Employing the digital platform for control system development in a coal mining enterprise

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Abstract. The article discusses the issues related with a digital platform for distributed energy resources in the framework of mining enterprises. The paper examines the directions of sustainable development of the infrastructure of a mining enterprise, among which it is necessary to highlight the use of digital twins, taking into account the relationship of technological processes with the processes of transport of electrical energy, the development of small generation and the use of renewable energy sources. The authors proposed a two-level architecture of a coal mine control system, the implementation of which is possible with the introduction of IoT devices. It includes the EDGE layer and the Cloud / on-premise layer, which implement the corresponding functions. In the future, such a control system will make it possible to implement the concept of unmanned mining with the effective use of machine learning methods. In conclusion, it was noted that it is important to ensure the synergy of the developed platform solutions in the electric power industry and the mining industry to reduce the total costs of creating digital mining enterprises and step-by-step implementation of the Industry 4.0 concept.

1. Introduction

Despite the global trend towards abandonment of hydrocarbon fuels, coal demand and the development of the coal industry will persist for the next few decades. The Development Program of Russian Coal Industry up to 2035 (hereinafter referred to as the Program) \cite{1} assumes a change in coal demand by 2035 from --1.16\% (conservative scenario) to +13.95\% (optimistic scenario). At the same time, the following must be ensured:

- mastering of technology of coal mining without the constant presence of underground staff in coal mine extraction area (“unmanned mining”);
- development and implementation of innovative technologies with elements of the industrial strategy of “Industry 4.0” based on digital platforms and technologies;
- organization of interaction between science and industry to strengthen the scientific and technical base of coal mining companies and industry research centers, ensuring the continuity of the processes of technological modernization of production in accordance with advanced world practices;
- development of combined cooling, heat and power (CCHP) that operates on methane extracted from coal seams;
- development of the industrial Internet of Things (IoT) in the underground coal mining (formation of a unified information and control infrastructure for monitoring and controlling of technological equipment, providing communication and signaling, monitoring, alerting and searching for workers in emergency situations).

When analyzing the global experience of digitalization of coal mining enterprises, it becomes clear that Chinese scientists have achieved the greatest success in this area. They have considered 3 stages of development for Chinese coal Industry-3.0., 4.0., and 5.0 [2]. The 3.0 stage strives to fulfil “reduced staff, ultra-low ecological damage and emission level near to natural gas” from present time to 2025. The 4.0 stage plans to achieve the goal of “near-unmanned mining and near-zero emission” in 2035, and the 5.0 stage should achieve the objective of “no coal above ground, no staff underground, zero-emission and zero damage”.

To achieve the intended objective, the digital economy needs to involve the use of a digital platforms. Such platforms are designed to accelerate the pace of digitalization and improve production efficiency. Chinese scientists are well into the process of the development of digital platforms for mining enterprises. Thus, [3] considers necessity to create a digital platform for the design of “digital coal mines”. It is noted that the design process is accompanied by changing a large amount of documentation. As a result, some problems with documentation’s versions and possible mistakes might happen. This significantly affects the speed of implementation of the “Industry 4.0” concept. In [4], dynamic digital platform is proposed, that implements the principles of non-destructive quality control of the powered support units. The structure of a digital platform, which is required for organizing the gathering, analysis and transmission of data and information as well as the organization of applied control systems, is proposed in [5]. The applied automation systems used in the control of mines’ working areas are considered in [6]. Moreover, [6] predicts widespread usage of IoT-devices in coal mines of the future. However, it should be noted that the amount of research in the applications of IoT-technologies in coal mines is very limited.

In [7], the main tasks for increasing coal mines’ power supply efficiency are outlined. It is said that for solving these tasks, modern technologies should be involved, such as IoT and BIG DATA. In addition, distributed generation is increasingly used at enterprises of the mineral resources sector. For example: 1) installation of mobile solar power plants by SunSHIFT Pty Ltd (Australia) at open-pit coal mines [8]; 2) implementation of electric dump trucks and the subsequent development of charging infrastructure for electric transport as one of the options for business diversification [8]; 3) installation of a 36 MW hybrid solar power plant at the gold mine in the southwest of Mali, using “all-sky” cameras to improve the quality of the forecast of solar generation and to reduce fuel consumption for diesel generator sets [9].

