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Digital twin technology as an instrument for increasing electrical equipment reliability

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Digital twin technology as an instrument for increasing electrical equipment reliability

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Abstract. The article describes the experience of practical realisation of digital twin technology for voltage and current measurement transformer 110 kV installed in real power station. In terms of the research electrical equipment state monitoring system has been developed as a set of sensors and diagnostic system, based on essentially different approaches of non-defective diagnostics. 3D model construction of the equipment under monitoring is also described as a part of digital twin concept. It is shown the valuable impact of digital twin technology application.

1. Introduction

Digital twin concept assumes to use a number of technical solutions, namely, set of sensors, monitoring, data acquisition and data storage systems, internet of things technologies for data transmitting and various data processing approaches and algorithms e.g. artificial intelligence.

Parametric virtual prototype of real object, system or process is resulted from digital twin technology application. Based on all historical data and current measurements it allows not only to simulate but to solve the problem of life cycle management.

Under the Russian Federation economics digitalisation overall and particularly digitalisation of the energy sector digital twin approach becomes new instrument for overcoming essential technological issues and achieving national goals of scientific and technological development of the industry in terms of integration of latest technologies in the field of smart managing systems, big data analysis, machine learning and artificial intelligence techniques and providing effective ways against anthropogenic challenges for society, economics and government.

2. Basic concepts and implementation principles

Initially digital twin concept was proposed by Michael W. Grieves in [4]. Nowadays, digital twin is determined as real time replica of all product life cycle components including interfaces, functionality and algorithms [5]. Digital twin combines data of real time operation, detailed mathematical model, which parameters are determined based on collected data. A long with digital twin digital shadow concept has been introduced.

Digital shadow can be determined as system of interconnections which describes real object behaviour usually in normal conditions. Such interconnections can be found in collected superfluous big data coming from real object via industrial internet technology

Digital shadow can forecast real object behaviour only for the states which data has been collected, but not for the new states [6].

In terms of [1] and [2] JSC Rosseti (major Russian electrical grid operator) developed the concept of digital transformation 2030 [3], which defined basic directions pf such activity. The concept determines destination model, Big Data management instruments, digital network framework, company digital management. Possible digital technologies integration effect has also been evaluated. New scientific and technological topics was formulated as follows [3]: digital substation, active-adaptive network with distributed smart system of automated control and management, complex business process effectiveness and management system automation, implementing of new technologies and materials in electrical industry, perspective technologies of digital transformation.

In terms of the concept digital twin technology applications have been determined as follows: utility connection, operation and contingency control, technical maintenance and repair, supervisory system of business asset and capital development. Business asset managing is closely connected with technical state estimation of the equipment and particularly with state analysis based on main functional blocks.

In this case digital twin technology which is considered as combination of physical and digital models allows not only to increase high voltage electrical equipment technical state identification accuracy but to establish hidden relations between various parameters and to collect new practical knowledge using Big Data analysis and machine learning algorithms. The general idea and further application of digital twin concept are depicted by Fig. 1.
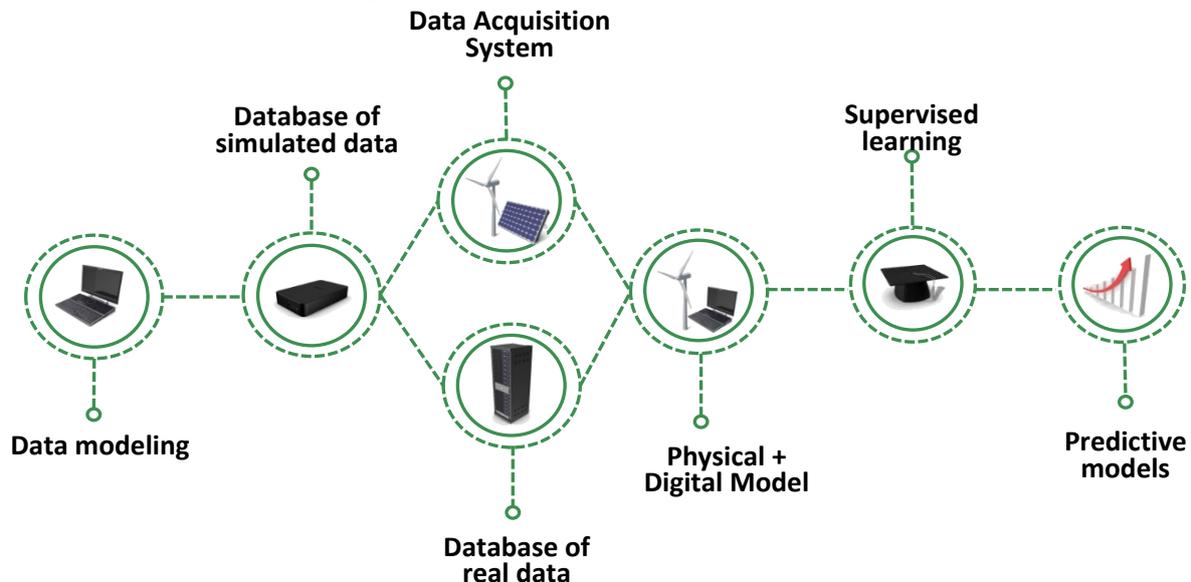
Figure 1. Digital twin constructing technology

