

Applying of IIoT technologies in an automated information system for monitoring and accounting of energy resources

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Abstract. The authors consider the actual task of increasing the scalability and ease of deployment of a distributed automated system for monitoring and metering of energy resources (ASMMER, hereinafter referred to as the System). The system intended for experimental investigation of complex transient modes of operation in high-voltage circuits of power supply systems (up to 25 kV) of the experimental Sverdlovsk Railway (Russian Railways) pilot site. This article proposes a solution using the technologies of the Industrial Internet of Things (IIoT). The protocol stack for the system, that was formed and implemented programmatically, reduces the amount of traffic in the system and supports existing and developing devices with LoRa and XNB technologies. The proposed solutions allowed the development of mobile information-measuring systems using wireless technologies (ZigBee, LoRa, XNB) and independent power sources. The proposed set of solutions allows providing a modular architecture for the rapid addition of new devices and functions through the use of IIoT technologies.

1. Introduction

The implementation of the Digital Railway project involves the transformation of existing industry systems and the creation of new ones using integrated digital technologies and well-known and promising tools for transport technology [1].

The list of priority directions and tasks of Russian Railways in energy and resource saving includes the development of information and communication technologies, the development and implementation of intelligent systems for monitoring infrastructure devices that can reduce the level of unbalance and energy loss in the traction network and reduce energy consumption for own needs traction substations. In this paper, we consider one of the ways to solve these problems—the development of mobile Data Measurement System (DMS) devices, that provide monitoring, assessment and prediction of the state of the infrastructure of the traction network.

The technology of the Industrial Internet of Things (IIoT) [2] [3] is one of the aspects of end-to-end digital technologies and it makes possibility to implement mobile information-measuring systems. Applied to the considered problem and to the system, IIoT technology can be represented as an industry-wide system of interconnected networks and DMS associated with them with integrated sensors and software for data collection and exchange, with the possibility of remote monitoring and control in automatic mode [4]. Prospects and area of applications of the Industrial Internet of Things on Russian Railways and foreign experience in implementing the Internet of Things in rail transport are considered in a number of works by Russian and foreign authors [4] [5] [6].

This article discusses the architecture and technical solutions implemented in a working prototype of a power control and metering system for the pilot site of the Sverdlovsk Railway [8] using IIoT. The new qualitative characteristics of the system that have been achieved make it possible to carry out a comprehensive analysis and assessment of energy losses due to suboptimal operating modes of electric substations and electric rolling stock (increased and reduced voltage, power flows between traction



substations, losses in step-down transformers, voltage surges due to recovery, etc.). Based on this, further recommendations can be made to improve the energy efficiency of energy supply systems.

2. The architecture of the system and formulation of the problem

ASMMER, designed for the experimental site of the Sverdlovsk Railway has a multi-level architecture (figure 1). The architecture of ASMMER includes the following main levels:

- Level of mobile Data measurement system (DMS).
- Level of Local data computing system (LDCS).
- Data computing system (DCS).
- External users of services (EUS).

The problems of improving and scaling systems with a developed distributed network infrastructure, in particular ASMMER [8], are aggravated by an increase in the amount of transmitted information and the number of connected network devices (DMS devices). Often, for existing channels, the problem can be solved by improving the efficiency of data transfer protocols and optimizing data traffic from the DMS or any other terminal devices to centralized information collection systems.

One of the ways to increase the efficiency of the system's network infrastructure is to use IIoT technologies and protocols that are already adapted for scalable systems with a large number of elements. At the same time, a transition from a static and monolithic system architecture to an architecture with a developed transport infrastructure is possible. This makes it relatively easy to connect and build up a significant number (up to several thousand) of terminal and nodal intermediate elements.

3. Detailed solutions

3.1. Architectural and technological solutions for information support

Let us consider the main architectural features and the protocol stack of a system implemented using IIoT technologies and protocols.

The LDCS level provides data acquisition and intermediate storage of information from the DMS taking into account time stamps and the geographical location of LDCS (using accurate time systems and GPS/GLONASS).