Considering the above, it can be concluded that a significant part in creation of “digital mining enterprise” is the digitalization of power supply with introduction of distributed generation, energy storage devices and control systems. Therefore, the digitalization of power supply systems can be separated into individual cluster of “Industry 4.0” called “Energy 4.0” [10]. The main idea of “Energy 4.0” is effective usage of distributed energy resources, based on modern optimization and forecasting methods, artificial intelligence and BIG DATA technologies. The
implementation of “Energy 4.0” in practice is intended to bring an additional reduction in the unit cost of electrical energy by up to 30%. In this regard, the development of digital platforms for electric power industry is becoming urgent, ensuring a reduction in the cost of digitalizing power supply systems for industrial enterprises. Some digital platforms made by developed European countries, for example, Powerpeers (the Netherlands), SonnenCommunity (Germany) and others [11]. Such digital platforms allow to optimize the process of integration and operation of power units of small energy. Russia is also developing a digital platform for the management of intelligent distributed generation – “Platform” (“A-Platform”). A-Platform is intended for the development, implementation and execution of control systems for objects of intelligent distributed generation [12,13].

In view of the foregoing, usage of “A-Platform” is promising for modern coal mining enterprises.

In this article the directions of sustainable development of the infrastructure of coal mining enterprise and the structural diagram of an enterprise when implementing distributed generation and a digital platform are described. This is followed by the discussion of the issues related with using digital twins in coal mining enterprises. The functional architecture of a coal mine management system is also presented followed by concluding remarks.

2. Lines for mining enterprises sustainable development
When implementing the Industry 4.0 concept, it is necessary to take into account the following lines of sustainable development of the infrastructure of a mining enterprise:

- Improvement of the controllability and observability of processes with the subsequent construction of digital twins and ergonomic human-machine interfaces. This line is of particular importance for the movement towards the creation of an unmanned coal mine and the improvement of approaches to the design of energy efficient mining enterprises.

- Integration of technological processes, transmission and distribution of electricity when designing systems for optimal control of production processes, including the management of an electrical complex. Since the consumption of a mining enterprise is primarily determined by the technological process, when managing the power supply system, it becomes advisable to consider the specifics of the technological process in order to improve the quality and energy efficiency of energy supply. Of interest is the implementation of intelligent control algorithms for reactive power compensation devices and FACTS devices (D-STATCOM, DVR, HF) [17].

- Implementation of power generation units using coal mine methane at different stages of seam development. During the technological process, a large amount of coal mine methane is released, which in most cases is emitted into the atmosphere. Considering that coal mine methane accounts for 17% of the contribution to greenhouse gas emissions, its utilization by conversion into electrical and thermal energy (cogeneration) is of key importance not only for increasing the efficiency of the enterprise, but also for the global ecology.

- Usage of renewable energy sources, including on reclaimed land. At coal mining enterprises located in areas with a high potential of renewable energy sources, it is advisable to use generation on renewable energy sources to minimize emissions into the atmosphere. This approach to achieve the main goal of Industry 5.0, namely the elimination of emissions into the atmosphere, including during the production of electricity consumed by a coal mine.

- Business diversification of coal mining enterprises. The business of coal mining enterprises can be diversified by deploying data processing centers on enterprises’ infrastructures [14], as well as by creating their own infrastructures of electric filling stations. This is especially important, given that large mining enterprises are located close to small cities located on regional and federal highways.
• Creation of control systems to minimize energy supply charges through:
  – the use of modern technologies for the accumulation of electrical energy (including for
    emergency power supply);
  – optimal control of consumers-regulators;
  – participation in the provision of demand response services. The above directions make
    it possible to form a structural diagram of a coal mining enterprise with the integration
    of distributed energy resources (Fig. 1).

![Figure 1. Block diagram of a coal mining enterprise with the integration of distributed energy resources](image)

3. Creation of digital twins using the digital platform
For effective implementation of business scenarios, it is reasonable to apply digital twins that
can be used in mining enterprise (Fig. 2):

  (1) Virtual approbation and evaluation of design solutions (decision support)
  The project organization uses the components of digital twins (digital models) to evaluate
  design decisions during the modeling phase, considering the life cycle of the coal mine, which are
  used during the implementation phase to create digital twins. At the same time, at the design
  stage, abnormal situations can be simulated, the safety of the enterprise can be assessed and
  appropriate measures are provided.

  (2) Calibration and verification of models and control algorithms
  Digital twins can be used to improve equipment control algorithms, especially in the early
  stages of mine commissioning. In this case, as the data accumulates, the control algorithms are
  optimized using machine learning methods, the processes of starting and stopping the equipment
  are optimized, the control algorithms for converter units are adjusted to increase the efficiency of
  the electric drive, the feed rate of the shearer is adjusted to achieve optimal energy parameters.

  (4) Training and virtual training of personnel
  Combined with VR technology, staff can be trained at the enterprise while on the surface.
  This eliminates the occurrence of emergencies and allows the optimization of the process of
  equipment repair.

  (5) Predictive monitoring of equipment health and identification of maintenance needs
Figure 2. Management organization based on the digital twin (including the tasks of the digital mining enterprise)

The application of machine learning methods ensures the optimization of the life cycle of mining equipment, reduction of equipment downtime, and an increase in the utilization rate of equipment machine time.

