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# MODEL OF AUTOMATED CONTROL OF THE ELECTRIC POWER SYSTEM TO ENSURE RELIABILITY AND EFFICIENCY OF POWER SUPPLY IN THE EVENT OF DISTURBANCES AND IMBALANCES

*В. Зубак, І. Кіпріянов, Є. Філіппов.* **Модель автоматизованого управління електроенергетичною системою для забезпечення надійності та ефективності електропостачання при прояві збурень та небалансів.** В статті представлено імітаційну модель автоматизованого управління електроенергетичною системою, що забезпечує надійне та ефективне електропостачання в умовах збурень і небалансів. В даній роботі виконується розробка інформаційної моделі електроенергетичної системи, моделей станів об’єктів та діаграм переходів даних дій. Розроблені моделі електроенергетичної системи дозволяють проаналізувати взаємодію об'єктів і процесів та швидко виявляти потенційні проблеми, оптимізувати роботу системи для підвищення її надійності та ефективності. Одним з основних аспектів є адаптивність системи, яка дозволяє оперативно реагувати на зміни в балансі потужності, що є критично важливим для забезпечення стабільного функціонування електроенергетичної системи. Запропонована модель забезпечує надійне та ефективне електропостачання завдяки врахуванню специфіки взаємодії об’єктів і процесів у системі. Інтеграція цих об'єктів дозволяє системі адаптуватися до внутрішніх і зовнішніх змін, таких як збурення чи небаланси, що гарантує стабільну роботу в умовах непередбачуваних ситуацій. У статті розглядаються основні принципи роботи кожного з об'єктів, а також їх взаємодія між собою. Моделі стану відображають життєвий цикл об'єктів при виникненні подій в електроенергетичній системі, що дозволяє більш точно прогнозувати їх поведінку та ефективно керувати системою. Розроблені діаграми переходів даних дій дозволяють зручно та ефективно моделювати функціональну природу дій об'єктів, що відображають важливі процеси для підтримки стабільності енергетичної системи. Використання об'єктно-орієнтованих моделей значно підвищує ефективність виявлення проблем та оптимізації роботи окремих елементів енергосистеми. Це дозволяє зменшити ризики несанкціонованих відключень та сприяє точному плануванню і коригуванню роботи енергосистеми з урахуванням змінних умов. Застосування таких моделей забезпечує ефективне прийняття управлінських рішень і дозволяє швидко відновлювати баланс потужності та напруги в системі, що гарантує безперебійне електропостачання навіть у умовах збурень.
*Ключові слова*: електроенергетична система, надійність, ефективність, небаланс, об’єктно-орієнтований аналіз, об’єкт, атрибут, зв’язок, процес

*V. Zubak, I. Kipriianov, Y. Filippov.* **Model of automated control of the electric power system to ensure reliability and fficiency of power supply in the event of disturbances and imbalances.** The article presents a simulation model of automated control for the electric power system that ensures reliable and efficient power supply under disturbances and imbalances. This work involves the development of an informational model of the electric power system, state models of objects, and data flow diagrams of actions. The developed electric power system models allow for the analysis of interactions between objects and processes and quickly identify potential issues, optimizing the system's operation to enhance its reliability and efficiency. One of the key aspects is the system's adaptability, which enables prompt responses to changes in power balance, critical for ensuring the stable operation of the electric power system. The proposed model ensures reliable and efficient power supply by considering the specifics of the interaction between objects and processes within the system. The integration of these objects allows the system to adapt to both internal and external changes, such as disturbances or imbalances, ensuring stable operation even under unpredictable conditions. The article discusses the main principles of operation of each object and their interaction with one another. The state models reflect the lifecycle of objects in the occurrence of events within the electric power system, allowing for more accurate predictions of their behavior and effective system management. The developed data flow diagrams of actions facilitate convenient and efficient modeling of the functional nature of actions of objects, reflecting crucial processes to maintain the stability of the power system. The use of object-oriented models significantly improves the detection of issues and the optimization of the operation of individual elements within the power system. This reduces the risks of unauthorized disconnections and contributes to accurate planning and adjustment of the energy system's operation, taking into account changing conditions. The application of such models ensures effective decision-making and allows for the rapid restoration of power and voltage balance within the system, guaranteeing uninterrupted power supply even under disturbances.
*Keywords*: power system, reliability, efficiency, imbalance, object-oriented analysis, object, attribute, relationship, process

