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SOLUTIONS FOR SMART METERING UNDER HARSH ENVIRONMENTAL CONDICIONS

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The described case study concerns application of wireless sensor networks to the smart control of power supply substations. The solution proposed for metering is based on the modular principle and has been tested in the inter-system communication paradigm using selectable interface modules (IEEE 802.3, ISM radio interface, GSM/GPRS). The solution modularity gives 7 % savings of maintenance costs.The developed solution can be applied to the control of different critical infrastructure networks using adapted modules. The proposed smart metering is suitable for outdoor installation, indoor industrial installations, operation under electromagnetic pollution, temperature and humidity impact. The results of tests have shown a good electromagnetic compatibility of the prototype meter with other electronic devices. The metering procedure is exemplified by operation of a testing company's workers under harsh environmental conditions.

Keywords: *power distribution, wireless sensor networks, smart meters, harsh environmental conditions.*

1. INTRODUCTION

Nowadays, under development are new measurement techniques in the field of power supply that rely upon wireless sensor networks and radio-based data transmission from smart readers to the concentrator points. The safety, security and reliability of the critical infrastructures (CI)* are strongly controlled by governmental bodies [1]. The growing complexity of equipment and systems, as well as rapidly increasing cost incurred by loss of operations and for maintenance, have brought to the fore the aspects of reliability, maintainability, availability, and safety of equipment and systems [2].

The main objective at designing smart meters for harsh exploitation conditions is to clearly define these conditions and select materials that would be appropriate for product development. The main strategy is here to identify all potential hazards that may disturb operation of electronic equipment, and only then to work out the safety instructions, guarantees, etc.

* **Critical infrastructure** is a term used by governments to describe assets that are essential for the functioning of a society and economy

The main hazards for electronic equipment could be identified as follows [3].

- Electric Shock and Energy Hazard.
- Mechanical Hazards.
- Heat, Fire, and Tracking Hazards.
- Moisture, Liquids, and Corrosion Hazards.
- Radiation, Toxicity, and Similar Hazards.
- Sonic and Ultrasonic Pressure Hazards.
- Explosion and Implosion Hazards.
- Abnormal Operation Hazards.
- Human Factor Hazards.
- Ergonomic Hazards.

In the research, technical solutions related to the data reading and transmitting wireless sensor networks are analyzed with the aim to minimize the negative impact exerted by electromagnetic energy radiation and to protect electronic devices (e.g. meters and counters applied in smart power, water & heat distribution networks).

In this work, development of smart metering hardware is proposed for the use of its components in harsh environment conditions. The development is now in a prototype stage.

The proposed solution for modular smart metering has been developed in the framework of the Riga Technical University's project "Methods for Critical Infrastructure Control", and is applicable to the infrastructure networks – both the existing legacy and future smart distribution networks.

The smart metering solution has been tested in laboratory conditions, with the worked-out methods and techniques for testing and evaluation of the properties of the materials used.

2. ANALYSIS OF LEGECY NETWORK SOLUTIONS

The project team have analyzed typical solutions for automated meter reading already used or recently developed in Latvia in electrical, water and district heating networks. The results are summarized in subchapters that follow.

A. Power distribution legacy network

A power supplier applies electricity meters to measure active and reactive electrical power of both directions according to the IEC 62053-11, IEC 62053-22, IEC 62053-21, and IEC 62053-23 standards. The primary monitoring interface is a 20 mA current loop operated by a master station (Fig.1).

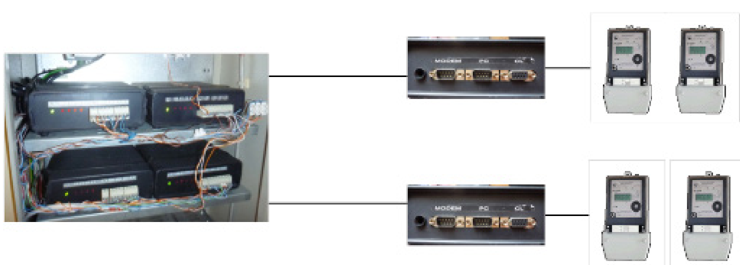


Fig. 1. Metering solution for power supply substation using existing wired connections.

