Application of digital twins of equipment for managing complex renewable energy

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Abstract. The paper describes a control system for renewable energy complexes with optimization of operating modes based on digital twins of equipment. The application of digital twins allowed us to develop a simulator that simulates the main processes occurring in the ground heat pump system. The simulator allows: to perform computer experiments to study different modes of Polygon operation; to demonstrate the physical essence of the ongoing processes to form the qualifications and skills of students in the field of non-traditional and renewable sources of electric and thermal energy. The use of digital twins also allows the implementation of a renewable energy combination management system to improve the energy efficiency of hybrid power complexes. The algorithm developed by the authors for selecting combinations of renewable energy sources to increase the energy efficiency of the complexes takes into account the current values of the operating parameters of the equipment, the forecast of energy consumption, as well as the forecast of power generation by each of the components of the complex.

1. Introduction
Currently, the use of renewable energy sources for generating heat and electricity is widely developed. One of the important aspects of using a combination of different types of renewable energy sources is the real-time optimization of the combinations of equipment involved.

The Polygon of renewable energy sources [1] located on the territory of the branch of "MPEI" in Volzhsky one of the functions of which is to develop algorithms for managing renewable energy complexes and identify parameters for describing digital models of equipment.

When you expanding the hardware model description elements that lead to digital twins creation are virtual prototypes of a real object, a group of objects, or processes.

2. Methods
The technology of creating and using digital twins in the energy sector is becoming more widespread. Leading companies use this technology in their activities [2]. According to [3], the use of digital twins can significantly increase efficiency at all stages of the creation and operation of objects. For example, according to [5], the use of digital twins of operating wind turbines can enable asset owners to virtually and remotely monitor, test, and predict the performance and condition of turbines and subcomponents and carry out performance and reliability tests in a virtual environment.

The Polygon of renewable energy sources [1] located on the territory of the branch of "MPEI" in Volzhsky is used to create digital twins. The following equipment was considered: heat pumps of the "heat carrier-water" and "air-water" types, solar vacuum collectors, circulation pumps, electric heaters, storage tanks, fancoils, heating radiators.
The digital twin stores information about the technical parameters of the equipment used, the date of its commissioning, information about operating hours, repairs, failures, dynamic characteristics, data from measuring devices, experimental data, etc. When using the equipment, the current values of technological parameters, reports, and other data can be synchronized with the digital twin. Based on the collected data, forecasts and estimates are formed that can be used to improve the operation and maintenance of a real object.

When describing renewable energy equipment, you can select duplicate data fields, as well as individual data fields. For example, the first group of parameters can include name, model, date of manufacture, date of commissioning, geometric dimensions, 3-D model, etc. The second group includes characteristics that are individual for a specific type of equipment, for example, for a heat pump, you can distinguish: operating temperature range, flow characteristics, and dynamic characteristics.

An example of the description of digital twins is shown in table 1.

| Table 1. The parameters of the equipment of renewable energy. |
|---------------------------------------------------------------|
| Parameter                               | Heat pump | Circulation pump | Electric heater |
|-----------------------------------------|-----------|------------------|----------------|
| Title                                   | MammothJ036WHEBLA/CS | WILO Star 25/8 | EVAN -5.6 |
| Company manufacturer                    | MammothInc (USA) | WILO | EVAN |
| Production date                         | 2010      | 2010             | 2010 |
| Commissioning                          | 2011      | 2011             | 2011 |
| Size, mm                                | 820 x 660 x 530 | 500x200x160 | |
| Power consumption                       | 2.29/2.93 kW | 176.0 W         | 6 kW |
| Permissible temperature range           | 15-55 °C (heating cycle) | -10° C / +110° C | 30-75°C |
| Dynamic characteristics                 | \(W(p) = \frac{1}{183 \cdot p + 1}\) | \(W(p) = \frac{1}{3100 \cdot p}\) | |

The use of digital twins allowed us to develop a simulator that simulates the main processes occurring in the ground heat pump system [6].

Using the ground heat pump simulator allows you to: perform computer experiments to study various modes of operation of the Landfill; show the physical nature of the processes, their mutual dependence, as well as a number of significant subtleties; to form the qualifications and skills of students in the field of non-traditional and renewable sources of electric and thermal energy (heat pump type "Ground-water").