At the DCS level, a telemetry data collection server from LDCS and a telemetry application server are deployed. Telemetric information is accumulated in a data storage system based on a failover cluster. The telemetry application server provides access for external users and services to telemetry information through virtualized web, FTP and proxy servers.

The time synchronization system (TSS) is implemented at all levels of the hierarchy and provides a single time on all components of the system.

The ASMMER protocol stack using the technologies and protocols of the IoT is presented in figure 2. In particular, the system is focused on the use of LPWAN (Low-Power Wide-Area Network), for example, technologies such as LoRa and XNB [7] [9]. The advantages of LPWAN technologies include the ability to integrate an almost unlimited number of DMS, high signal penetrating power and high energy efficiency (table 1).

Table 1. Data transfer technology characteristics.

	Data transfer technology			
	LPWAN: LoRa, XNB	WPAN: ZigBee	WLAN: WiFi	WWAN: GSM/UMTS/LTE
Nucleus				
Energy efficiency	high	medium	low	medium
Data transfer rate	low	medium	high	high

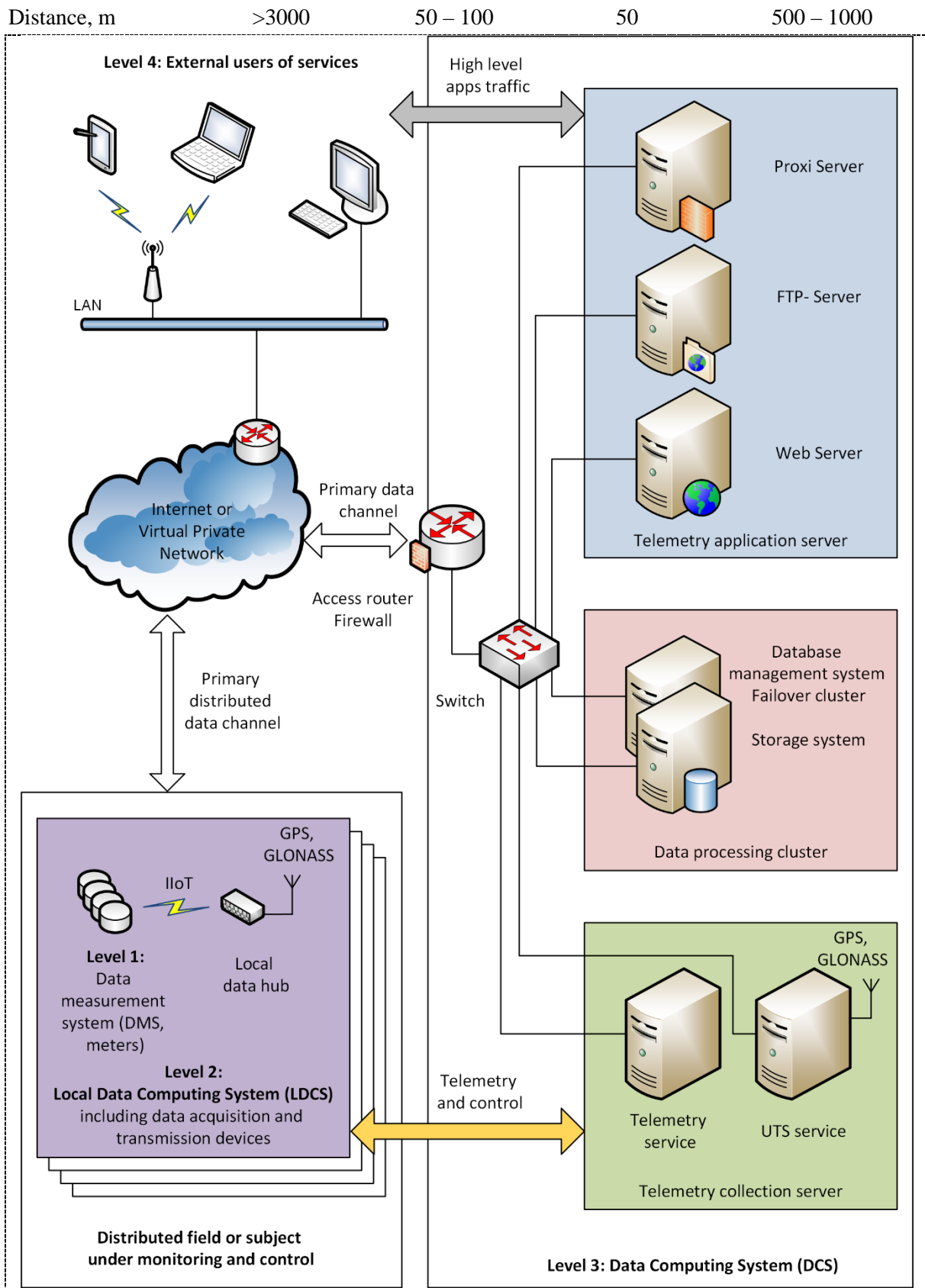
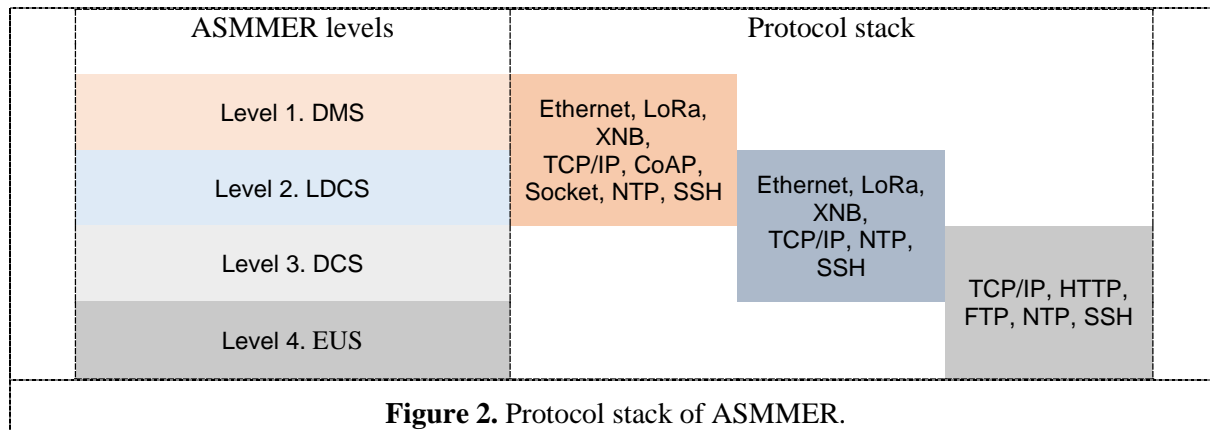