## 1. Introduction

Electric power system (EPS) is the foundation of modern society's functioning, as it ensures the stable supply of electrical energy (EE) for various industries and consumers. The main objective of the EPS is to provide reliable and efficient power supply of appropriate quality [1]. However, given the increasing complexity and dynamism of these systems, especially under disturbances and imbalances,

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the need arises for effective energy flow management to ensure the reliability and stability of power supply [2, 3].

Existing methods of energy system management, including centralized and distributed control, allow maintaining system stability and balance through state monitoring and load correction [4, 5, 6]. However, they have several drawbacks. For example, centralized management methods often face scalability and flexibility issues, as they require significant time for data processing and decision-making in the event of disturbances. At the same time, distributed management may be less effective under large disturbances, as it does not always provide the required level of coordination among all system elements.

To overcome these limitations, there is a need to implement new approaches to automated control based on object-oriented models, which allow for more efficient real-time energy flow management.

This approach not only optimizes the interaction of objects within the system but also enables rapid response to disturbances and imbalances, thereby enhancing the reliability and efficiency of power supply.

The development of automated control technologies and the use of object-oriented models can become an important and necessary tool for analyzing and optimizing the functioning of the EPS. The object-oriented approach enables modeling the system through the interaction of objects and their processes [7], allowing for detailed analysis of responses to various disturbances and optimization of EPS operation.

## 2. Analysis of literary sources

Widely accepted EPS models for analyzing system dynamics are typically described by differential equations, which serve as a universal method for modeling but are complex and challenging to comprehend.

The use of object-oriented analysis (OOA) in system modeling is gaining increasing relevance due to its ability to structure complex systems by reflecting interactions among system components. Unlike traditional approaches that focus solely on mathematical models, object-oriented modeling enables the integration of lifecycle concepts, states, and processes of components into the model, fostering a better understanding of the system as a whole.

The OOA theory was developed and supported by prominent researchers such as S. Shlaer, S. Mellor, and G. Booch, among others. It simplifies the analysis of complex systems by dividing them into objects and processes. This approach not only ensures system structuring but also facilitates the identification and modeling of interactions between components, which is essential for systems where these interactions are critical to overall dynamics.

The central idea of OOA is to view the system as a set of interacting objects, each representing an abstraction of real-world entities [8, 9].

OOA is effectively employed in modeling complex systems. For instance, studies [10 – 13] demonstrated the use of class and state diagrams to analyze the dependencies between system components, while data flow diagrams of actions (DFDA) illustrate the dynamics of information flows. This approach allows for real-time system analysis and management, ensuring reliability and efficiency.

Currently, OOA is applied across various domains, ranging from nuclear fuel overload systems [14] to insurance operations.

Applying OOA to EPS represents a novel approach in the energy sector. This type of analysis facilitates the development of more flexible and adaptive system models capable of effectively accommodating operational changes, such as power imbalances or emergency situations resulting from disturbances.

## 3. Purpose and objectives of the study

The purpose of the work is to develop a simulation model of the power system based on **OOA** to ensure automated control of electric energy flows under conditions of disturbances and imbalance, which contributes to effective and reliable power supply.

Objectives of the article:

The goal is achieved by solving a sequence of the following tasks:

– develop an information model of the power system to determine objects and connections between them;

– develop a model of the states of power system objects;

– develop a model of processes in the power system;

– analyze the flow of processes in the system based on object-oriented models.

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### 4. Models and Methods of EPS Modeling

According to [8], the OOA of EPS is carried out in three stages, namely the information model, the state model, and the process model.

### 4.1 Information Model of EPS

At the first stage of OOA, an information model of EPS objects is developed as an abstraction of real-world entities [8]. Each object has its own characteristics. A common characteristic for instances of the same object is referred to as an attribute. Next, the interaction of EPS objects is represented. Relationships between objects are denoted as "R".

