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Modern Approaches to Design of Traction Power Network Facilities Using BIM Technology

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ABSTRACT

Optimisation of architecture and construction projects of power supply systems can be achieved with the help of BIM technology, which allows creating a single information model of interrelated processes. It permits to automatically prevent many design mistakes, and BIM makes analysis of project decisions made easier and more visual, significantly improving quality of design, and working documentation.

BIM technology is a modern approach to design-build-operate cycle. We can say that BIM is organised information about an object, used both at the design and construction stage, and during its operation and dismantling.

A single information space, that is a database containing all information about the technical, operational, energy and other features of the facility constitutes an important component of this technology. Due to an accurate and detailed development of the model, this technology makes it possible to carry out various calculations and analyses. A computer model of a new object created during the design process contains all the information about it. With BIM design, a designer at any level has the opportunity and direct need to think about an object as about a holistic model, in real time, and in conformity with its economic component.

Competent use of software products for development of BIM models, as well as of the visual programming environment and of the subsequent execution of working documentation, significantly reduces design time and the number of errors. Thus, the costs and time for correcting errors are minimised.

The above features of BIM technology allow full use of its advantages when adopting digital modelling in construction of railway power facilities. This process also offers an opportunity to directly relate development of engineering design solutions and electrical engineering calculations within simulation modelling.

The objective of the study was to analyse of practical adaptability and features of adoption of this technology while designing catenary. Generalised expertise served to demonstrate key points in implementing relevant information environment, features of development of digital twins of objects of power supply infrastructure and of their operation.

Keywords: *transport, railway, BIM, design, modelling, automation, power supply, traction power network, catenary.*

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INTRODUCTION

BIM technology (Building Information Modelling) allows creating a single information model of interrelated processes throughout the life cycle of an object, from the stage of development of basic design solutions to its reconstruction or dismantling[1].

The objective of using information modelling technology is explained through the fact that it allows to automatically prevent many common mistakes of designers, and conflict analysis and checking of design decisions becomes much easier, clearer, and more efficient using BIM technologies. Information modelling technology makes it possible to identify all errors within the project at an early stage, significantly improving quality of design and working documentation [1; 2]. Thus, the costs and time for correcting errors are minimised. Also, this technology allows visualising the process of building an object from scratch for the customer already in the design process, with the ability to display the time and economic components of its stages.

All these advantages of the information modelling fully apply to railways, namely, to design of their high-tech and sophisticated infrastructure, requiring, and that starting from the design stage, proactive coordination of groups of experts, permanent interaction with the customer, synchronisation of engineering, organisation, and economic aspects of a project.

The relevance of creating a single information model is that a group of specialists from various design sections develops together a single BIM model of an object [3–5], particularly of a railway infrastructure object. This allows all participants in the modelling process to see in real time all the current changes made to the project. It is also worth noting that modern realities are developing in such a way that, along with competent and economically sound technical solutions, the customer wants to get a visualisation of the finished object as close to reality as possible already at the initial design stages [6–7].

As well as for solution of any engineering task, information modelling needs relevant tools. Processes involving BIM technology in designing rail infrastructure make no exclusion, in that case these tools are various software.

Now, there are many software products on the market for development of BIM models and subsequent development of working documentation[2]. The main and most used in Russian conditions are Civil3D, ArchiCAD, Renga, Revit [8], each possessing its own advantages, though the analysis there-of has been beyond the scope of the research of the authors. It should be noted that the technology of BIM information modelling fully reveals itself only with introduction of automation based on development and use of various «scripts» and «plugins» [9–11]. Such tools are well developed, i.e., in the Autodesk Revit software package.

The *objective* of the study described in the article is to analyse the features of adoption of modern methods of digital modelling for construction of railway power facilities based on the use of software environment of BIM technology while designing catenary systems, as well as their advantages, for development both of BIM models and of full-fledged working documentation, as compared with traditional design methods. Implementation of BIM technology was considered regarding the activity of JSC Russian Railways.

The solution of the so set tasks was carried out using general scientific *methods* of research, theoretical analysis and synthesis, graphical interpretation of information, as well as modelling and programming [12–14].