In the given case, the master station provides service to four-meter devices (maximum eight for 26 V master stations). Each of the meters is wired to a concentrator unit, with the data request and reply processing via PC.

For scenarios where the data readings have to be delivered without existing wired connection, GSM/GPRS modem serial bridges are used. This solution is considered as legacy, because in this case the RS485 RS232 standards are partly used along with remote data readout devices based on GSM/GPRS modems.

B. Heat distribution network

The remote data reading system of *Rigas Siltums* substation (the relevant pilot project was implemented together with *SIA Microdators* in 2009-2010) is based on the concept including:

- Measurement data reading using Internet access.
- The use of wireless Internet access through the GSM network.

The corresponding GPRS-based technical solution consists of the following elements (Fig.2):

- the 220V AC input ensuring overload protection and on/off switching;
- a typical 220V AC-12V DC voltage converter (recommended DC voltage range 9..18V);
- *SIA Microdators* electronics block-gateway TB1v4. This module has the TELIT GM862 GSM modem as a central element. The module contains all the most important elements for implementation of GPRS modem functions, including the alignment with a 50-ohm antenna and SIM card connectors. Hence, for the switching system it is only required to provide + 3.8V power supply and a serial data interface circuit with Multical type heat meters installed at substations;
- GM862 module, which contains an internal processor and the memory with Python programming;
- the module containing a second serial TELIT GM862 interface for programmer's needs. In addition, connecting the RS232 level converter allows fulfilment of programming and reprogramming functions.

In practice, visiting the object is needed but seldom since the program can be downloaded remotely from a server via data network.

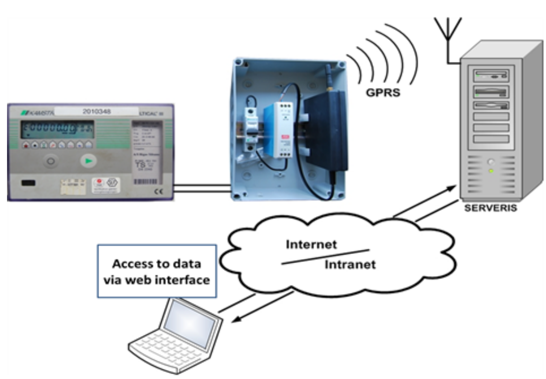


Fig. 2. GPRS-based solution for heat supply metering.

On the Multical side of the meter the optical separators are installed that ensure complete TX & RX wire galvanic insulation of transmitting and receiving data lines and a high interference immunity.

The "master" in relation to Multical and the server is *Telit Python* program; therefore, *Kamstrup Multical meter* program is a "slave". For the data exchange a *Kamstrup* (KMP) Co. Protocol is used. The Multical meter stores in its memory the data that can be read with the desired frequency without current data retention functions at the *Python* level. The *Python* and server programs according to the "Rigas Siltums" technical staff requests determine the data reading schedule.

The system functions in such a way that the measurement data from the heat meters are transmitted to the server system several times per hour according to the prescribed schedule as well as to the received request.

The following parameters of a heat distribution network are measured and processed:

Q – Heat energy amount (MWh).

V – Water amount (m^3).

T1 – Temperature (at the entrance) (^oC).

T2 –Temperature (at the exit of system) (^oC).

T1-T2 – Temperature difference (^oC).

P – Actual power (MW).

F – Hourly water consumption (m^3/h).

C. Water distribution network

A typical municipal automated meter reading system for water distribution networks usually use mobile network broadband communications (GSM/GPRS/UMTS, etc.). Short-range transmission systems in drive-by or walk-by scenarios are often used at the water utilities in Latvia to acquire the needed sensor metering data for further analysis. These solutions imply a fixed cost: the payment to communication companies for service, or – in the case of drive-by scenario – the constant fuel expenses [4].

The results of the study carried out by the project team provides a comprehensive base for further research and engineering to advance these solutions for a wider market as long-term alternative to the existing ones, since the advanced systems have potentially more cost-effective parameters and are easier to maintain.

