Digital information exchange technologies at electric power facilities of the railway transport and its cost-benefit

A N Kobylitsky¹, I V Ignatenko¹, S A Vlasenko¹, E Y Tryapkin¹ and I A Rebrov²

¹Far Eastern State Transport University, 47, Seryshev str., Khabarovsk, 680021, Russia
²JSC Railway Research Institute, 10, 3d Mytischinskaya Street, Moscow, 129626, Russia

E-mail: vsa_ens@mail.ru

Abstract. This article provides the economic assessment of the application of digital information exchange technologies at electric power facilities of Transenergo, a branch of the JSC Russian Railways, which is one of the first in the world to implement a pilot project of a specialized traction substation of the railway transport. One of the goals of the Digital traction substation project is a universal and scalable information infrastructure controlled by the uniform operation rules. A significant part of the economic indicators of the digital traction substation is advanced diagnostics of equipment, timely condition-based repair, increased reliability due to duplication of information processes of management and protection, modeling and forecasting of equipment operating modes and condition. In this article, the authors attempt to develop approaches to the economic assessment of the application of digital information exchange technologies at electric power facilities of transport and determine the most effective digitization level for traction substations.

1. Relevance of the research

Today, economically developed countries have developed a trend towards the introduction of digital platforms – unified systems for managing knowledge, technologies, and competencies. In the Russian Federation, accelerated implementation of digital technologies in the economy and social sphere is one of the national development goals. Effective application of new digital technologies will determine the international competitiveness of both individual companies and entire countries [1].

The digitalization of production and technological processes is a current process that takes place in the world economy [2]. The role of the digitalization at the present stage of development of the productive forces of humanity is no less important than automation and robotization of production processes. According to various estimates, the introduction of new-generation digital technologies can increase productivity in companies by 40% [3].

The digital economy concept has not yet been fully developed in the Russian Federation or other countries. However, it is generally considered that the digital economy is the economy of a new technological generation, an economic activity in which the key production factor is data in digital form.

The digitalization processes affected railway transport in the Russian Federation too. JSC Russian Railways is implementing a comprehensive innovation project named "Digital railway". The transition to minimally-manned or unmanned technologies for servicing railway infrastructure is an absolute priority of JSC Russian Railways. The process digitalization in the Railway transportation and infrastructure business block will allow the JSC Russian Railways to successfully compete with the
world's transport business leaders [4]. The authors propose to look into the economic efficiency of applying the digital information exchange technologies at the Transenergo power facilities, namely, the digitalization of traction substations. Transenergo is a functional branch of JSC Russian Railways, whose main goals are to fulfill the functions of meeting the Russian Railways’ needs in electric energy, purchase, transfer, and distribution of electric energy connected to the electric networks of JSC Russian Railways.

Tasks of the "Digital traction substation" project include:
- increasing the energy efficiency of a traction substation while maintaining its capacity;
- improving the reliability of the traction power supply system by reducing the failure rate of power facilities [5];
- introduction of intelligent control elements;
- increase of labor productivity, introduction of minimally-manned technologies;
- reducing occupational injuries;
- technology competitiveness for a new generation of staff [6].

The main effects of the Digital traction substation project are:
- changing the process model of the traction substation operation;
- transition to real-time monitoring and condition-based repairs instead of performing inspections, inter-repair tests, and scheduled maintenance;
- reduction of energy consumption and prevention of emergency shutdowns;
- current load forecast using big data analysis;
- real-time control of a digital traction substation using an intelligent "assistant";
- automation of energy dispatcher actions under various conditions [7].

Calculations for the Digital traction substation project were performed on the example of a functional unit of Transenergo – the power supply division, using real data.

2. Experimental studies
The capital investments for the construction of a traction substation of a traditional type were assessed using the industry budget and regulatory framework of JSC Russian Railways [8]. The estimated documentation is compiled for the base price level as of 01.01.2000 with conversion to current prices as of 2019. The traction substation construction cost also includes overhead costs, estimated profit, costs for temporary buildings and facilities, winter work, maintenance of the customer's service and construction control, and unforeseen work.

