Complex simulation model of functioning mine telecommunication system using Power Line Communication technology

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Abstract. This paper considers a modern development of telecommunication systems as a part of electrical complexes of underground facilities, namely, application of PLC technologies for complexing electrical systems. A description is provided of the main tool of experimental studies of such systems, a simulation model of operation, its structure, development sequence and main elements, as well as an experimental validation of the model. The proposed model will allow solving a wide range of problems in the process of studying telecommunications systems and power supply systems for underground structures. Model development included the formulation of complex research tasks, the creation of the conceptual model, the formation of a set of requirements for the modeling algorithm, the development of a mathematical model, creating a simulation program in C++ with the use of JBuilder, the company Embarcadero version 10.3, as well as the verification of the simulation model. Based on the considered structure of the PLC network, it is proposed to include an information generation module, a connection module, a transmission line module, a modulation, encoding and decoding module, an information processing and noise reduction module, a subscriber module and a performance evaluation module in the model of integration of power supply and telecommunications systems for underground structures. To solve the problem verify the model was developed methods of research the effectiveness of various algorithms for transmission power supply networks underground structures, allowing an informed choice of data transfer methods and rational selection of the non-necessity to implement the methods selected equipment and conducted a series of experimental studies on real industrial underground facilities.

1. Introduction
Complexing telecommunication systems with the power supply systems in mines and other underground facilities is a possible area of improvement of telecommunication. Information transmission concurrent with power supply using the same wiring channel is already efficiently put into practice in various applications [1]. It should be noted that there are situations in practice when laying new cables is either undesirable or deemed impossible. In such cases, there is usually a possibility to limit oneself to existing electrical infrastructure, namely, using existing wiring of the power supply system to arrange a rather high-speed and stable information transmission channel throughout the facility [2].

2. Principal theoretical provisions
It is proposed to use a simulation model of the combined telecommunication and power supply system of a mine (underground facility) as a principal tool for experimental studies and decision-making in this area. The developed model will allow solving a wide range of tasks during the investigation of
both telecommunication and power supply systems. Construction of the model proceeded in the following sequence:

1. Formulating a set of research tasks
2. Constructing a concept model
3. Forming a set of requirements to the simulating program
4. Constructing a mathematical model
5. Development of the simulating program (simulation algorithm)
6. Verification of the simulation model
7. Validation of the simulation model

On the assumption of the assumed composition of the PLC network, the power supply and telecommunication complexing model for underground facilities will include: list of task being solved; information generation module; connection module; transmission line module; modulation, coding and decoding module; information processing and noise reduction module; subscriber module; and parameter evaluation module. (Figure 1).

\[\text{Figure 1. Simulation model for complexing power supply and telecommunication systems in mines (underground facilities)}\]

**Information generation module.** It provides simulation modeling of information streams in accordance with the adopted protocols, as well as hashing the stream with an electromagnetic noise environment [3].

**Connection module.** It provides conversion algorithms for transmitted signals for inductive taps with separate phase wires in distribution cables of the mine, for branching to/from low-voltage socket, for branching to cable ground with respect to the local ground, for wireless branching to or from the cable and for inductive branching of the radio frequency (RF) throughout the HV cable or away from it [4].
Transmission line module. It implements signal passage through the elements of the power supply system (electrical wiring, lay-ups, branch boxes, phase conjugation devices, electric switchboards, secondary distribution panels, electrical protection breakers, automatic breakers and sockets, earth connection) [5].

Modulation, coding and decoding module. It contains algorithms for operation of electric decoding modem, which usually consists of network and channel level controller, transceiver, amplifier and isolating circuit.

Subscriber module. It provides formation of received and transmitted signals of subscriber devices interacting through the PLC network (controllers of fans, transmitters, communication systems, etc.) in accordance with the protocols being implemented.

Information processing and noise reduction module. It implements the processing algorithms for the information that is circulating through the PLC network with the purpose of providing noise reduction and control of data integrity. PLC systems oriented to solving the tasks of broadband subscriber access usually use two technologies. The first one uses the signal with so-called spread spectrum (SS), which significantly improves noise immunity of the transmission [6]. When using the SS modulation, the signal power is spread through a broad frequency band and the signal becomes unnoticeable on the noise background. At the receiver side, the meaningful information is extracted from the noise-like signal using a pseudorandom code sequence unique for a given signal. Using various codes, one may transmit several messages at once through a single broad frequency band. This principle underlies the Code Division Multiple Access method (CDMA). Let us note, that in addition to noise immunity, the SS modulation provides a high level of information protection. QPSK modulation is used as a basic modulation. The second technology is based onto orthogonal frequency multiplexing with simultaneous transmission of signal on several carriers (OFDM -Orthogonal Frequency Division Multiplex). This method also guarantees a high transmission accuracy and stability against signal distortion [8-10]. It should be noted, that the research considered a PLC system that implements the principle of multiple “point-point set” access. For example, the local transformer substation supplies several underground facilities with electrical power, while simultaneously providing the subscribers with network access, communication, etc..