In our work, a particular attention was paid to metering under harsh environmental conditions for installation and maintenance of electronic equipment. Figure 3 shows the installation procedure for a water pressure sensor in a water well with an antenna mounted on its cover.

a)

b)

Fig. 3. a) Installation of water pressure sensor in a water well; b) Experimental layout of water pressure sensor testing in water well: antenna and hydrant for leakage simulation [4].

3. CONCEP OF MODULAR SOLUTION

The proposed modular solution is based on the concept that is common for practical applications – not only as related to power supply but also for control of other infrastructures. According to calculations, application of modular concept reduces the maintenance cost by 7% in the geographical region of interest [4].

For local data readout via optical interface, an optical head is used to connect the meter to the PC serial port. Communication is performed according to the standard IEC62056-21 protocol, with appropriate software used for data reading and processing. In the cases of remote data readout the electrical interface is used for connection of the meter to Automatic Meter Reading (AMR) system.

In turn, for local data readout via electrical interface, an appropriate converter is used (e.g. current loop RS232 or RS485/RS232). For further data transmission, the PLC, RF, PSTN, GSM, GPRS modems can be implemented. The electrical interface uses IEC62056-31 protocol.

The proposed system contains a multi-interface modular platform with three main node components:

Metering node – connects to the meter via switchable/selectable interfaces (current loop, IEC1107 optical interface). Metering nodes have rechargeable batteries for operation during a power outage and for long-term standalone operation in consumer metering scenarios (e.g. wireless IEC1107 interfaces or drive-by current loop interfaces). Inter-system communication is possible using selectable interface modules (e.g. IEEE 802.3, ISM radio interface, GSM/GPRS).

Repeater node – provides data retransmission to a gateway sink node by self-organizing mesh network in ISM band providing balanced power usage for power-constrained system components.

Gateway node – selectable inter-system and backend communication interface architecture. This provides request and readout pre-processing and secure data delivery and queuing.

The trial network system comprises two types of transmitters for metering: a pulse counter for the water meter (with at least two inputs for cold and hot water) and a pressure meter from pipeline manholes equipped with temperature sensors (Fig.4).

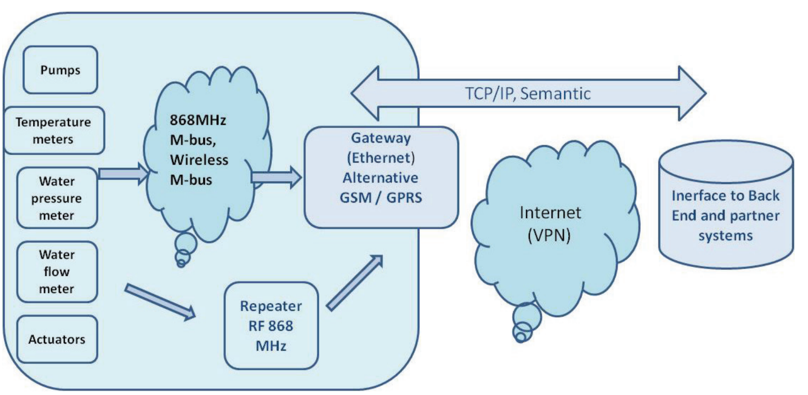


Fig.4. Architecture of wireless sensor system.

The gateway devices contain an initial firmware that is common for all of them. The firmware is running based on Open Embedded operational principles, with data pre-processing and delivery service capable of dynamic live module loading and initialization from a centralized server or server pool. Each gateway at the first start up in networked mode reads the MAC hardware of the gateway baseboard controller and tries to register itself in a centralized first-time registration server/service (FTRS).

The registration is confirmed automatically or manually, with the following parameters specified: device name, group, type, network settings, gateway dynamic loadable modules, VPN configuration, Wi-Fi settings, encryption settings and the *working mode registration server/service* (WMRS) and *working mode data submission server/service parameter* (WMDSS). The WMRS and WMDSS parameters allow the gateway control function delegation to other servers for load balancing or third party service operators by allowing them to perform all parameter and control functions as the FTRS.