On average, the traction substation construction cost as of 2019 will be 1,757.6 million rubles (excl. value added tax), including: construction work 57.1 million rubles (3.3%); installation work 44.1 million rubles (2.5%); equipment 880.6 million rubles (50.1%); other costs 775.6 million rubles (44.1%).

The introduction of digital systems will reduce the repair time and increase the equipment durability due to optimal timing and quality of preventive maintenance based on automated accounting of equipment operating time and the use of technical diagnostics results [9]. The effect of a traction substation digitalization depends on the scope of technical and reconstructive measures (table 1).

| Table 1. Benefit of various levels of a traction substation digitalization. |
|-------------------------------------------------|
| **Digitalization level** | **Technical and reconstructive measures** | **Digitization benefit** | **Economic benefit** |
| Zero | Data bus (redundant switch) | Ability to monitor the traction substation performance indicators | Due to transition to condition-based repair |
| First | Station bus (redundant switch) | Reducing the maintenance personnel, a possible transition to unmanned operation; full redundancy of management | Due to personnel reduction (salary costs and social benefits) |
Second Station bus (redundant switch) together with the connecting bus

Reducing the number of equipment, including those with a high content of non-ferrous metals; reducing labor costs for equipment maintenance (checking the technical condition, inspection of terminal connections)

Due to reduction of current expenses for depreciation, labor, and social contributions; reduction of capital expenditures

Third Station bus (redundant switch) together with connecting bus and process bus

Reducing secondary power losses; reducing the equipment cost; reducing requirements for electromagnetic compatibility to the “office” level

By reducing the cost of electricity for the substation's own needs; reducing other material costs; reducing capital expenditures

In general, the economic benefit of the digitalization will be seen in reduced capital expenditures on equipment, reduced current operating expenses for labor and social contributions, depreciation, electricity, materials, and other material and related expenses.

As a result of reviewing the experience of implemented projects on the production processes digitalization in JSC Russian Railways and PJSC Rosseti, the zero-level digitalization will reduce the maintenance and servicing cost for high-voltage equipment of traction substations by 30% for all cost elements [10]. Cost savings will amount to 1.9 million rubles.

Investments in the zero-level digitalization of the traction substation will amount to 51 million rubles, with the economic efficiency indicators as follows:

- Discounted Payback Period (DPP) – over 10 years;
- Net Present Value (NPV) for the 10th year – 37.43 million rubles;
- Internal Rate Of Return (IRR) – 12%;
- Profitability index (PI) for the 10th year – 0.45.

These economic efficiency indicators show that the zero level digitalization of the traction substation is not advisable [11].

According to the authors’ estimates and based on the calculations, the most justified from the economic and technical point of view is the “first-level” digitalization of existing traction substations.

According to the authors' calculations, the estimated cost of the first-level digitalization of the traction substation will be 65.61 million rubles, which exceeds the zero level for 14.16 million rubles. The relative digitalization cost of zero and first levels is low, and its share in the total construction cost of traction substation is, respectively: in the total cost for the zero level – 2.09%; the total value of the equipment for the zero level – 5.79%; the total cost for the first level – 3.73%; in the total cost of the equipment for the first level – 7.45%.

During the new construction of traction substations, their digitalization must be carried out on the second and third levels. In this case, the digitalization will benefit both Transenergo and other divisions of the Russian Railways (RZD) holding.

Let’s look deeper into the economic efficiency calculation of traction substations digitization on the first level. The authors assumed the following provisions in the economic efficiency calculations. In the railway transport, the commercial and public efficiency of projects was determined in accordance with the "Guidelines for evaluating investment projects in railway transport" [8].

For projects that require large amounts of investment, with the construction period of more than one year and where facilities are built (reconstructed) in multiple stages, the economic efficiency is evaluated by dynamic indicators that take into account the time factor [12]. That means time-diverse results and costs were commensurated by bringing them to the initial period (time \( t = 0 \)) using the discount rate in order to account for the time factor in assessing the investment project efficiency.
Numerous calculations to determine the economic efficiency of large investment projects in railway transport have shown that in most cases the duration of the calculation period should not exceed 10 years (in technical and economic calculations) [13].