RESULTS

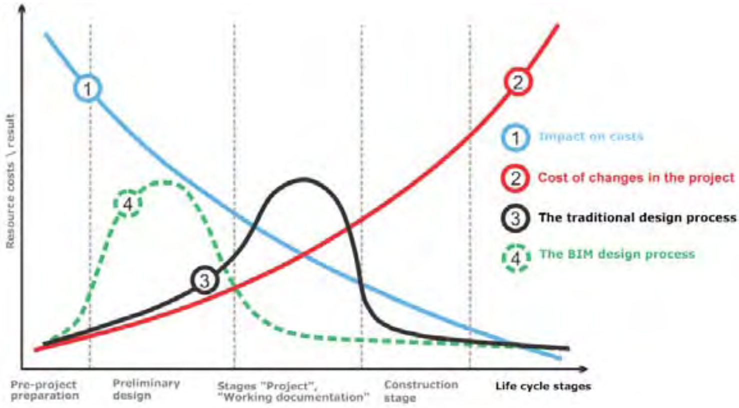
Benefits of BIM Technology

Specialists involved in development of a single information model of a railway infrastructure object must not only have the appropriate qualifications in the respective fields, but also be confident users of software products for developing BIM models.

BIM technology has several advantages over traditional design methods. When using BIM technology, the bulk of work regarding important design changes is shifted to the stage of preliminary design and development of project documentation, which significantly reduces the cost of correcting each design error [15–17]. Based on the graphs in Pic. 1 the cost of changes to be made increases with each stage of the life cycle.

[1] What is BIM technology? [Electronic resource]: https://www.autodesk.com/industry/aec/bim. Last accessed 10.03.2021.

[2] See, e.g.: Ozhigin, D. Analysis of the current situation in Russian BIM-market in the field of civil construction [*Analiz tekuschey situatsii na rossiyskom BIM-rynke v oblasti grazhdanskogo stroitel'stva*]. [ELectronic resource]:https://ru-bezh.ru/denis-ozhigin/39134-analiz-tekushhej-situaczii-na-rossijskom-bim-ryinke-v-oblasti-gr. Last accessed 10.03.2021.



Pic. 1. Advantages of BIM modelling over traditional modelling [chart[3], modified by the authors].

At the same time, with traditional CAD design technology, the largest number of collisions and shortcomings in specifications are detected and corrected mainly at the stages of development of working documentation and construction, resulting in a greater amount of financial and production costs.

Prerequisites to Use BIM Technology to Implement Projects on Rusian Railways

The market economy witnesses competitive struggle for speed, quality, and cost within all the industries. This does not bypass leading transport companies, including JSC Russian Railways, one of the largest amidst them in Russia. Significant points in the updated general scheme for development of JSC Russian Railways network until 2030 comprise:

• Identification of existing and prospective «bottlenecks» affecting transit capacity of segments of the railway network of JSC Russian Railways.

• Measures aimed at development of railway infrastructure[4].

To implement these points on agenda, it is necessary to optimise the entire system of design and calculation works. Besides, currently, the customer is increasingly trying to include in the design task a clause on creation of an information (digital) model of the object.

The leading design organisations in Russia, comprising Transelectroproject (TELP), which shares leading positions in implementing the most modern means of feasibility studies and design activities in the field of rail power supply systems, are already using BIM technology for the synthesis of engineering solutions for the purposes of electric power supply systems of the rail infrastructure. I.e., TELP, has already cumulated almost all the tools and libraries of elements necessary for fast and accurate construction of 3D models.

The Use of BIM Technology in Design of the Catenary

The information model of the overhead catenary[5] is an extended linear object containing a large set of support, carrying and supporting structures, various equipment, as well as a suspension cables and additional wires suspended using poles [with cantilevers, brackets, supports, registration arms, stays, steady arms, etc.] (Pic. 2).

The primary task while creating an information model of a catenary is to develop a library containing all the necessary families to fill the object model.

Creation of a family is a rather time-consuming process. It is necessary to carefully think over the logic of work within the model in advance. This process is very important, as it affects the stability of the information model of an object.

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[3] E.g.: What is BIM? [*Chto takoe BIM Building Information Modeling?*] (the article of genpro.ru). [Electronic resource]:https://xn----dtbhaacat8bfloi8h.xn--p1ai/bim-who-is; Designing using BIM technology [*Proektirovanie po BIM-technologiyam*]. [Electronic resource]:https://proekt.tessib.ru/bim-technology/designing-bim-technology/. Last accessed 14.03.2021.

[4] JSC Russian Railways has prepared an updated version of the general scheme for development of the railway network of JSC Russian Railways until 2020 and 2025 [*OAO «RZD» podgotovilo aktualizirovanniy variant generalnoi schemy razvitiya seti zheleznykh dorog «RZD» do 2020 i 2025 godov*]. [Electronic resource]: https://company.rzd.ru/ru/9397/page/104069?id=54527/. Last accessed 14.03.2021.