Figure 1. The structure of the distributed system for monitoring of electricity parameters.

Mobile DMS devices are connected to the LDCS subsystem using LPWAN technologies and local networks oriented to industrial operation (ZigBee and others), or, in special cases, wireless technologies of global networks of communication operators (for example, GSM, GSM-R, UMTS, LTE, etc.).



The transport architecture is based on the TCP/IP stack, while CoAP and HTTP are used on the application layer of the stack. To transfer information between high level subsystems and low level devices, global or corporate networks can be used for mutually reserving each other.

A feature of the interaction between the DCS and the EUS is the use of standard Internet/Intranet-oriented technologies, tools and data exchange protocols using a universal web client—browser, that allows you to implement the client part on various software and hardware platforms.

The proposed architecture has a high degree of scalability, stability, accessibility, versatility and unification. The last characteristics can be expanded through the use of service-oriented architecture (SOA), based on the use of services with standardized interfaces, for example, based on the XML language [8] [9].

3.2. Field level hardware solutions

The authors also propose to unify technical solutions at the DMS level. Mobile DMS, that performs the functions of measuring, converting and transmitting electrical parameters, has a typical modifiable block diagram shown in figure 3. It includes invariable (universal) components and modifiable (specialized). Universal part is marked by straight font on the figure 3 and specialized part is marked by italic. The measurement subsystem consists of specialized sensors, for example, precision voltage dividers, shunts, measuring transformers, etc.