3. Results and Discussion
The basis for the construction of the simulator is a mathematical model of heat pump control based on existing equipment in the branch of the MPEI in Volzhsky, obtained using digital twins.

Based on the literature data, as well as analytical calculations and experimental data, models of equipment components that are part of the simulated system were obtained. The simulator's mnemonic diagram is shown in figure 1.
Also, based on digital twins, you can use the hardware database in the training process, which allows you to select the desired model, export data to CAD for design and calculations.

The use of digital twins also makes it possible to implement a system for managing combinations of renewable energy sources to improve the energy efficiency of hybrid power complexes. A hybrid energy complex is a technical system that combines within a single technological process generator of electric, thermal and other types of energy of various types, accumulators, means of switching, transmitting and converting energy into a form suitable for use by consumers.

The authors developed the algorithm for selecting combinations of renewable energy sources to improve energy efficiency of the complexes takes into account the current values of the parameters of the equipment, the forecast of energy consumption and forecast energy production by each component of the complex. Generation forecasting is based on the developed models of digital twins of renewable energy equipment [6].

Implemented on the basis of the considered ACS algorithm, it has a three-level structure, including the level of field equipment and devices, the level of local control of the complex, as well as the cloud level of implementation of optimization tasks.

The combination of modern technologies (IoT, SmartGrid, digital twins) will significantly increase the efficiency of energy facilities. Similar projects have already been implemented in many countries [8,9,10].

Based on the collected data, rather complex algorithms are used using machine learning methods, fuzzy logic, etc. [11,12].

When controlling hybrid power complexes, it is important to be able to predict energy production and consumption. Implementation of such functions is proposed for control systems of hybrid power complexes [13-19].

The authors used the technology of digital twins in describing algorithms for predicting heat energy consumers. For example, figure 2 shows a thermal energy forecast graph using digital twins. Characteristic points are highlighted during construction:

$t_{\text{start}}$ – The time when heat consumption starts.
$t_{\text{max}}$ – Time of maximum heat consumption.
$t_{\text{end}}$ – The end point of heat consumption.
The application of the above mentioned technologies for hybrid power complexes allows us to significantly increase the energy efficiency of systems. Figure 3 shows the comparison of the amount of thermal energy consumed by the classical control algorithm and the system state prediction algorithm.

Figure 3. Daily electric energy consumption for the summer 2017.

The authors show that for the Volgograd region the application of digital twin technology and the implementation of the control algorithm with state prediction allows to increase the efficiency of hybrid energy complexes by 16% and for other regions of the Russian Federation up to 20% in case of high non-uniformity of energy consumption during the day.

Application of the detailed description of the equipment allows us to create not only for control of the system energy efficiency indicators, but also to carry out actions on virtual commissioning, to switch to the maintenance of the system according to the condition of the equipment, as well as to create simulators for training of the personnel serving the complex [7].

4. Conclusion

Constant feedback from the operating product allows us to evaluate the behavior of the object in real time, predict the behavior of the physical system for earlier detection of faults, prevent sudden failure of the equipment, which generally increases the efficiency of the decisions made. It becomes possible to find the most optimal scenarios of technological processes and to predict deviations in the operation of equipment on the basis of statistical models and analysis. The use of digital twins made it possible to develop a simulator simulating the main processes taking place in the soil heat pump system. The
use of a ground heat pump simulator allows computer experiments to be performed to investigate the different modes of operation of the Polygon, as well as to form the qualifications and skills of students in the field of non-traditional and renewable sources of electric and thermal energy. The use of digital twins also allows the implementation of a renewable energy combination management system to improve the energy efficiency of hybrid power complexes. The algorithm developed by the authors for selecting combinations of renewable energy sources takes into account the current values of equipment operation parameters, the forecast of energy consumption, as well as the forecast of power generation by each of the components of the complex.

Calculations show that the application of the proposed algorithms allows us to obtain an increase in the energy efficiency of renewable energy complexes up to 20% for objects having high daily non-uniformity of energy consumption.

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