[5] Here-after called catenary, while other terms are also used, e.g., overhead line, overhead lines, overhead wiring, overhead contact system, overhead equipment, overhead line equipment, traction wire, trolley wire. – *Translator's note.*

Pic. 2. 3D visualisation of the catenary project [developed by the authors].

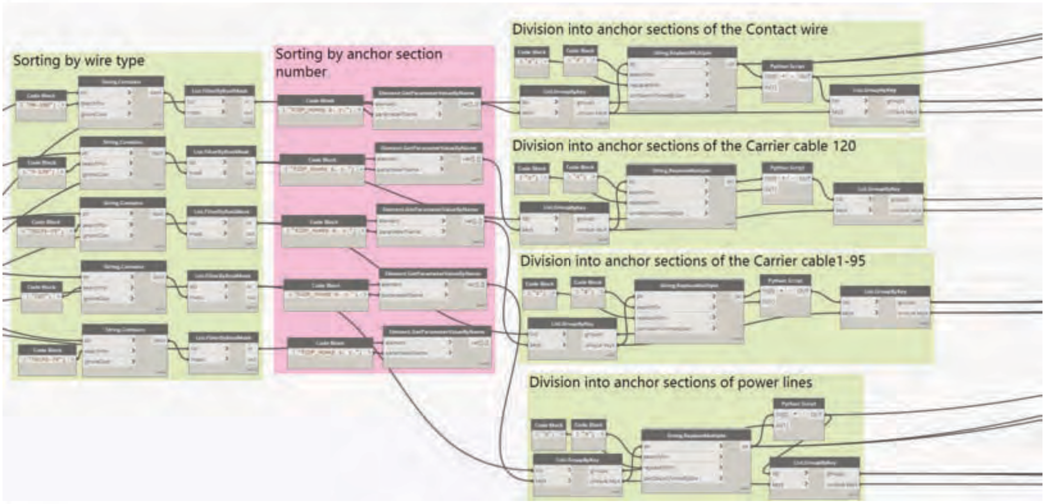
The internal structure of advanced BIM software products provides for a set of categories, and any family belongs to a certain category. For example, the foundation family belongs to the category of foundation of supporting (load-carrying) structure. In turn, the family has standard sizes. And a foundation family has standard sizes of different lengths and load-carrying capacity (for example, a TCA type [three-rayed foundation with bevel and anchored supporting consoles] foundation with a length of 4,5 and a bearing capacity of 59 kN•m, a TCA type foundation with a length of 5,0 and a bearing capacity of 79 kN•m, etc.).

Families are assigned with all the parameters inherent in catenary installations: name, brand, designation, weight, GOST [state standard], etc. Each family within the model is developed using a Shared Parameters File. This file allows using consistent names and avoid redundant data on basic and additional parameters when creating families. Also, this file is necessary for the correct representation of families in text form (specifications). Mandatory parameters include such properties or technical characteristics that allow us to uniquely identify the family, and that also contain data making possible to develop technical documentation, order, purchase and mounting of a specific element during the construction process. Additional parameters include properties or technical characteristics necessary for engineering calculations, technical and economic information, technical, performance, operational and other features[6]. This is necessary to automatically generate specifications of equipment and materials. The specification within the BIM object is the same model, only presented in a tabular form, each line of table being an element of the model. An important feature is the relationship between the specification and the model. If one changes an element in the specification, it is changed in the model, and vice versa. Thus, discrepancy between the specification and the project is absolutely excluded. Specifications can be created and sorted into categories, families, family parameters, and then used in other projects.

Using the created families, it is possible to assemble a complex family, that is to proceed with an «assembly» (Pic. 3), in which all elements are interconnected and configured to facilitate design.

Pic. 3. An example of assembling a complex family. Catenary pole [developed by the authors].

[6] E.g., SP 328.1325800.2017 [Construction Code] Building information modelling. Components. Guidelines and requirements. Rules of description of the elements of information model.



Pic. 4. Structural chart of a model for automating the process of designing a contact network device implemented in a visual programming environment [composed by the authors].

All families are strictly classified into types, categories and subcategories of objects based on library elements. Modelling of components and elements of a digital information model of a linear object of electrification and power supply of railways is carried out in accordance with their true dimensions on a scale of 1:1, in the metric system of measurements.