All gateways initiate a SSL VPN based on FTRS or WMRS VPN setting parameters to the data processing service that receives the gateway data through the encrypted VPN tunnel and stores them in database. For the prototype application and further integration into any third party network and standalone, the service agent at the data processing service or the gateway itself has to be integrated. In the prototype case, a web service demonstrating configuration and data reception/visualization (charting) is used. The querying has been implemented using RESTful web services. An example of RESTful API for electricity counter service is given in Table I.

Table 1

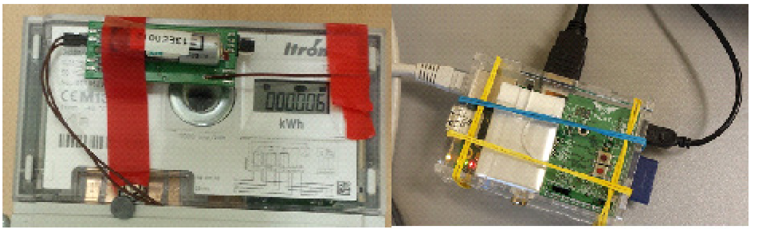
API for electricity pulse counter service

URL	http://arrowhed.bitde.lv/api/:agentname/reg/	
Method	POST	
Query string	mac=	Register MAC address
	dev_t=	Register metering device type
	input_c=	Register metering device input count or detected device number (type, serial number strings)
	time_v=	Time of last metering device discovery/indication at gateway
	data=	Last data block submitted for reverse querying (to be replaced with hash function and local database/buffer)
Returns	200 OK & XML	
	401 Unauthorized	
	404 Not found	

The return data blocks of metering device are specified as defined by IEC62056-21, IEC61107, and adapted to comply with the manufacturer model sub-specification using Object Identification System (OBIS) codes. The system provides standard identifiers for all data within the metering equipment (both measurement values and abstract values). OBIS names are used for the identification of COSEM objects and also for identification of the data displayed on the meter and transmitted through the communication line to the data collection system.

Figure 5*a* shows one of the three electricity meter devices (Itron) used in experiments. The device is equipped with transmitter interface module (ISM radio 868 MHz). In Fig.5*b* a gateway is seen that uses for prototyping a RaspberryPi single-board computer with Broadcom BCM2835 system on a chip (SoC). The prototype includes ARM1176JZF-S 700 MHz processor, VideoCore IV GPU and has 512 megabytes of RAM.

Ethernet interface board design was developed using OrCAD 15.5 program. The main chip of this interface is WIZnet W5100. Further, the WIZnet chip is to be replaced with a W5100 DIP housing. The task is to create a universal gateway enabling the use of different interfaces for external devices.



a) b)

Fig. 5. a) Electricity meter device Itron equipped with a transmitter interface module; b) Gateway with a RaspberryPi single-board computer used for prototyping.

Figure 6 shows the process of gateway registration in a centralized first-time registration server/service (FTRS). After successful registration, the data from three Itron metering devices are received and processed by the gateway and stored in the central system database.

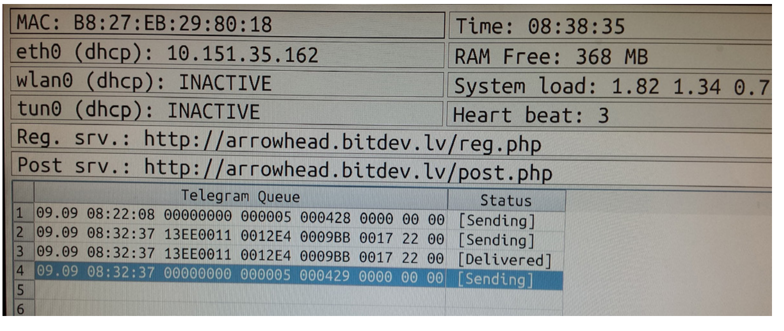


Fig. 6. Gateway and registration of three electricity metering devices in a centralized server/service.

The main advantage of the proposed solution is optimization of the network layout to suit environmental situation using selectable interfaces that scale with existing/legacy infrastructure. Such modular architecture offers easier extension by utilizing the base system components.

The offered extensibility makes it possible to expand the multi-interface operation by combining different communication protocols with external or third- party equipment/systems. The inter-system communication data exchange is provided in self-describing formats (e.g. SenML) allowing easier integration and compatibility. The core platform provides expandability for diverse sensors and metering equipment.