The circuit board designed for universal DMS meter has universal digital part (power supply module, ADC (ADS131E08), a central processor or microcontroller module with Cortex-M4 core (CPU/MPU), two reserving SD memory cards, ferro-magnetic memory (FRAM), real-time clock (RTC)) and a varied analogue part (circuit for connecting sensors and normalize signals).

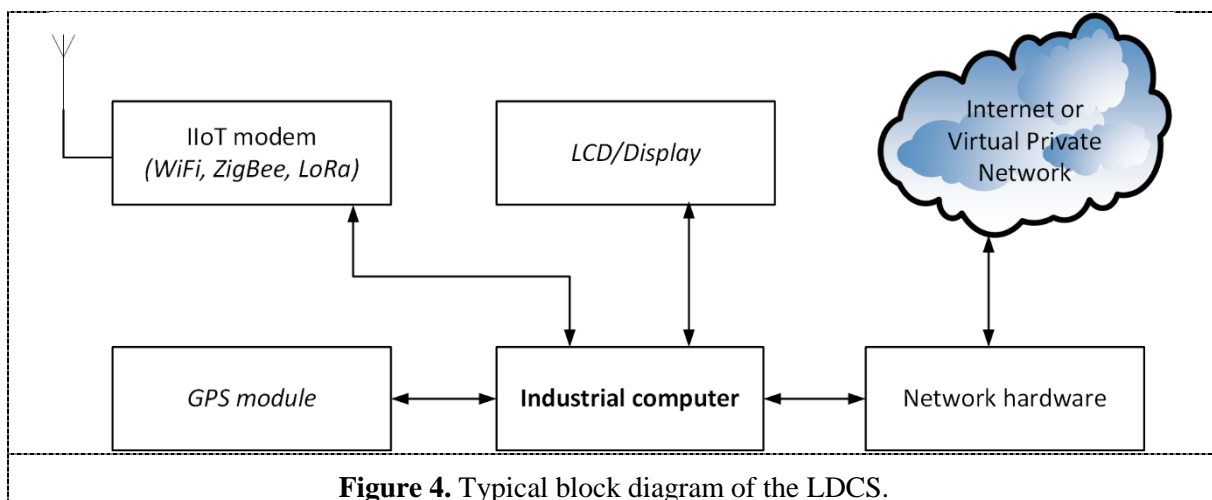
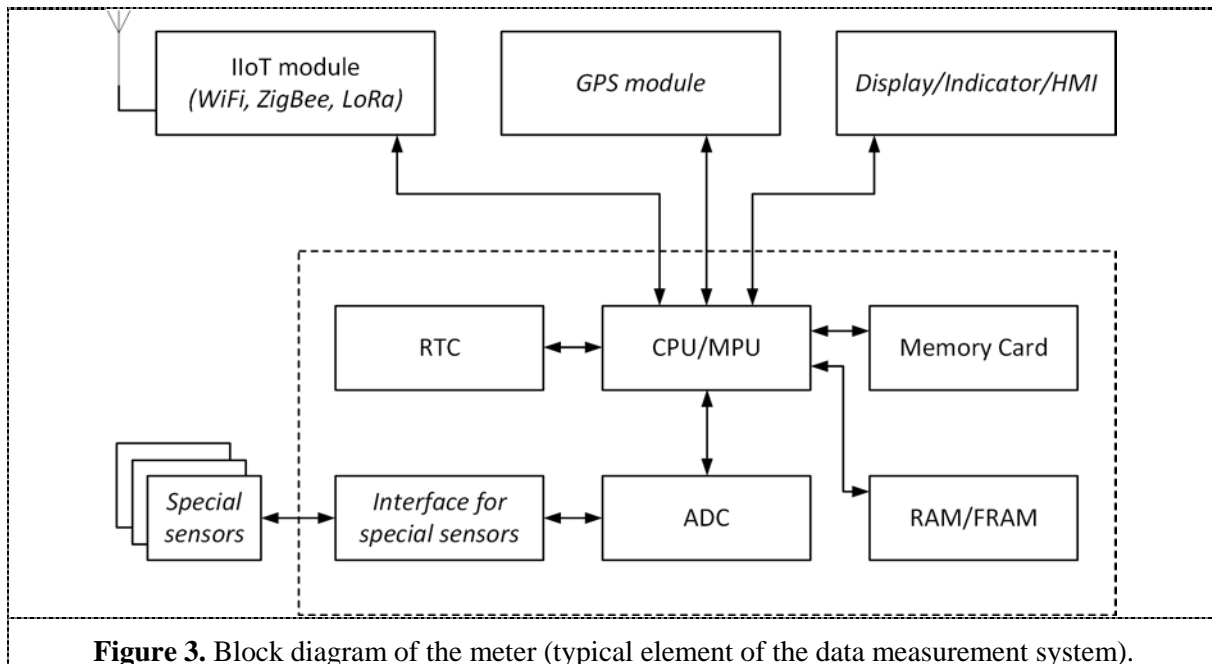
The printed circuit board contains a number of external interfaces for connecting extension modules (wireless IIoT module, GPS/GLONASS module) and control and data output devices (display, indicators, HMI device).