An important feature of the use of BIM technology when creating an information model is the use of templates. With proper preparation of the template, the entire information part will have already be included in the BIM model. As part of preparation of a template, all the necessary views, specifications and sheets for drawings are configured. As the BIM model is built, the specifications are automatically filled in and, in case of any changes in the assembly's elements of a complex family, they are automatically updated [18].

Designing a catenary network is a rather complicated and time-consuming process that takes quite a lot of time and includes the following set of tasks:

• Placement of poles of the contact network.

• Mapping of catenary wires and additional wires.

• Calculation and selection of poles, supports and supporting structures.

• Preparation of specifications for equipment, products and materials, bills of work.

• Design of drawings.

This process can be significantly automated using the virtual tools developed within the BIM software, as well as using the built-in additional environment for visual programming (for example, the Dynamo software environment) (Pic. 4). Powerful tools for automating design processes allow, particularly:

• To carry out automatic selection and installation of crossbars, as well as their reinforcement with supporting structures (Pic. 5).

• To automate the mapping of catenary wires.

• To automate the filling of the table of anchor sections and additional wires.

All this allows avoiding errors that occur during manual calculations and speed up the design by automating routine tasks.

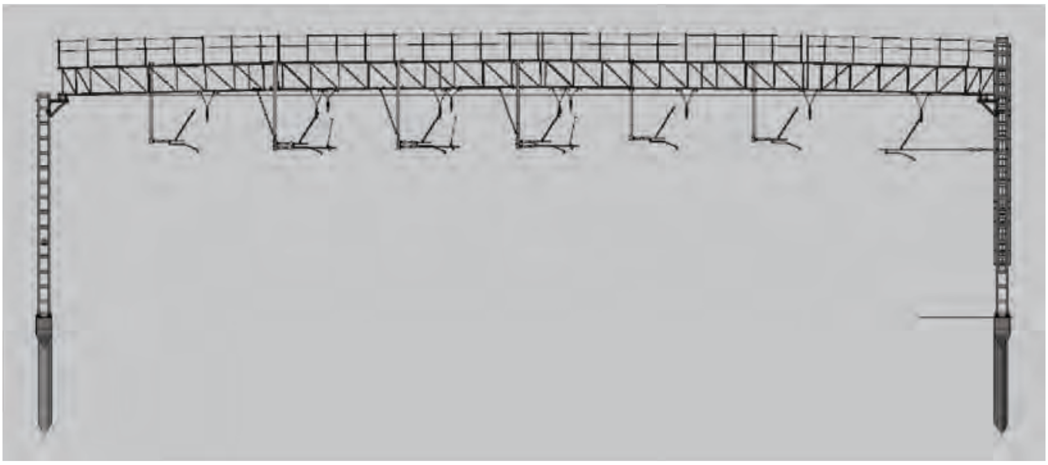
Outlook for Development of BIM Technology in Designing Overhead Catenary

In the future, the potential of symbiosis of the electrical calculation part and the design part regarding the contact network device will be implemented.

Now, first, an electrical calculation of the traction power supply system is carried out, based on simulation modelling. Its results act then as input data for development of design technical solutions for contact network devices [19].

By switching to BIM technologies in a broader form, electrical calculations and design solutions will be implemented in a single digital environment, moreover, within a single digital model. This will allow us to quickly, and most importantly with greater accuracy, correct the «digital twin» at various levels of performance of a comprehensive task.

The prospect of introducing a calculation and design model (digital twin) in symbiosis with a software product intended for electrical



Pic. 5. An example of assembling a complex family. Reinforcement of a rigid cross member with supporting structures using automation of selection of visual programming tools [developed by the authors].

calculations (for example, ETAP [20–22]) will bring development of a complex of calculations and design of railways in Russia to a qualitatively new level.

Similar technologies are currently being tested at Russian University of Transport at the Department of Transport Electric Power Engineering.

BRIEF CONCLUSION

The transition of a design organisation to design based on BIM technology means not only replacement of traditional design methods (2D drawings) with an information model. The changes will affect the core business processes of the organisation, which involve technical specialists and managers at all levels. Of course, such changes lead to redistribution of powers, areas of responsibility, internal document flow, to modification of the nature of relationships with partners, and so on.

With BIM design, a designer at any level has the opportunity and experiences direct need to think about an object as about a holistic model in real time, as well as about the economic component tied to it. It is also worth noting that the competent use of the tools of the BIM modelling software package, as well as of the environment for visual programming, significantly reduces the design time and significantly reduces the number of errors made.