4. ELECTROMAGNETIC COMPATIBILITY

To receive approvals required under the EMC* directive, the manufacturer must turn to a competent organization which can appoint an affiliated test laboratory. The tests done by this laboratory are to be accepted by the competent body [5].

For testing our metering solution the EN 61000-4-5 and EN 55015 standards [6] were used. The tests were run in a shielded room at the Latvian Electronic Equipment Testing Center (LEITC) in a semi-anechoic chamber. The power fed to the chamber was filtered, thus providing a clean power source without high frequency fluctuations. The shielded chamber also protects from the influence of external electromagnetic radiation on the measurements. One of the main elements of the system – a gateway node prototype – was tested according to the European standards so that the requirements of EMC directive were fulfilled.

The surge (overvoltage) pulse is defined in Table 2.

Table 2

Surge pulse used for testing

Standard: EN 61000-4-5	
Tested generator:	UCS500 M4
Pulse (Short circuit)	8/20 us
Pulse (Open circuit)	1.2/50 us

According to the EN 61000-4-5 standard, the relevant electrical equipment (the prototype device) was tested for the ability to operate under network voltage surges. In our case (see Table 3, Fig. 7), the device was exposed to 40 pulses with voltages -4000V and +4000V (peaks ± 5%). After each five pulses the angle changed by 90°; respectively, the phase shift was tested in the angular range of 0° - 270°. The pulse repetition interval was 10s.

Table 3

Equipment testing parameters

Voltage	4000	V
Pulse repetition interval	10	s
Angle (Start):	0	degree
Angle (Stop):	270	degree
Angle (Step):	90	degree
Mode:	Synchronous	
Polarity:	Alternate	
Coupling:	L-N	
Events:	5	

The tested prototype continued to operate in the normal mode without interruptions, which means that it is surge-immune and fully complies with the EN 61000-4-5 standard.

*EMC: Electromagnetic compatibility – i.e. compatibility of electrical and electronic systems to ensure that operation of one system in not adversely affected by emissions from any other system.

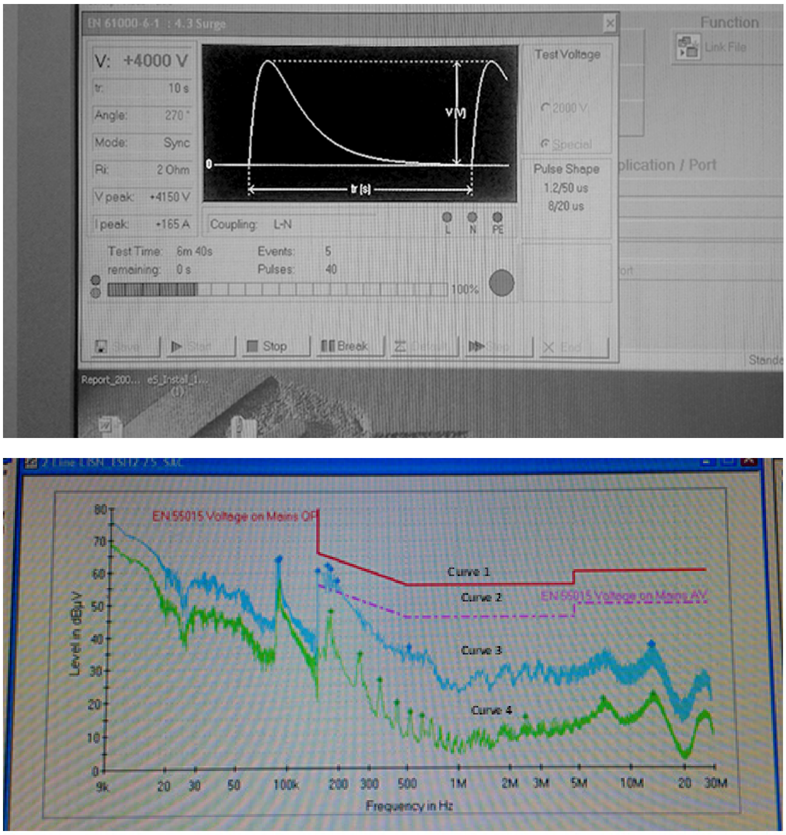


Fig. 7. Testing the surge immunity and emissions of the prototype device according to the EN 61000-6-1 and EN 55015 standards.