All objects in the information model are connected by two types of relationships:

– One-to-Many relationships, for example, "R9" represents the relationship between the objects "Regulator" and "Generating station";

– One-to-One relationships, for example, "R8" represents the relationship between the object "Regulator" and the object "Monitor". The information model of the EPS is shown in Fig. 1. It consists of the following objects: "Regulator", "Monitor", "Generating station", "Transmission line", "Transformer substation" and "Consumer". Each of these objects has its own attributes and description. The attributes are shown in Fig. 1 for each object and are designated as "–". The identifier of an object is designated as "*".

Description of the objects in the information model:

Regulator – analyzes and manages processes in the EPS, by receiving information about each system object from the "Monitor" object;

Monitor – gathers information from each EPS object except the "Regulator". It stores the status of the objects and data on power, voltage, and frequency values in a data archive. It transmits the received information to the "Regulator" object;

Generating station – produces EE in the EPS on demand from the "Regulator" object, increasing or decreasing generating capacity as commanded;

Transmission line – transports EE;

Transformer substation – transforms EE into the appropriate voltage class;

Consumer – consumes electricity.

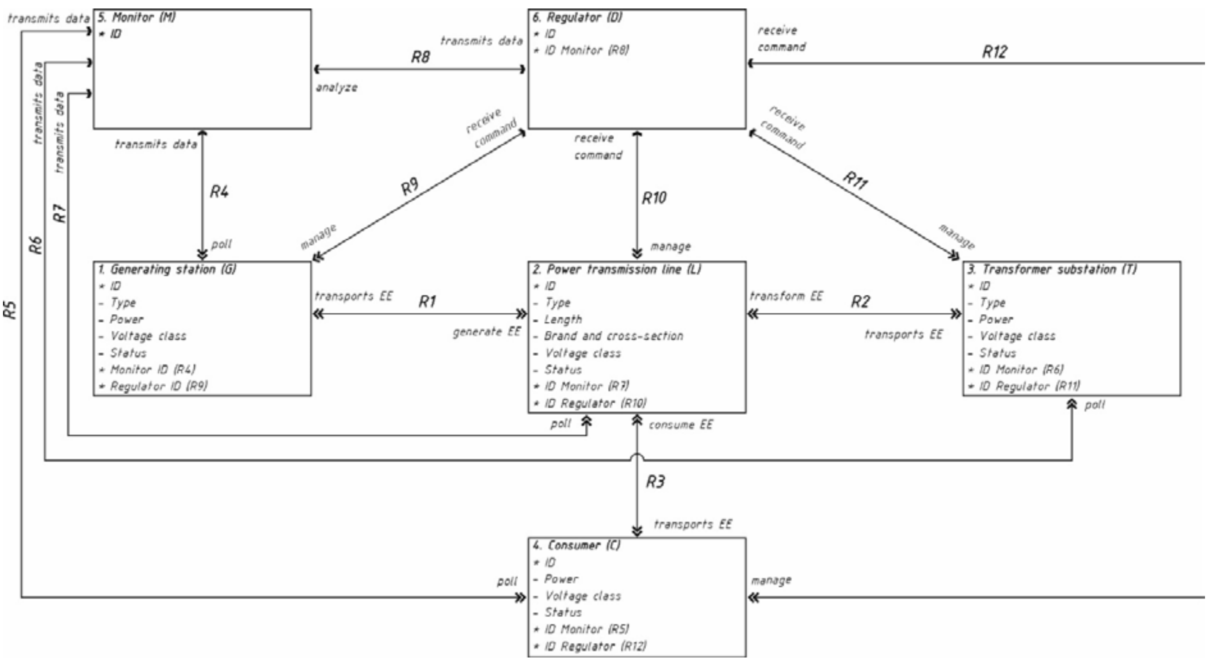


**Fig. 1.** Information model of the EPS

### 4.2 Model of States of EPS objects

At the second stage of OOA, the behavior of objects is analyzed [8]. The abstraction of an object's behavior is formalized through its life cycle, which reflects the object's state model. This behavioral model is universal for all instances of the respective object. The state model is represented in diagrammatic form and is known as a state transition diagram for the object. Fig. 2 shows the state transition diagram for the “Regulator” object. Each state is represented by a square and has a name. Transitions between states are indicated by arrows.