Oddly enough, but «assessment of the full life cycle of an object makes it clear that design using traditional methods accounts for the smallest share of investments, that is only about 5 %. However, design errors can result in significant unplanned costs at later stages of the facility's life cycle, namely during its construction and operation»[3].

Based on the description of notions suggested in the article regarding the application of BIM technology in designing overhead catenary and generalised algorithm of stage-by-stage execution of design process, it has been shown that while applying general technology of digital modelling it is necessary to consider features of the infrastructure objects to be designed, to create relevant libraries including libraries of digital twins allowing their use for designing different facilities. The core promising task of the scientific inquiry is to specify in details the existing developments and to integrate calculation and design model (digital twin) in symbiosis with software referring to electrical calculations. A particular attention should be paid to development of a harmonised system of analysis of economic advantages of digital modelling as compared to traditional design methods and tools, as well as to several other issues.

Progressive cumulation of experience and practices of implementation of projects together with applied research, in our opinion, is capable to achieve even more efficiency of the use of BIM technology for the purpose of railway design, construction and operation.

REFERENCES

1. Volkov, A. A., Sukneva, L. V. BIM Technology in Tasks of the Designing Complex Systems of Alternative Energy Supply. XXIII R-S-P seminar Theoretical Foundation of Civil Engineering (23RSP). *Procedia Engineering*, 2014, Vol. 91, pp. 377–380. DOI: 10.1016/j.proeng.2014.12.078.

2. Cheng-Ting, Chiang; Chun-Ping, Chu; Chien-Cheng, Chou. BIM-enabled power consumption data management platform for rendering and analysis of energy usage patterns. International Conference on Sustainable Design, Engineering and Construction. *Procedia Engineering*, 2015, Vol. 118, pp. 554–562. DOI: 10.1016/j.proeng.2015.08.480.

3. Dmitriev, A. N., Vladimirova, I. L., Kallaur, G. Yu., Tsygankova, A. A. Approaches to Classifying Building Innovations while Implementing Information Modeling and Project Management. *Journal of Engineering Science and Technology Review,* 2019, Vol. 12 (2), pp. 143–151. [Electronic resource]: http://www.jestr.org/downloads/Volume12Issue2/fulltext201222019.pdf. Last accessed 14.03.2021.

4. Baht, I. M., Nicolae, P. M., Nicolae, I. D., Baht, N. Analysis of Green Building Effect on Micro grid Based on Potential Energy Savings and BIM. *Advances in Science, Technology and Engineering Systems Journal,* 2020, Vol. 5, Iss. 6, pp. 30–35. DOI: 10.25046/aj050604.

5. Adibah Ayuni Abd Malek, N., Ming Chew, J., Akmam Naamandadin, N., Zaiha Zainol, N., Muhammad, Kh. A study on association between tilt angle, solar insolation exposure and output of solar PV panel using BIM 3D modeling. *MATEC Web of Conferences,* 2018, Vol. 195, pp. 1–12. DOI: https://doi.org/10.1051/matecconf/201819506009.

6. Gan, V. J. L.; Han, Luo; Yi, Tan; Min, Deng; Kwok, H. L. BIM and Data-Driven Predictive Analysis of Optimum Thermal Comfort for Indoor Environment. *Sensors*, 2021, Vol. 21, pp. 1–22. DOI: 10.3390/s21134401.

7. Nik-Bakht, M.; Lee, J.; Dehkordi, S. H. BIM-based reverberation time analysis. *Journal of Information Technology in Construction (ITcon),* 2021, Vol. 26, pp. 28–38. [Electronic resource]: https://www.itcon.org/papers/2021_03-ITcon-Nik-Bakht.pdf. Last accessed 20.12.2021.

8. Talapov, V. BIM Technology. The Essence and Features of Adoption of Information Modelling of Buildings [*BIM-technologiya. Sut' i osobennosti vnedreniya informatsiooonogo modelirovaniya zdaniy*]. DMK-press, 2015, 410 p. [Electronic resource]: https://avidreaders.ru/download/tehnologiya-bim-sut-i-osobennostivnedreniya.html?f=pdf. Last accessed 14.03.2021.

9. Ahuja, R., Sawhney, A., Arif, M. Prioritizing BIM Capabilities of an Organization: An Interpretive Structural Modeling Analysis. Creative Construction Conference, 19–22 June 2017, Primosten, Croatia. *Procedia Engineering,* 2017, Vol. 196, pp. 2–10. DOI: 10.1016/j.proeng.2017.07.166.

