$$I_{PH}(t) = \frac{\bar{I}_A(t)}{1000}\left[I_{SC} + k_I\left(T_{pv}(t) - 25\right)\right], \quad (4)$$

where I_{SC} is the short-circuit current.

After calculating the output power and photocurrent of photovoltaic converters, it became permissible to calculate the output voltage:

$$U_{pv}(t) = \frac{P_{pv}(t)}{I_{PH}(t)}. \quad (5)$$

The presented mathematical model determines the necessary parameters and has advantages that are associated with the change in weather conditions and the interaction of the elements of the photoelectric converter.

The considered model is necessary to obtain data on the behavior of the system. The use of this data makes it possible for the digital twin to predict the behavior of an object and solve the problem of managing its life cycle.

5 Database design and construction

When designing and operating a digital twin of a solar power plant, it is necessary to use a large amount of data, namely: characteristics of weather conditions, characteristics of equipment, etc.

This dataset needs to be organized and stored. For this, it was decided to use a relational database. The PostgreSQL DBMS was chosen because it meets all the requirements listed below.

1) Functionality and convenience:
   a) developed SQL language, ease of development and compactness of the code;
   b) the ability to run on a variety of OS: Windows, Linux, NIX, BSD, MacOS;
   c) ease of administration.
2) Resource intensity.

The design of the database was carried out on the basis of ontologies built in the section “ontological engineering”. As a result of the design, the following entities were identified:

- weather characteristics;
- solar panels;
- network inverters (SMA);
- panel calculation;
- calculation of a block of panels;
- calculation of a block of panels with an inverter;
- photovoltaic system.

Relationships between entities are shown in Figure 4 below.

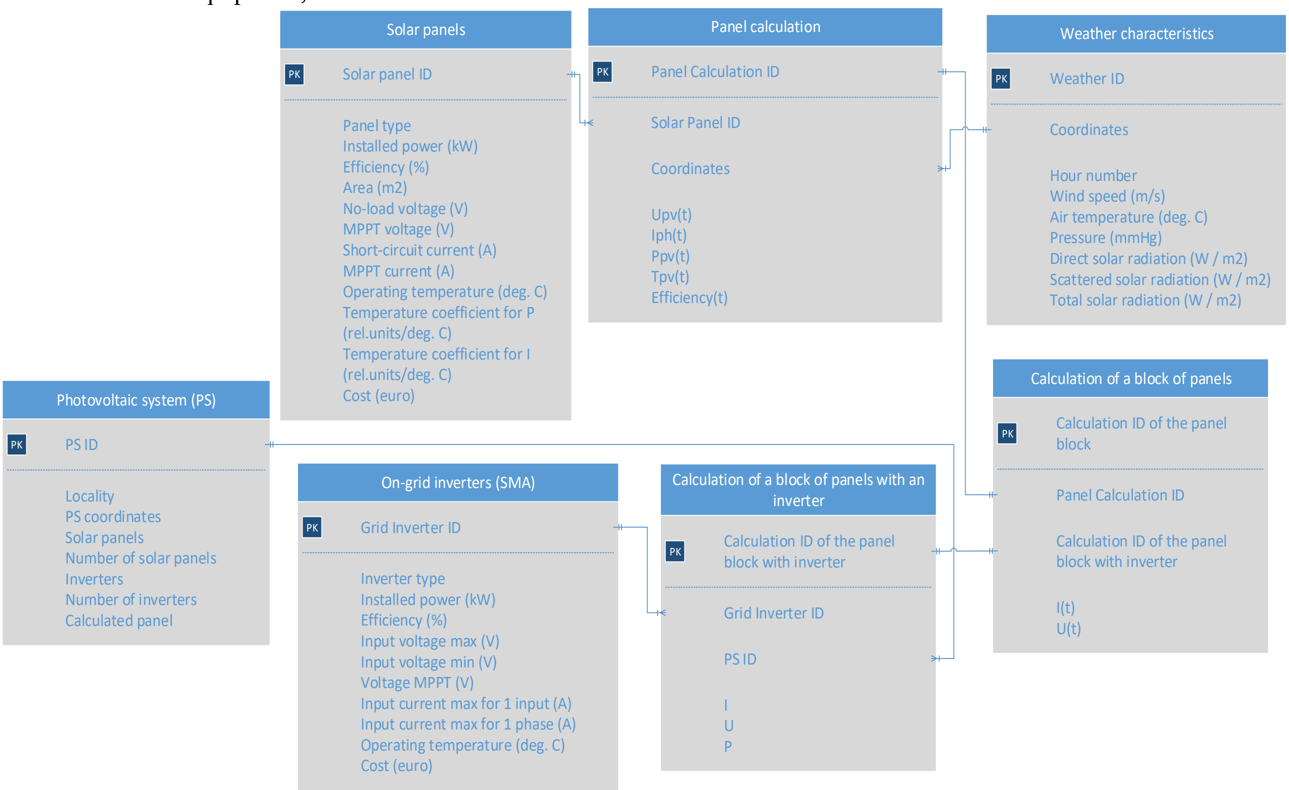
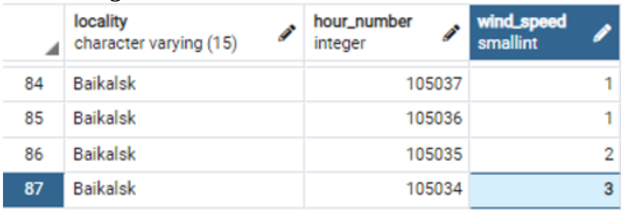