3. Electrical equipment digital model realisation

Proposed technique was implemented for active oil-filled measurement current and voltage transformers installed in open electrical switchgear 110 kV of one of power stations in Russia.

Digital model was established by means of diagnostic system integration developed under the project and based on a number of non-destructive analysis approaches, namely ultraviolet light monitoring, heat monitoring and internal discharge measurements for oil-filled equipment isolation.

The complex system for technical diagnostic of measurement current and voltage transformers 110 kV has been established. The system consists of on-line monitoring system and portable units for technical state identification without switching equipment off, namely:

- Current and voltage transformer isolation internal discharge monitoring system;
- Current and voltage transformer monitoring and diagnostic system CDM delepoded by Dimirus: CDM unit, connection device DB-2/TT, measurement controlling device Pt-100A, moisture controlling device SHm-1;

- Stationary infrared light monitoring system, which includes thermal camera packed with objective and central server;
- Ultraviolet light monitoring system, consisting of Filin-6 defect detector.

When the diagnostic system was established equipment parameters measurements was performed, for each equipment was chosen its own set of parameters. Technical state analysis was performed based on collecting data. Groups of defects or limit states for various parts was defined using obtained data of different technical on-line diagnostic approaches. It should be mentioned that obtained limit states can not be identified by means of conventional diagnostic procedures at all or on so early defect development stage. Developed diagnostic system is depicted by Fig. 2.
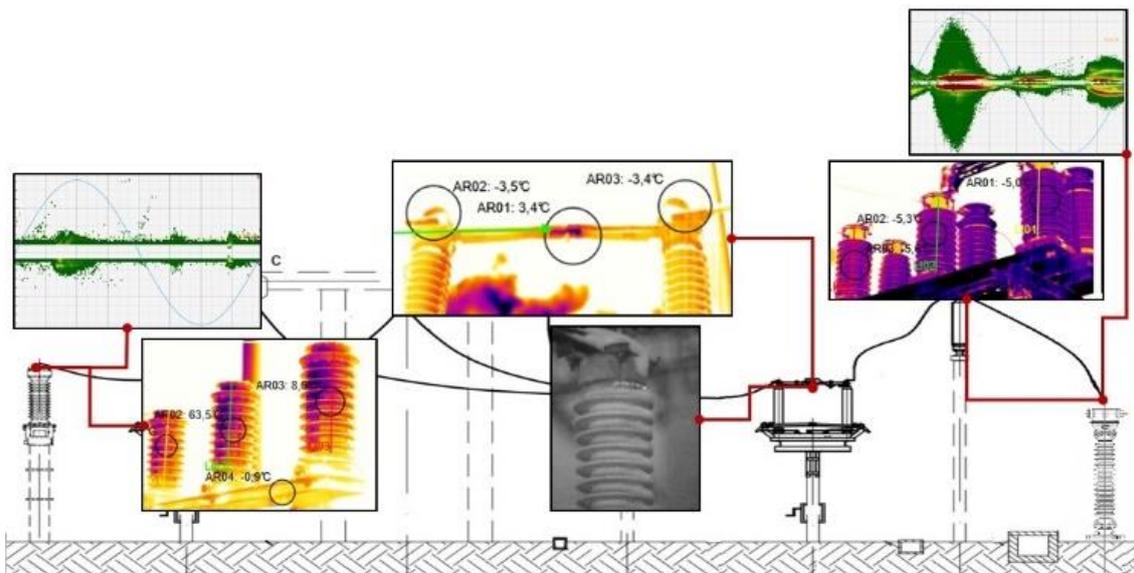
Figure 2. Electrical equipment digital twin diagnostic system realisation

