoring..
- Street lights billing and switching applications.
- Renewable sources and microgeneration billing, control, integration.

Interesting feature on this list is monitoring and control of street light system which use astronomical clock with encoded information about sunrise and sunset times. This approach to issues of city lighting helps in decrease of power consumption, what gives tangible economic benefits and contributes to the reduction of the emission of green house gases [5].

Range of measurements realized by the S650 AMI meter includes measurement of current, voltage and power as the instantaneous values and averaged values for chosen period of time. The measurements of power factor, total harmonic distortion (THD), asymmetry and losses are also available. Build in functions allow to monitor: power and energy consumption, power quality, tariff management and economic analysis.

The communication interface of smart meter is based on IEC-61850 standard, what gives a full external access to device functions and measurements from any supervisory system. The AMI meter usually have also binary input and output ports to connect external sensor and relay. Standard application of AMI meter in the LV substation with connection to external sensor and relay is presented in Fig. 2.

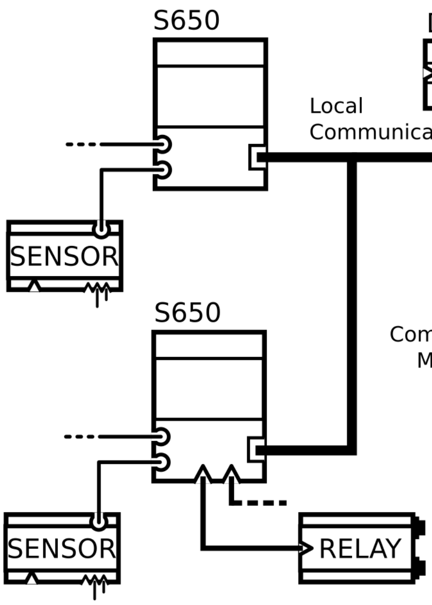

Fig. 2. Common application of AMI meter with additional sensors and relays

The S650 AMI device offers extended abilities of registration all measured signals within wide range of time duration. Registered values are stored in flash memory inside a device.

III. SMART GRID APPLICATIONS OF AMI DEVICE

Modern smart metering device are very well prepared to perform the established role in the electrical power system. Feature rich functionality and ability to perform complex measurements. Its advantage is flexible communication, which allow to inter operate with local and remote devices and services. Taking into account metering and functional abilities of the modern AMI device such as described above, the wide area of new application for this type of device can be defined. In first step two major types of application can be distinguished:

- Central application mode.
- Remote application mode.
- Mixed application mode.

In central application mode all functions of the appliance depends on data gathered from power network by monitoring center, in this case there is a single computation node for analysis and decision process making. In this case the result of operation can be: stored for further analyses, send to network operators, send back to AMI devices or send to other part of the power system (e.g. MV substation) [6].

Remote application mode does not require a connection with the monitoring center, all functions are realized by the automatics systems installed in LV substation. This mode of operation assumes the data exchange between AMI device and IED (Intelligent Electronic Device) if needed (see Fig. 3). Result of computation may be send to monitoring center or any actuator in LV substation.

A mixed application mode joins both previous methods of operation and may be needed for realize a complex task in emergency state. Practical realization of presented solutions may require of the additional IED devices, installation of the sensors or upgrade its firmware in the AMI meter. Fig. 4 illustrates extended configuration of low voltage automatics system in substation to implement complex solution of smart grid application [7].

Most advanced smart grid appliance may send data to consumer devices which are spread over whole ow voltage network. This can be done in a wired or a wireless mode and requires build separate communication infrastructure. Important part of smart grid application is communication not only with the company employees but also with the consumers. Information can be send in both ways or only one way, depends on specific needs. In particular cases instant and interactive information exchange may be desired. Providing messages to consumers depends on purpose may be realized via different ways [8]:

- Cellular network SMS services.
- Internet or Ethernet communication.
- Crisis warning systems.
- Visual or audio signals.
- Local broadcasting stations.

Basing on instantaneous measurements and other values registered by the AMI metering system the significant extension of its abilities can be done. By equipping the AMI device in few additional sensor its efficiency is significantly increased and interconnect with IED allow to repeatedly rise up its usability for power system. There is a wide area of possible application for low and medium voltage network utilizing smart meter system measurement capabilities and communication layer. Many of this application would be impossible to deploy without the robust AMI metering system infrastructure [9].