Fig. 4. Database entities and connections between the

 https://doi.org/10.1051/e3sconf/202128903002

6 Database interface

It is possible to work with the database using the administration tools provided by the PostgreSQL DBMS. The editing interface is shown below:



	locality character varying (15)	hour_number integer	wind_speed smallint
84	Baikalsk	105037	1
85	Baikalsk	105036	1
86	Baikalsk	105035	2
87	Baikalsk	105034	3

Fig. 5. PostgreSQL interface

To add and delete records in a table, it is necessary to use SQL queries, which, in turn, complicates the work with the Digital Twin, so it was decided to develop its own interface for working with the database, including the following forms:

- forms for editing (adding / deleting / changing) tables;
- form providing the ability to connect solar panels to inverters under special conditions (the number of ports in the inverter, connecting only the same panels to the inverter, etc.).

An example of the developed interface is shown in Figure 6 at the bottom of the page.

7 Digital twin architecture

The digital twin architecture is shown in Figure 7 at the bottom of the page.

The architecture includes the following blocks:

- Digital shadow:

Includes a database and interfaces for working with it, which are responsible for interacting with the database and implement the possibility for the functioning of the used machine learning methods, which are necessary to restore the system behavior model, as well as to predict subsequent data used for the digital twin to work;

- Digital model:

It is necessary for the operability of the entire system as it implements the application interface used for convenient interaction with all other components of the digital model, such as a mathematical model and a system for collecting operational information;

- Control system:

It is used to introduce a control action on a real object, the prototype of which is a digital twin.