During the first level digitalization, maintenance of high-voltage equipment of the traction substation will be carried out by visiting teams of the maintenance division, while the substation will operate without the continuous presence of personnel.

The personnel of the traction substation includes: head, senior electrician, electrician, and duty electrician. The headcount of a traction substation normally does not exceed 10-14 people. Thus, the salary budget will amount to approximately 7.8 million rubles per year, and the payroll including social contributions, social payments, and occupational health and safety costs will amount to 11.2 million rubles.

However, with the smaller payroll of traction substation staff, there are additional costs for a team which performs condition-based repair of high voltage and electrical equipment [14]. It is assumed that the maintenance team will serve the substations of the power supply division according to the service rate of one team per three traction substations.

The cost savings resulting from the first-level digitization of the traction substation are calculated as follows:

$$E_{year}^d = E_{fts}^d - \Delta P_{fmt} - \Delta P_{mt},$$

(1)

where $E_{fts}^d$ is the payroll savings resulted from reduction of TS personnel; $\Delta P_{fmt}$ is an additional costs for the maintenance team; $\Delta P_{mt}$ is an additional costs for a motor transport of the maintenance team.

The cost savings resulting from the first-level digitalization of the traction substation will amount to approximately 6.8 million rubles per year.

At the economic efficiency calculation the discount rate is assumed to be 6.5%; the salary indexation rate in JSC Russian Railways is 7.5% per year. Investments in the TS digitalization on the first level amount to 65.61 million rubles, the calculation is made for 10 years.

The economic efficiency indicators are:
- Discounted Payback Period (DPP) 10 years;
- Net Present Value (NPV) for the 10th year – 1.01 million rubles;
- Internal Rate Of Return (IRR) – 6.8%;
- Profitability index (PI) for the 10th year – 1.5.

These economic efficiency indicators show the feasibility of the traction substation digitalization at the first level of digitalization [15-19] (table 2).

**Table 2.** Summary performance indicators for the traction substations digitalization on the zero and first levels.

| No. | Indicator | Value of the indicator before digitalization | Zero type digitization | First type digitization |
|-----|-----------|---------------------------------------------|-----------------------|------------------------|
| 1.  | Labor productivity, million t-km gross/person, electric traction | 183.78 | 183.78 | 244.25 |
|     | For reference: with the phased digitalization of 1 traction substation per year, million t-km gross/person, electric traction | – | – | 188.02 |
| 2.  | Reduction of power supply distance personnel serving 1 digital traction substation | – | – | 10.84 |
|     | Reduction of power supply division personnel serving all digital traction substations in the power supply division | – | – | 119.08 |
|   |   |   |   |
|---|---|---|---|
| 5. | Labor productivity growth when all substations in the power supply division are digitalized, % | – | – | 32.9 |
| 6. | For reference: with the phased digitalization of 1 traction substation per year | – | – | 2.31 |
| 7. | Reduction of personnel when all substations in the power supply division are digitalized, % | – | – | –24.8 |
| 8. | For reference: with the phased digitalization of 1 traction substation per year | – | – | –2.2 |
| 9. | Operating costs when all substations in the power supply division are digitalized, million rubles. | 1083.18 | 1081.28 | 1021.98 |
| 10. | For reference: with the phased digitalization of 1 traction substation per year | – | – | 1076.38 |
| 11. | Reducing costs when all substations in the power supply division are digitalized, % | – | –0.2 | –5.6 |
| 12. | For reference: with the phased digitalization of 1 traction substation per year | – | – | –0.6 |

Reviewing the table 2, the following conclusions can be made:
- the traction substation digitalization at the first level is much preferable than at the zero level;
- the growth of labor productivity in the Transenergo power supply divisions can reach 32.9%, with the phased digitalization of one traction substation per year –2.31%;
- cost savings of up to 5.6%, with the phased digitization of 1 TS per year –0.6%;
- personnel reduction by 24.8%, with the phased digitalization of 1 TS per year –2.2%.