Parameter evaluation module. It provides gathering parameters and characteristics of signals transmitted and received at all the points of the network with the aim of assessing the studied decisions. The software implementation of the model is in C++ using the JBuilder environment by Embarcadero, version 10.3. It resulted in a functionally complete program solution that allows solving almost all research tasks by means of simulation modeling.

Verification of the simulation model was represented by implementation of initial states and conditions of an abstract system in the model and comparison of the modeling results with the expected results, that is, by solving a set of control examples used to debug the program. In order to test the applicability of the model, a number of experiments were carried out on actual electrical power supply systems in the mines of Uralkalii and at the Vorgasherskaya mine, using telecommunication equipment produced by NI.

3. Experimental research

When building a system to transmit data through power networks, a significant input to the efficiency of the system comes from a correct selection of equipment that shall meet the requirements of the environment in the location where the data transmission channel is being constructed. In order to solve this problem, a research methodology was developed to study efficiency of different data transmission algorithms through power networks of underground facilities that allows for reasonable selection of data transmission methods and rational selection of equipment necessary to implement the methods. A number of experiments were carried out on actual underground industrial facilities. In order to conduct the experimental research in constructing a communication channel, the following set of equipment was used: PLC modem G2-BASE-200-BUS to organize Ethernet network for cables that supply mines and specialized combines, inductive PLC connecting device G2-UN-IND, d40 and d60 filters pro-
duced by Hypercom. The studies were carried out at a tunnel shaft in a mine belonging to Belaruskali. Main broadband PLC modem (router) G2-BASE-200 is a head unit for transmitting/receiving data through power networks using special filters of connecting devices (0.4, 6-10, 35 kV) through coaxial lines (CTV) and other wiring. It is used as a head main line modem for the Automated Informational Measuring System for Commercial Power Fiscal Metering (AIMS CPFM) and APCS, as well as in provider’s data transmission networks, including as Ethernet bridge (optical media converter).

Inductive connecting device is intended for inductive connection of PLC modems to 6, 10 and 20 kV cable networks and arrangement of data transmission through such networks (between transformer substations with small-scale input cells). Type of installation: wrapping the phase wire of the cable in a switchboard or at a long rebroadcasting segments. Nominal voltage: 6-20 kV. Dimensions: h =100mm, d ext =105 mm, d int = 40 mm. Weight max 1.2 kg. Type of connection: wrapping phase-armature+circuit. Bandwidth is stated as either a narrow band 40-500 kHz or a broadband 2-40 MHz. Maximum current on a cable 6-20 kV 360 A.

Inductive tap is practically an RF transformer that uses the distribution cable a one side of the transformer with a single winding and uses one or several windings of the signal wire for the second side. The way of installing the inductive connecting device is shown in Figure 2. The ring surrounding the cable consists of material with high magnetic permeability that serves as a core of the transformer, perceiving and inducing current in the cable. Requirements to this tap include that it shall continue operating in the normal mode as a transformer even when excessive current (350+ A) passes through the distribution cable; additionally, it shall demonstrate the frequency characteristic and block the mains frequency of 60 Hz.

![Figure 2. RF tap of the distribution line](image)

Large currents passing through the cable create a magnetic field around the cable that saturates most magnetic materials, leading to worsening of transformer characteristic through at least a part of the power cycle. This problem was partially resolved by inclusion of non-magnetic materials into the toroid, thus improving the operational characteristic of the field many times over.

The most common type of magnetic material used in the modern inductive taps for large current lines consists of nanocrystalline magnetic alloys. Clamping inductive taps of two types were used: low-frequency sleeves for data transmission through the power networks that operate at frequencies below 150 kHz, and high-frequency BPL that are intended for broadband data transmission through main power transmission lines operating at frequencies of > 2 MHz. During the testing, compatibility, thermal stability and data transmission speed were studies in D40 and D60 filters used with the G2-BASE-200 modem. The results of the tests are shown in Table 1.
Table 1. - Results of testing the G2-BASE-200 modem together with Hypercom d40 and d60 filters