6. Assessment and forecasting of generation, consumption, storage of energy resources
   It allows to ensure effective integration of distributed energy resources into the structure of a mining enterprise and to ensure a reduction in electricity charges when introducing modern technologies.

7. Planning of mining, preparation and coal face works (BIM - technology)
   The introduction of BIM technologies allows using the digital twin of the deposit to optimize the movement of equipment and the process of coal mining. All this allows for an additional increase in energy efficiency.

8. Evaluation of the performance and energy efficiency of the enterprise
   It is relevant at the design stage of a coal mine to ensure the optimal selection of savings and reduce capital costs for the purchase of equipment.

9. Evaluation of the performance and energy efficiency of the enterprise.
   The platform should allow aggregating data from different subsystems to assess financial and economic indicators and optimize the technological process.

The experience of creating digital twins in production shows that to ensure the compatibility of digital models and describe processes, it is advisable to use an ontological approach to the formation of information support. This approach is based on the construction of an ontology, which is a formal description of entities, including their properties and relationships between them [15][16]. The use of this approach makes it possible to ensure the unity of information
support for the digital twin of a physical object through a qualitative description of the semantics of the processes of interaction between the elements of the control system and ensuring the compatibility of standards for different subject areas.

The ontological model is the basis for generating the structure of the information model, which presents various parameters that characterize a physical object. In this case, the information model of the object serves as the basis for verifying the ontological model. The information model provides a binding of measurement data for a physical object and is a source of master data for a mathematical model. At the same time, the measurement data, and the results of the operation of the mathematical model make it possible to verify the information model. Measurement data enter the mathematical model to ensure its operation and verification. The operator calibrates the digital twin and enters data into the information model. The information and mathematical models together represent a digital model that has no information connected with a physical object and is designed to simulate various situations. By combining the digital model with real-time data, a digital twin is formed. This approach allows for minimal costs to make changes to the information support of the platform, which, considering the rapid development of mining equipment, makes it possible to reduce the cost of forming an automated process control system.

4. Functional architecture of a coal mine control system based on a digital platform

Within coal mine, the platform architecture of the control system can be organized in two levels (Fig. 3):

![Figure 3. Block diagram of the architecture of a coal mine management system](image)

1) Cloud level. At this level, the following functions have to be performed:
   - provision of services for the development of applications;
   - provision of a microservices library for the implementation of technological process control algorithms;
   - provision of maintaining tools for information models and digital twins creation;
   - provision of services for working with Big Data, its processing and visualization;
• provision of services for diagnostics and equipment condition management;
• software and hardware monitoring.

The platform operator is responsible for the correct execution of functions at different levels. If necessary, the Cloud layer can be transferred to the on-premise layer if the owner of the coal mine is not ready to transfer data to the public cloud.

2) Edge level. At this level, the following functions are supposed to be performed:

• collection of measurements from automation systems and / or directly from sensors of mining equipment;
• implementation of commands / signals aimed at fulfilling production plans while ensuring the required level of reliability and safety and minimizing specific energy consumption;
• ensuring the required level of information security;
• implementation of the functions of video monitoring and recognition of dangerous actions.

Note that when modernizing modern coal mines, it is possible to integrate the Cloud level with existing SCADA systems. In the future, it is advisable to use the designers of such systems in order to provide an economical improvement of the systems during operation. In addition, to achieve a synergistic effect, it is possible to agree on the access of platform ecosystem participants (developers of equipment and applications, universities and research institutes) to the platform data for the purpose of scientific research aimed at improving mining equipment and related control systems.

The EDGE layer implements simple control algorithms that form control actions to ensure reliable operation in case of a communication loss with the cloud. Note that with the development of the hardware and the emergence of Tensor Processing Units (TPU) specialized in working with neural networks, a greater number of intellectual functions can be transferred to the EDGE level, which is especially important in conditions of the need to ensure a high level of security.

5. Conclusion

Digital platforms can reduce the cost of creating automatic control systems in an industrial enterprise. Taking into account the high share of imported equipment at mining enterprises, the problem of their integration into Russian systems for collecting, analyzing and transmitting data arises, in connection with which the issue of creating and using digital platforms at mining enterprises is relevant.

The digital platform discussed in this article is intended mainly for smart distributed energy. However, it can be considered as one of the solutions to improve the energy efficiency of a mining enterprise by implementing various scenarios when introducing electric energy storage devices, small generation, renewable energy sources. The presented functional structure of a control system based on a digital platform assumes active integration of IoT devices in coal mines and can be integrated with SCADA systems.

At the same time, it is important to ensure the synergy of the developed platform solutions in the electric power industry and the mining industry in order to reduce the total costs of creating digital mining enterprises and step-by-step implementation of the Industry 4.0 concept.

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7
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