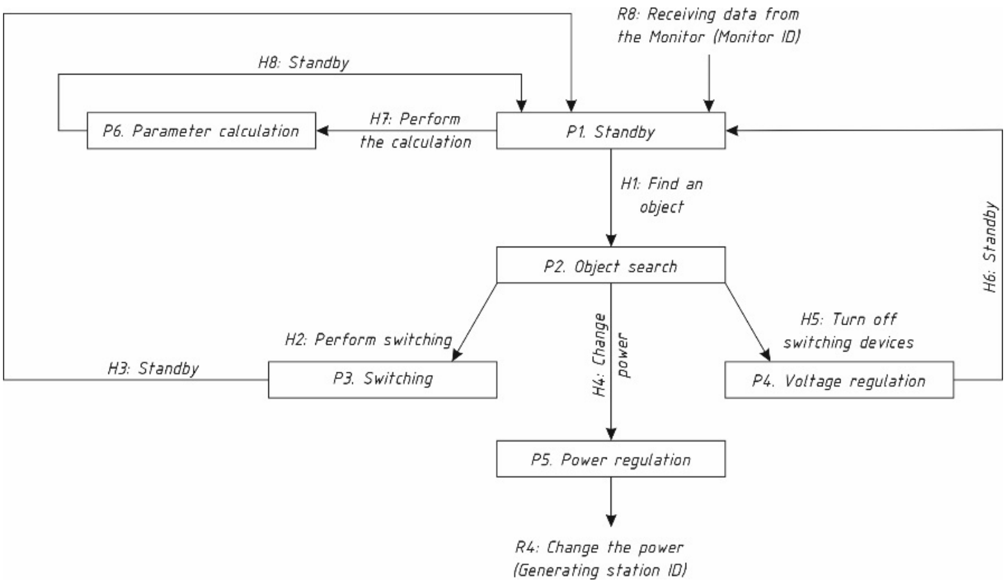


**Fig. 2.** State transition diagram of the “Regulator” object

The “Regulator” object takes the following states:

P1 – Standby; P2 – Object search; P3 – Switching; P4 – Voltage regulation; P5 – Power regulation; P6 – Parameter calculation.

The transitions between states are described by the following events:

R8 – Receiving data from the “Monitor” object;

H1 – Find an object; H2 – Perform switching; H3 – Standby; H4 – Change power; H5 – Turn off switching devices H6 – Standby; H6 – Change voltage; H7 – Perform calculations; H8– Standby.

The description of the states and events for the objects “Monitor”, “Generating station”, “Trans-mis-sion line”, “Transformer substation” and “Consumer” is not explicitly provided. Instead, they are defined by analogy to the state model of the “Regulator” object. The state model for the “Generating station” object is illustrated in Fig. 3.