10. Zhou, M., Tang, Y., Jin, H., Zhang, B., Sang, X. A BIM-Based Identification and Classification Method of Environmental Risks in the Design of Beijing Subway. *Journal of Civil Engineering and Management,* 2021, Vol. 27, Iss. 7, pp. 500–514. DOI: 10.3846/jcem.2021.15602.

11. Farooq, J., Sharma, P., Kumar, R. S. Applications of Building Information Modeling in Electrical Systems Design. *Journal of Engineering Science and Technology Review,* 2017, Vol. 10 (6), pp. 119–128. DOI: 10.25103/jestr.106.16.

12. Heo, J., Moon, H., Chang, S., Han, S., Lee, D.-E. Case Study of Solar Photovoltaic Power-Plant Site Selection for Infrastructure Planning Using a BIM-GIS-Based Approach. *Applied Sciences,* 2021, Vol. 11, pp. 1–16. DOI: https://doi.org/10.3390/app11188785.

13. Azevedo, D. M., Marotti, A., Cardoso, A., Lamounier, E., De Lima, G. F. M., De Araújo, A. L., Guttler, C., De Oliveira Rocha, R., Bartholomeu, C. Development of Bim (Building Information Modeling) Concept Applied to Projects of Substations Integrated With the Geographic Intelligence System (GIS). *World Scientific and Engineering Academy and Society (WSEAS) in WSEAS Transactions on Power Systems,* 2021, Vol. 16, pp. 1–7. DOI: 10.37394/232016.2021.16.1.

14 Zhao, Liang; Zhang, Hong; Wang, Qian; Wang, Haining. Digital-Twin-Based Evaluation of Nearly Zero-EnergyBuilding for Existing Buildings Based on Scan-to-BIM. *Hindawi Advances in Civil Engineering*, 2021, Vol. 5, pp. 1–11. DOI: 10.1155/2021/6638897.

15. Balaras, C. A., Kontoyiannidis, S., Dascalaki, E. G., Droutsa, K. G. Intelligent Services for Building Information Modeling – Assessing Variable Input Weather Data for Building Simulations. *The Open Construction and Building Technology Journal,* 2013, Vol. 7, pp. 138–145. DOI: 10.2174/1874836820131022005.

16. Borodin, S., Lyapina, A. State examination of BIM-model on the basis of object technological dependencies model. *IOP Conference Series: Materials Science and Engineering,* 2018, Vol. 451, pp. 1–5. DOI: 10.1088/1742-6596/451/1/012082.

17. Mataloto, B., Mendes, H., Ferreira, J. C. Things2People Interaction toward Energy Savings in Shared Spaces Using BIM. *Applied Sciences*, 2020, Vol. 10, pp. 1–17. DOI: 10.3390/app10165709.

18. Penkovsky, G. F. Fundamentals of information technology and automated design in construction [*Osnovy informatsionnykh tekhnologii i avtomatizirovannogo proektirovaniya v stroitelstve*]. St. Petersburg, SPbGASU publ., 2008, 150 p. [Electronic resource]: https://www.studmed.ru/view/penkovskiy-gf-osnovy-informacionnyh-tehnologiy-i-avtomatizirovannogo-proektirovaniya-v-stroitelstve_623e64bf644.html. Last accessed 14.03.2021.

19. Andreev, V. V., Shevlyugin, M. V., Grechishnikov, V. A. Integral characteristics of branched tractional power-supply systems. *Russian Electrical Engineering,* 2012, Vol. 83 (12), pp. 672–675. DOI: 10.3103/S1068371212120024.

20. Tulsky, V., Shevlyugin, M., Korolev, A., Khripushkin, N., Baembitov, R. Application of ETAP™eTraX™software package for digital simulation of distribution network that feeds an AC traction power supply system. *E3S Web of Conferences*, 2020, Vol. 209, pp. 07011. DOI: 10.1051/e3sconf/202020907011.

21. Shevlyugin, M. V., Korolev, A. A., Golitsyna, A. E., Pletnev, D. S. Electric Stock Digital Twin in a Subway Traction Power System. *Russian Electrical Engineering,* 2019, Vol. 90 (9), pp. 647–652. DOI: 10.3103/S1068371219090098.

22. Shevlyugin, M. V., Korolev, A. A., Korolev, A. O., Aleksandrov, I. A. A Digital Model of a Traction Substation with Two Types of Current. *Russian Electrical Engineering,* 2018, Vol. 89 (9), pp. 540–545. DOI: 10.3103/S1068371218090134. ●

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