| Inductive filter type | Attempt | Interval | Transfer | Data transmission speed | Note |
|-----------------------|---------|----------|----------|------------------------|------|
| Filter no. 1. Hypercom d60 - (Modem G2-BASE-200) | no. 1 | 0-10.2 s | 10 MByte | 8.25 Mbit/sec | After 1 minute |
| Filter no. 2. Hypercom d40 - (Modem G2-BASE-200) | no. 1 | 0-10.2 s | 8.88 MByte | 7.31 Mbit/sec | After 1 minute |
| Filter no. 3. Hypercom d60 - (Modem G2-BASE-200) | no. 2 | 0-10.2 s | 10.4 MByte | 8.54 Mbit/sec | After 2 minutes |
| Filter no. 4. Hypercom d40 - (Modem G2-BASE-200) | no. 3 | 0-10.2 s | 10.4 MByte | 8.49 Mbit/sec | After 3 minutes |
| Filter no. 5. Hypercom d60 - (Modem G2-BASE-200) | no. 4 | 0-10.2 s | 10.2 MByte | 8.43 Mbit/sec | After 4 minutes |
| Filter no. 6. Hypercom d40 - (Modem G2-BASE-200) | no. 5 | 0-10.2 s | 10.2 MByte | 8.47 Mbit/sec | After 5 minutes |

4. Principal conclusions

The following conclusions have been made from the research results: Average data transmission speed in a combination of Hypercom d60 filter with a G2-BASE-200 modem amounts to 7.526 Mbit/sec, while the average data transmission speed in combination of Hypercom d40 filter with a G2-BASE-200 is 8.248 Mbit/sec. It should be noted that the equipment was not earthed during the measurements. The cable used was of type KShVEPbShv. The data transmission speed may vary depending on the cable length. In this case, the distance was 450 m (with a bend). Additionally, this experiment tested optimal variants for thermally stable installation of a G2-BASE-200-BUS model onto a power cable. This issue is also highly relevant as it affects the operation of the system as a whole.

The results of testing the G2-BASE-200 modem for compatibility with Hypercom d60 and Hypercom d40 filters, as well as determination of optimal thermal stability parameters allow for a conclusion that this type of connection to a high voltage network and data transmission through this network is efficient and prospective. Besides, the results of this experiment were used to validate and evaluate the accuracy of a developed simulation model, which was completely validated for this class of problems. Additionally, two other variants of connection were studied within the framework of this experiment: inductive and capacitive, using a SM130K tunneling machine. Figure 3 shows spectra of a PLC signal obtained at the receiving side with various methods of connecting to the line. Comparison of the spectral levels shows that the capacitive method is at a disadvantage of $15...20$ dB compared to the inductive one. It should be noted that from the process point of view, the inductive method is safer, as it assumes connection to a cable without removing its armature. Additionally, the inductive method showed better signal level during the testing. It should be also noted that the simulation model for this type is the first of its kind; currently there is a state registration pending.

Figure 3. Signal levels at the system input for inductive (a) and capacitive (b) connection
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References
[1] Vaganov V S Goffart T V and Dubkov I S 2018 Development of mobile devices as components of coal mine computer networks Mining Industry 1 (137) 54
[2] Okhrimenko V 2009 PLC technologies Electronic components 10 58-62
[3] Verkhulevsky K 2015 Transmission of information through electric grid with Semtech ICs Components and Technologies 11 (172) 50-54
[4] Hrasnica H Haidine A and Lehnert R 2004 Broadband Power-line Communications Networks John Willey & Sons
[5] Nevstruev I A Arseniev A V 2007 Constructing information access and transmission networks on the basis of electric grid Electrical and Informational Complexes and Systems 3 12-19
[6] Babenko A G Lapin S E Vilgelm A V and Orzhelkovsky S M 2011 Principles of construction of multifunctional safety systems in coal mines Experience and prospects for their application in Kuzbass Labor Safety in Industry 1, 16
[7] Zubov V P 2017 Status and directions of improvement of development systems of coal seams on perspective Kuzbass coal mines Journal of Mining Institute 225 pp. 292-297 DOI: 10.18454/pmi.2017.3.292
[8] Grachev A Iu Novikov A V and Panevnikov K V 2016 Multifunctional safety systems in coal mines positioning and personnel alert 121
[9] Vaganov V S 2014 Multifunctional safety systems applied in mining operations Mining Industry 3 (115) 25
[10] Kostin V N, Minakova T E 2017 Protective and control relays as coal-mine power-supply ACS subsystem IOP Conference Series: Earth and Environmental Science 87(3) DOI: 10.1088/1755-1315/87/3/032017
[11] Ivanchenko D I, Iakovleva E V 2017 Simulation of switching overvoltage in mine production unit Proceedings of the 2017 IEEE Russia Section Young Researchers in Electrical and Electronic Engineering Conference, ElConRus 2017 pp. 873-876 DOI: 10.1109/EIConRus.2017.7910694
[12] Cisco Connected Mining 2016, available at: https://www.cisco.com/c/dam/en_us/solutions/industries/automotive/docs/connected_mining_at-a-glance.pdf
[13] Gaikovich G F 2009 Standardization in industrial networks. Development of APCS wireless standards, Electronic Components 1 48