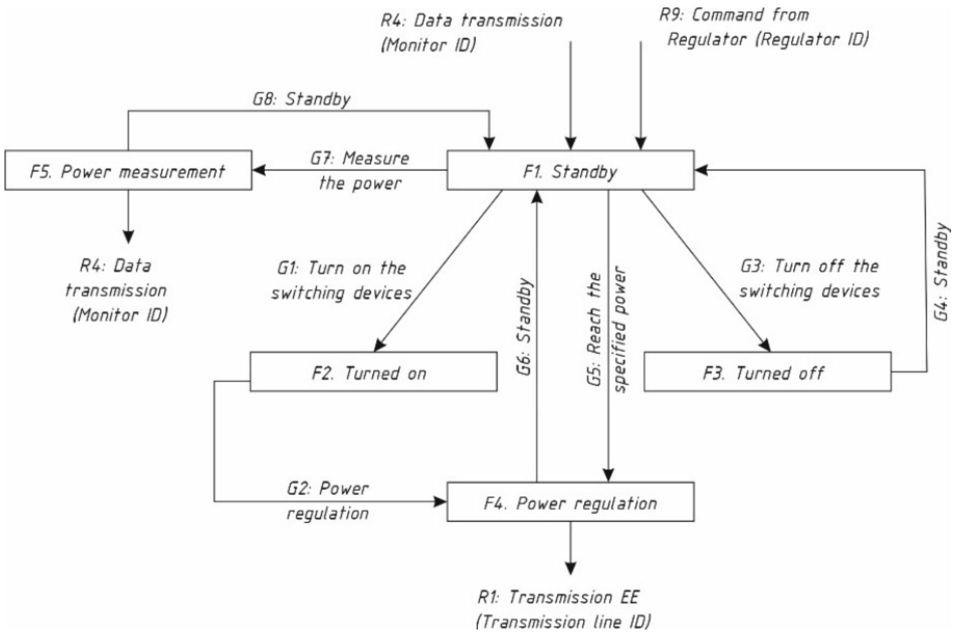


**Fig. 3.** State transition diagram for the “Generating station”

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The state model of the "Transmission line" object is shown in Fig. 4.

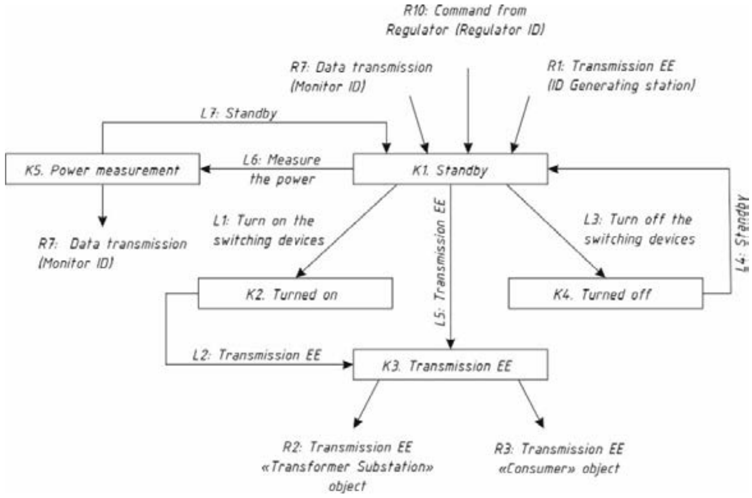


**Fig. 4.** State transition diagram for the "Transmission line" object

The state model of the "Transformer substation" object is shown in Fig. 5.

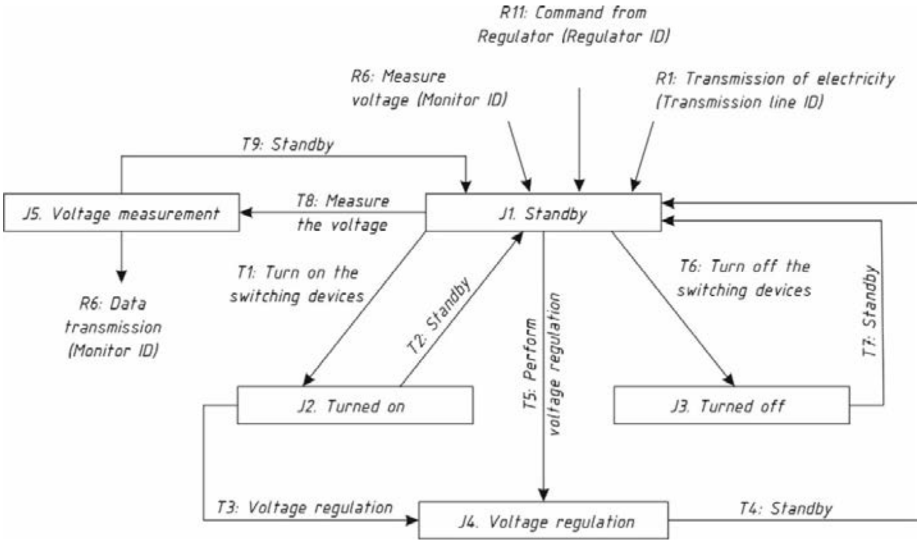


**Fig. 5.** Diagram of state transitions of the object "Transformer substation"

The state model of the "Monitor" object is not presented because it is simplistic. The "Monitor" object assumes the states of polling objects and transmitting data to the "Regulator" object.