At the next step, this prototype was tested according to the EN 55015 standard. The standard was chosen due to its applicability in a wide frequency range (9 kHz-30 MHz).

Since any electronic equipment connected to a power network creates electromagnetic disturbances, the EN 55015 standard is introduced to give guidance for manufacturers to reduce the EMI factor of their equipment (i.e. emissions of electromagnetic energy potentially threatening electromagnetic compatibility). The limit lines defined by EN 55015 are Curve 1 for Quasipeak detector and Curve 2 for Average detector measurements. Therefore, Curve 3 is Quasipeak measurement and Curve 4 is Average detector measurement. In Fig. 7 it is shown that the emission limits are not exceeded, while in the frequency range 150 kHz - 200 kHz these are close to the limiting lines, having only a 2-3dB margin.

5. CONCLUSIONS

The developed metering solution based on the modular principle has been successfully tested in the inter-system communication paradigm using selectable interface modules (IEEE 802.3, ISM radio interface, GSM/GPRS). The modular solution allows for saving 7% of the maintenance costs in the selected geographic region. The testing of prototype under harsh conditions was successful. The EMI tests have shown that the proposed solution can be applied to the control of different critical infrastructure networks (water distribution and district heating networks, electricity network, etc.) using adapted modules.

From the results it follows that the developed metering system is able to operate under diverse conditions: outdoor installation, indoor industrial installations; under electromagnetic pollution, temperature/humidity impact, etc.

Tests of the modular gateway node prototype for electromagnetic compatibility according to the EN 61000-4-5 and EN 55015 standards have shown that it possesses surge immunity and low EMI factor.

ACKNOWLEDGMENT

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VIEDĀS MĒRĪJUMU SISTĒMAS IZSTRĀDE DARBAM SMAGOS VIDES IETEKMES APSTĀKĻOS

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K o p s a v i l k u m s

Rakstā tiek piedāvāts jauns bezvadu sensoru tīklu risinājums elektroapgādes apakšstacijas viedai vadībai. Izstrādātais risinājums ir balstīts uz moduļu principu. Izstrādātais risinājums ir pielietojams, lai vadītu dažādu kritiskās infrastruktūras

tīklu (elektroapgādes, ūdensapgādes, siltumapgādes utt.) darbību, izmantojot atbilstošus salāgošanas moduļus. Izstrādātā risinājuma modulārā koncepcija ļauj izmantot kopīgos vadības principus ne tikai elektroapgādē, bet arī citu infrastruktūru darbības vadībai. Saskaņā ar aprēķiniem moduļu sistēmas koncepcijas piemērošana samazinās uzturēšanas izmaksas par 7% noteiktajā ģeogrāfiskajā reģionā.

Pētījumā tiek pārbaudītas elektriskās un optiskās saskarnes ūdens, siltuma un elektroapgādes tīklu vadībai. Kopīga pieeja palīdz vadīt nosauktās infrastruktūru sistēmas, izmantojot vienotus vadības principus un aparatūru. Infrastruktūras veidi un vides apstākli, kuros jādarbojas sensoru tīklu risinājumam, ir ļoti atšķirīgi pēc būtības: sensoru tīkls un viedas mēriekārtas ir pakļauti elektromagnētiska piesārņojuma, zemas un augstas temperatūras un mitruma ietekmei. Risinājums ir pārbaudīts uz sistēmu savstarpējo savietojamību, izmantojot izvēlētus interfeisa moduļus (IEEE 802.3, ISM radio interfeiss, GSM / GPRS). Tādēļ tika veikta prototipa testēšana. Testēšanas laikā moduļu vārtejas prototips tika pārbaudīts uz elektromagnētisko saderību atbilstoši EN 61000-4-5 un EN 55015 standartiem. Tika secināts, ka ierīce pilnībā atbilst pārsprieguma imunitātes un izstarojuma pieļaujamiem noturības parametriem.

28. 10. 2014.