The introduction of digital technologies for information exchange at electric power facilities will reduce the repair time and increase the equipment durability due to the optimal timing and quality of preventive maintenance based on automated accounting of equipment operating time and the use of technical diagnostics results, increase labor productivity, and reduce costs in the Transenergo power supply divisions.

3. Conclusions
The challenges posed by the global economy to modern enterprises can largely be overcome through the full digitalization of technological, economic, managerial, and production processes of corporations and individual sectors of the economy.

As a result of the introduction of digital traction substations and the modernization of business processes, the following effects should be achieved:
- increasing the reliability of power supply to consumers by continuous testing the control systems of digital traction substations with full redundancy of all communication and control channels;
- reducing technological losses of electricity through the use of methods of mathematical modeling of the power system state and automatic control of the traction network parameters depending on the train traffic;
- reducing financial costs for operation due to the implementation of the equipment monitoring and diagnostics system with the subsequent transition to condition-based maintenance of electrical equipment.

The digitalization of the Transenergo traction substations will not only provide the expected effects expressed in increased productivity and reduced costs, but also increase the reliability and continuity of the organization of transportation operations, as well as ensure remote work of employees without disrupting the operation. According to the authors, the digitalization of traction substations will automate many routine processes and improve working conditions in the power supply unit of JSC Russian Railways.
References

[1] Li Y, Dai J and Cui L 2020 International Journal of Production Economics 107777
[2] Krasnov S, Sergeev S, Zotova E and Grashchenko N 2019 E3S Web of Conferences 110 02052
[3] Zatsarinnyy A A and Shabanov A P 2019 Procedia Computer Science 150 552
[4] Podoba V A, Kobylitsky A N and Chudaev A V 2018 International Scientific Conference "Far East Con" (ISCFEC 2018) Atlantis Press 842
[5] Ignatenko I, Vlasenko S 2020 Advances in Intelligent Systems and Computing 1115 69
[6] Borisoglebskaya L N, Provotorova E N, Sergeev S M and Khudyakov A P 2019 IOP Conf. Ser.: Mater. Sci. Eng. 537 032036
[7] Chesalin A N, Grodzenskiy S Ya, Nilov M Yu and Tu Pham Van 2020 IOP Conf. Ser.: Mater. Sci. Eng. 862 042032
[8] Kobylitsky A N and Chudaev A V 2020 IOP Conf. Ser.: Mater. Sci. Eng. 753 052073
[9] Ignatenko I V and Vlasenko S A 2020 IOP Conf. Ser.: Mater. Sci. Eng. 760 012024
[10] Tryapkin E, Ignatenko I, Keino M 2018 MATEC Web Conf. 239 01051
[11] Wang L, Xu N, Xu N, Song Y, Wang Y and Song S 2019 IOP Conf. Ser.: Earth Environ. Sci. 242 022016
[12] Ianenko M, Ianenko M, Huhlaev D and Martynenko O 2019 IOP Conf. Ser.: Mater. Sci. Eng. 497 012118
[13] Jingfen Bai, Lin F, Yang X, Zuo J, Cheng Y and Yu C 2016 MATEC Web of Conferences 55 06007
[14] Hernández-Callejo L A 2019 Energies 12 1630
[15] Gibadullin A A, Pulyaeova V N and Yerygin Y V 2018 International Youth Scientific and Technical Conference Relay Protection and Automation (RPA) 18269336
[16] Borisoglebskaya L N, Provotorova E N and Sergeev S M 2019 IOP Conf. Ser.: Mater. Sci. Eng. 537 042032
[17] Li Z 2020 IOP Conf. Ser.: Mater. Sci. Eng. 750 012117
[18] Waleed A et al 2019 Advances in Science, Technology and Engineering Systems Journal 4 431
[19] Gibadullin A A, Pulyaeva V N and Yerygin Y V 2018 International Youth Scientific and Technical Conference Relay Protection and Automation (RPA) 18269336