The unified block diagram of LDCS is shown in figure 4. It can also be modified depending on functional requirements and applicable data transfer technologies. The central part of LDCS is an industrial computer with high fault tolerance.

4. Working prototype and testing

The considered architecture and principles are implemented in a working prototype of automated system for monitoring and metering of energy resources. There are six DC traction substations on the pilot site of the Sverdlovsk Railway. Each traction substation includes two or three rectifier devices

and from six to eight feeders. Rectifier devices and feeders, called metering points, are equipped with DMS that perform registration of the main electrical parameters—voltage and current.



Measurement and registration are carried out with a sampling frequency of 16 kHz, that allows the analysis of harmonic components of the signals in accordance with existing standards for electric power quality control, as well as the recording of various events and associated transients that can be analyzed by a specialized diagnostic system [8].

An example of the time diagrams of the current and voltage at one of the rectifiers of the DC traction substation registered and passed from the DMS level to the EUS level is shown in figure 5. An example of measurements for a feeder is shown in figure 6. Three cases are shown: with near-zero load for rectifier (figure 5, a) and recuperation for feeder (figure 6, a), with medium (figures 5, 6, b) and high (figures 5, 6, c) loads.

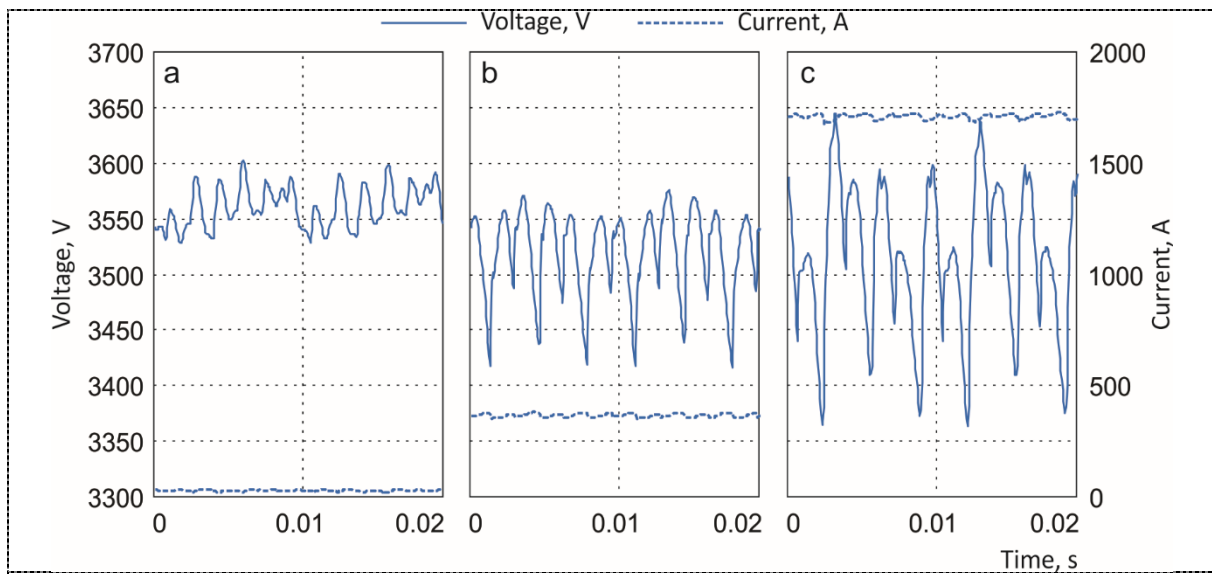


Figure 5. Examples of real-time voltage and current diagrams for rectifier on traction power supply substation.

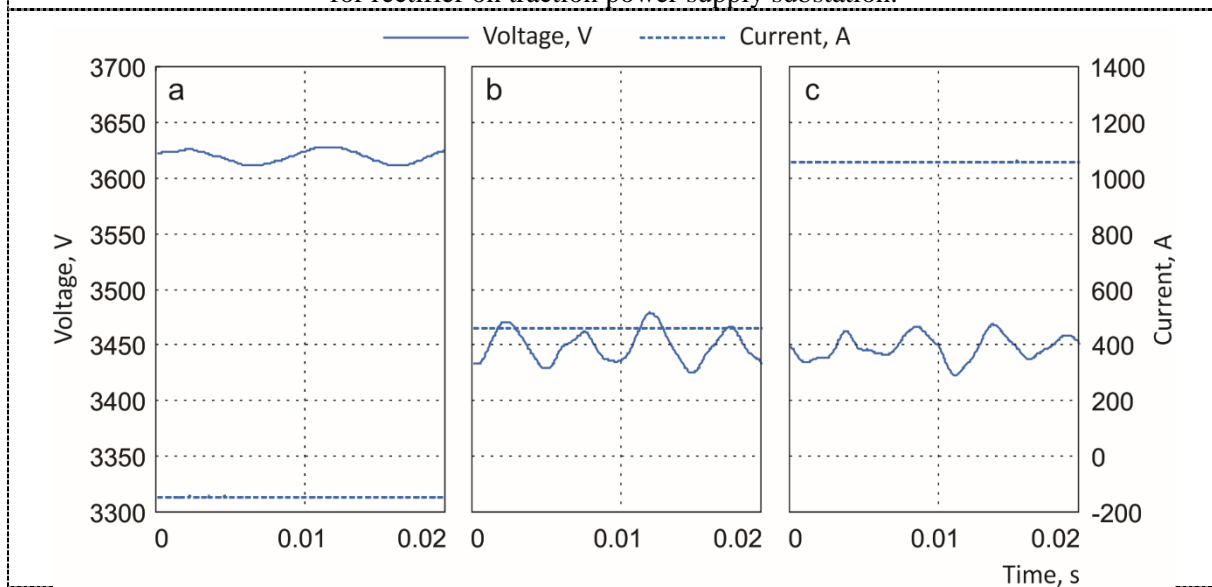


Figure 6. Examples of real-time voltage and current diagrams for feeder on traction power supply substation.

5. Conclusion

The paper discusses technical solutions based on the application of IIoT technology, that are implemented in the automated system for monitoring and metering of energy resources at the experimental Sverdlovsk Railway pilot site. The use of IIoT technology has increased the level of scalability and ease of deployment of the system with support for a variety of terminal equipment. The set of solutions is proposed that allows for modular architecture for the rapid addition of new devices and functions through the use of IIoT technologies. The main solutions are:

- Protocol stack, providing a decrease in the volume of traffic in the system with the support of existing and developing devices using LoRa and XNB technologies.

- The prototype of a mobile information-measuring complex with an independent power source and supporting ZigBee, LoRa, XNB technology and GPS/GLONASS positioning system.

Due to these advantages, the system can also be adapted to the needs of various enterprises, where it is necessary to keep records of any production resources and technological parameters that can be synchronously measured in real time for research and operational decision-making.

6. References

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