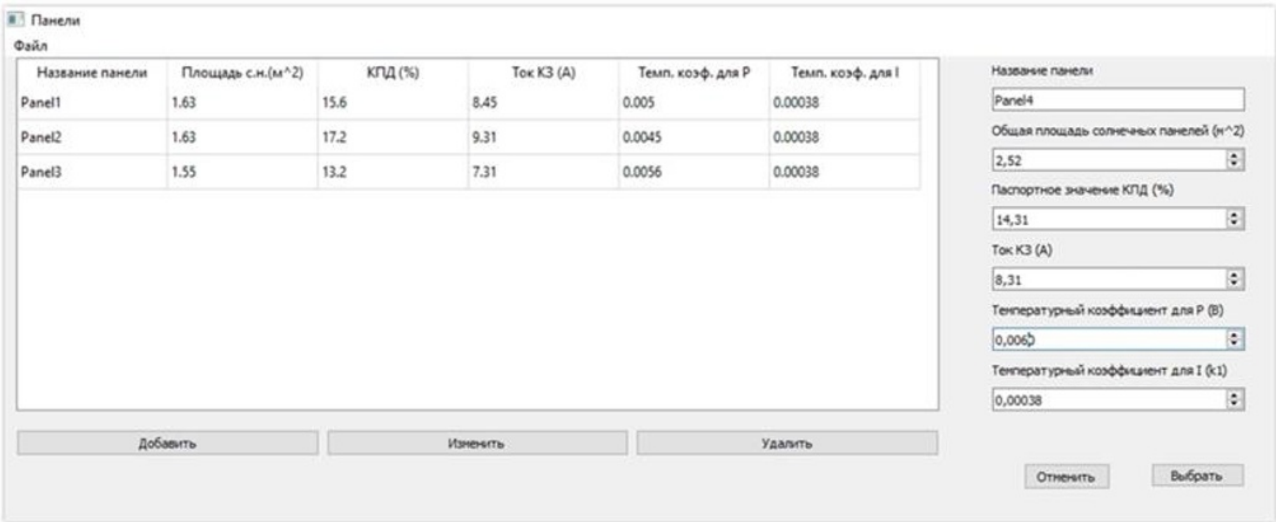


Fig. 6. Program interface

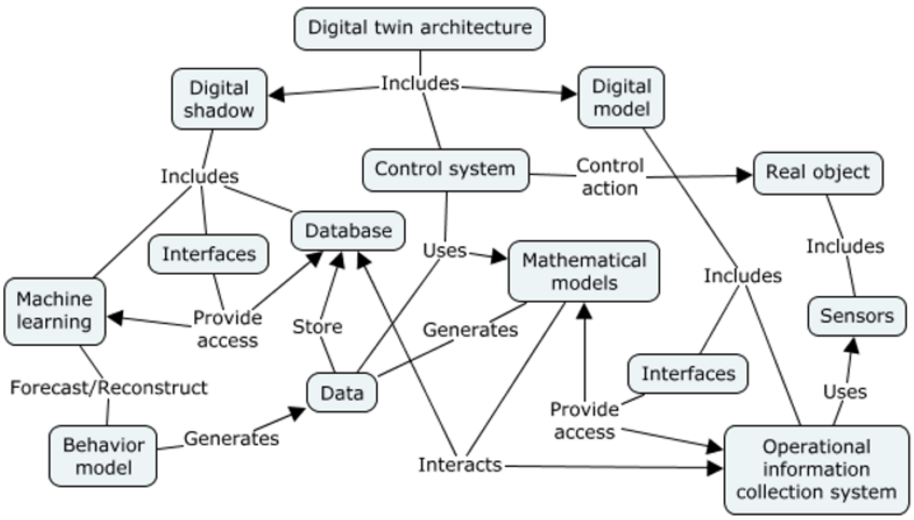


Fig. 7. Digital twin architecture

8 Further development

For the possibility of using the developed digital twin on real objects, it is necessary to make the following improvements:

- Refine the architecture of the digital twin by dividing it into a digital shadow and a digital model:

The transformation will lead to an improvement in the maintainability and portability of the code, since the module with basic calculations (digital model) and the module for working with data (digital shadow) will be separated;

- Prepare the digital twin to work with large amounts of data collected from a real object:

When working with real objects of the electric power industry, such a problem arises as large amounts of data coming from sensors that must be stored and processed.

To solve the problem of data storage, it is proposed: to increase the efficiency of queries, to reduce the number of repetitions in data storage to a minimum and to optimize the relationships between tables in the database; this would require migrating the datastore to a non-relational database. To solve the problem of data processing, it is proposed to use Big Data methods, which will allow processing data within an acceptable time frame.

After putting the digital twin into operation, it will be possible to verify the models (both neural networks and mathematical ones) according to data obtained from a real object.

Conclusion

It is proposed to use an ontological approach when designing a digital twin and a database for a solar power plant. Ontological engineering is considered as a necessary stage in the construction of a digital twin. The use of ontological models to describe the structure of the database, its main components and relationships is shown. The main purpose of ontologies in the development of digital twins is the formal description and integration of all components: models, databases, knowledge bases (ontologies) and their relationships, and can be used to build digital twins of a solar power plant. The article also notes the subsequent directions of the development of the system, which are actively being worked out by the authors.

The results were obtained within the framework of the basic project of the ISEM SB RAS AAAA-A21-121012090007-7 under the state assignment FWEU-2021-0007, with partial financial support from the RFBR grants No. 19-07-00351, 19-57-04003, 20-07-00994.

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