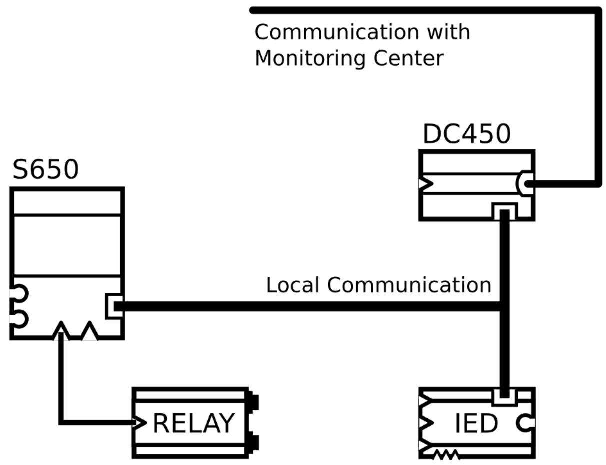

Fig. 3. Example schema of remote application mode- cooperation of the AMI meter with IED with data exchange

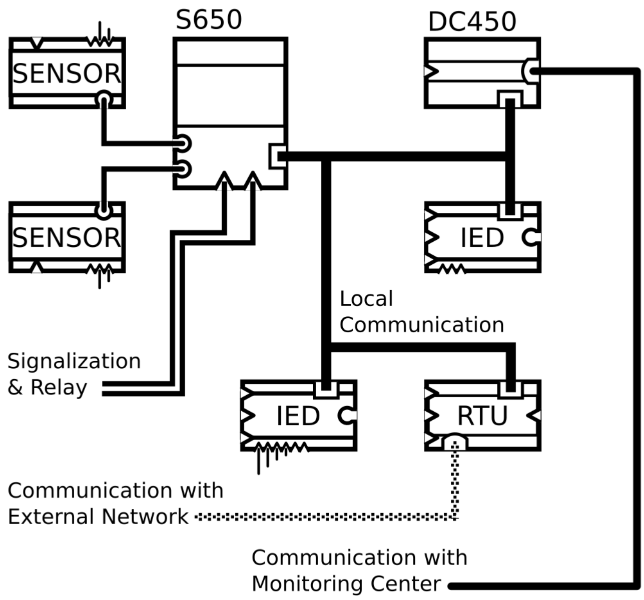

Fig. 4. Advanced application scheme - cooperation of the AMI device with several IED and external connectivity unit

Example areas of smart grid applications based on monitoring system of MV/LV transformer are listed below:

- Demand Side Management and Demand Side Response for voltage consumers – use of the AMI meter to control power consumption.
- Consumer Underfrequency Load Shedding – information from the AMI metering system is used to disconnection of consumer's load in a state of emergency.
- Fault Detection in MV Network – utilization of the AMI system data to fault identification e.g. phase feeder discontinuity [10].
- Automatic Voltage Control – control transformer tap changer based on the AMI system data, it is especially useful in rural networks.
- Crisis Information Network – extend the AMI system functionality with message sending ability.
- Power Quality Monitoring – visualization of the power quality issues for networks, calculation of SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) indexes.
- Power Flow Monitoring and Energy Losses – application for identification losses in MV and LV network.
- Energy Fraud Detection – utilization the data from the AMI system for identification of illegal electricity usage.
- Network Infrastructure Anti-theft Protection – the AMI system data is used to prevent stealing network apparatus.
- Virtual Power Plant Control – appliance for control of the microgrid generation.
- Weather Monitor Station – after equip the AMI meter with weather sensors, obtained data can be used for many purposes.

IV. Conclusion

Utilization of the AMI metering systems is growing in industrial and commercial sectors. Manufacturers of these modern systems are equipping their devices with many useful measurement options and functional abilities. Available functionality of AMI meter allows to extend their utility with an external applications. Retrofitting meter with new sensors and relays additionally increase its capabilities. Utilization of the data from the AMI metering systems allows developing future rich external applications. Smart grid applications collaborating with the systems installed in the power network can significantly improve the abilities, efficiency and safety of the power network.

The presented examples of application do not cover all possible areas of utilization. Further development of smart grid application should combine data obtained at different voltage levels of power systems. There is a possibility of significant expansion of abilities and functions of the AMI systems with artificial intelligence applications in the near future.

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