The state model of the "Consumer" object is shown in Fig. 6.

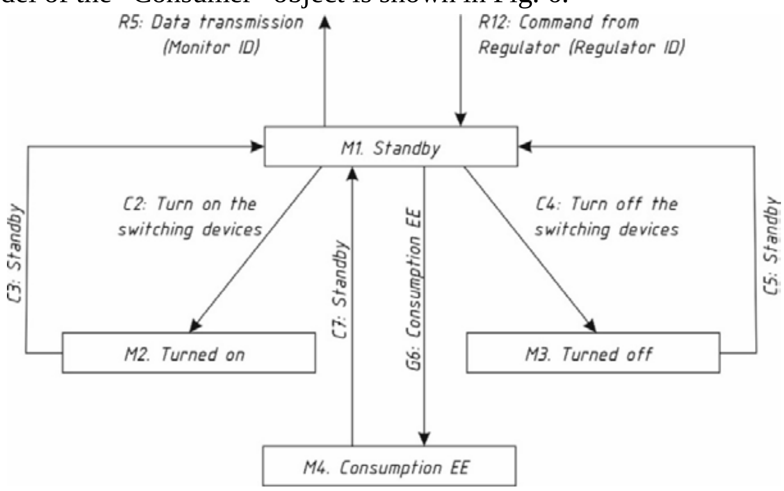


**Fig. 6.** State transition diagram of the "Consumer" object

**4.3 Process Models of the EPS**

Process models reflect the functional nature of actions. Each action is divided into fundamental processes that collectively define the required functional purpose of the system. To represent these fundamental processes, are used.

According to [8], a process includes calculations, data transformations, and any work necessary for reading or writing data to a data archive. Processes are divided into four types: accessors, generators, transformations, verifications.

Accessor – the purpose of the process is to access data from a single archive.

Generator – creates a single event.

Transformation – a process whose purpose is to calculate or transform data;

Verification – checks a condition and makes one of several conditional conclusions.

Each of the state processes is represented on the DFDA as an oval, with a name and a description of its purpose. If the process generates data as output, the data flow is shown as an arrow directed away from the process. If the process requires input data, the arrow points toward the process.

Data flows on the DFDA represent the constraints on the order in which processes are executed. Conditional flows, which control the execution of processes based on comparison results, are also shown on the DFDA. These conditional flows are depicted with a cross arrow and a hash mark.

Processes on the DFDA are defined for the objects in the informational model, as shown in Fig. 1.

The DFDA for the “Regulator” object is shown in Fig. 7 – 11.