4. Realisation of current and voltage transformer 3D model

One of the parts of digital twin concept is the development of electrical equipment 3D model. Such model can be used for calculation and analysis of operation. Under the research 3D models of current and voltage transformer 110 kV installed in open substation switchgear have also been developed. 3D model development was performed by means of inverse engineering problem which was used to restore unit size. Restoration process was supplied by electrical equipment scan-file because conductive part carried voltage and it was allowed to measure them directly. Proposed model was developed in AutoCAD with the scale 1:1. Obtained models are depicted by Fig. 3–4.
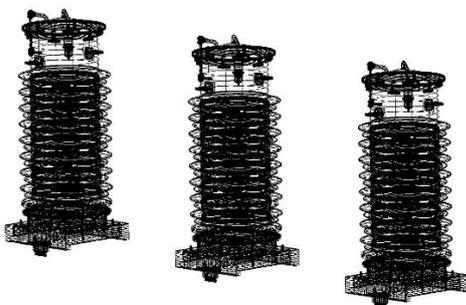
Figure 3. 3D model of current measurement transformer 110 kV (carcase)

Figure 4. 3D model of current measurement transformer 110 kV

5. Analysis of current and voltage transformers

Technical state estimation algorithm was performed using on of machine learning algorithm, namely decision tree gradient boosting. Indeed, various artificial intelligence approaches has been probed as a solution for the problem e.g. neural network [6], genetic algorithms [7], neural-fuzzy logic [8], machine learning [9]. Each method has its own advantages and disadvantages from result analysis efficiency of technical diagnostic and monitoring and in more detail, it is described in [10]. Gradient boosting like other boosting algorithm consequently build base model in such manner that each next model increases the quality of the group. Decision tree gradient boosting builds the model in form of tree sum [11]:

$$f(x) = h_0 + \upsilon \sum_{j=1}^{M} h_j(x) \tag{1}$$

where h_0 – first approximation, $\upsilon \in (0,1]$ – parameters, which regulates the learning speed and specific tree influence on the whole model, $h_j(x)$ – regression decision tress. New additive trees are added to the sum by mean of empiric risk greedy optimisation, described by some losses function $L(y, y') = L(y, f(x))$. Proposed method can be used for any differentiable losses function without valuable correction.

As a result, the algorithm is represented by a piecewise constant function describing the relation between the state Y (or defect, depending on the type analyzed data) and the set of operational parameters X_n. The average error Q in percentage [%], which was used to evaluate the testing error of the algorithm a on the sample X^l, is calculated as follows:

$$Q(a, X^l) = \frac{1}{l} \sum_{i=1}^{l} |a(x) \neq y^*(x)| \cdot 100\%, \tag{2}$$

where $|a(x) \neq y^*(x)|$ – error indicator; $y^*(x)$ – true value of the parameter; l – number of observations.

6. Conclusions

Digital twin technology allows not only to create completely new approach for electrical equipment state estimation in terms of new recommendations for every non-defective diagnostic technique implementation, but to from defect library for each technique to simplify and increase the accuracy of state identification.

Also, digital twin technology enables to stress equipment group with limit state of the equipment as a whole but also its specific parts. Such limit state cannot be determined by means of conventional diagnostics approaches established in technical standards at all or at least on so early stage of defect development.

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Acknowledgments