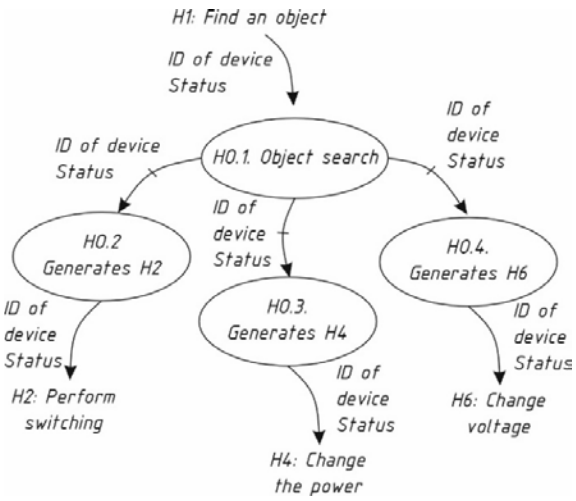


**Fig. 7.** DFDA object “Regulator” status “Object search”

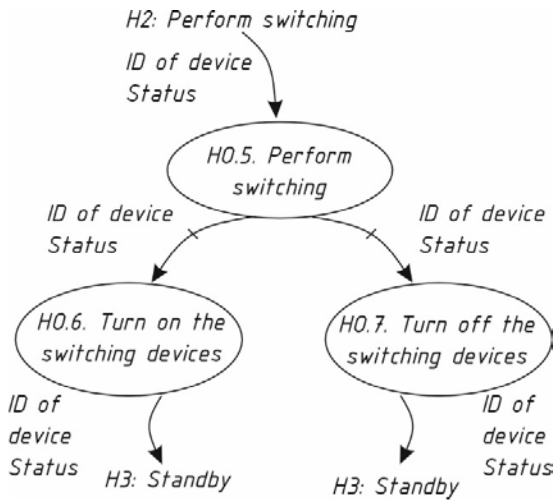


**Fig. 8.** DFDA object “Regulator” state “Commutation”

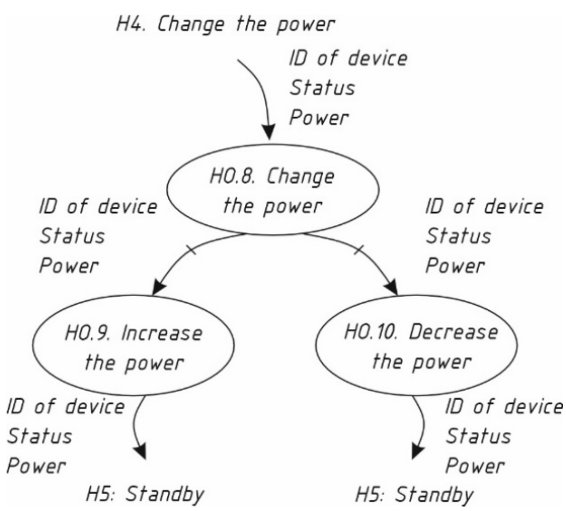


**Fig. 9.** DFDA object “Regulator” status “Power change”

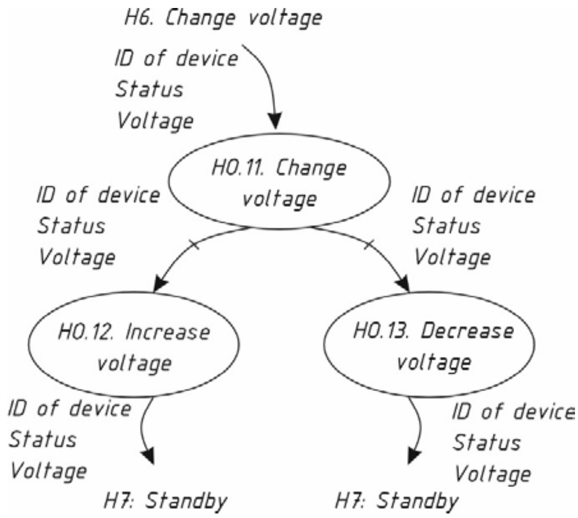


**Fig. 10.** DFDA object “Regulator” state “Voltage change

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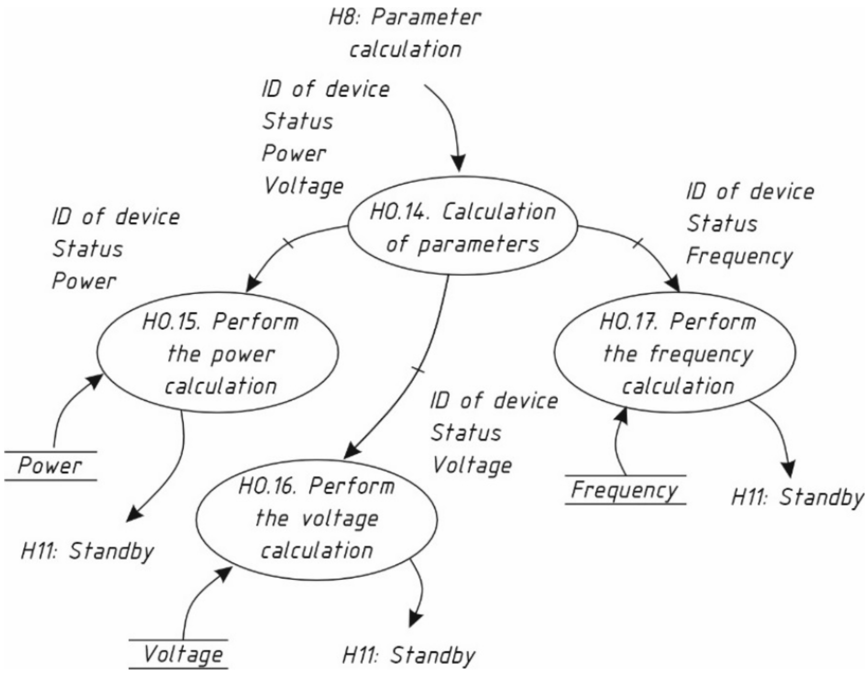


**Fig. 11.** DFDA object “Regulator” status “Calculation of parameters”

The list of state processes for the “Regulator” object is given in Table 1. It displays the identifier and name of the objects.

**Table 1**

State processes for the “Regulator” object

| Process identifier | Type | Process name |
|---|---|---|
| HO.1. | Accessor | Object search |
| HO.2. | Generator | Generates H2 |
| HO.3. | Generator | Generates H4 |
| HO.4. | Generator | Generates H6 |
| HO.5. | Generator | Perform switching |
| HO.6. | Generator | Turn on switching devices |
| HO.7. | Generator | Turn off switching devices |
| HO.8. | Accessor | Power change |
| HO.9. | Generator | Increase power |
| HO.10. | Generator | Decrease power |
| HO.11. | Accessor | Voltage change |
| HO.12. | Generator | Increase voltage |
| HO.13. | Generator | Decrease voltage |
| HO.14. | Accessor | Parameter calculation |
| HO.15. | Accessor | Perform power calculation |
| HO.16. | Accessor | Perform voltage calculation |
| HO.17. | Accessor | Perform frequency calculation |

The DFDA for the “Monitor” object is not provided due to the simplicity of its processes. The “Monitor” object has two processes: the first is polling the object, and the second is transmitting data to the “Regulator” object.

The DFDA for the “Generating Station” object is shown in Figures 12 – 15.

The list of state processes for the “Generating Station” object is given in Table 2.

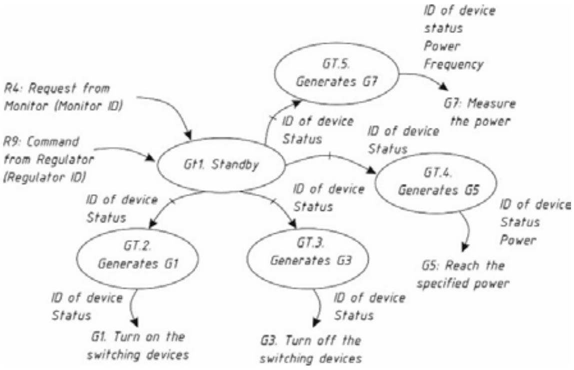


**Fig. 12.** DFDA object "Generating station" status "Standby"

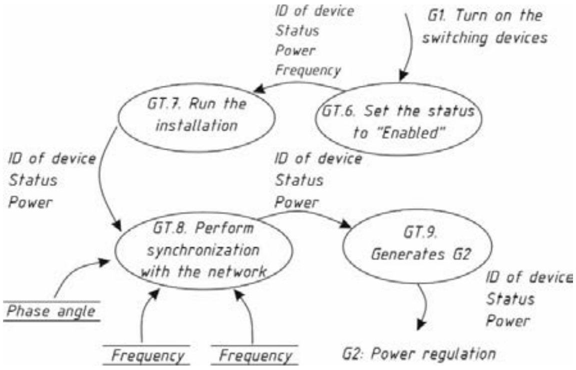


**Fig. 13.** DFDA object "Generating station" status "Turn on switching devices

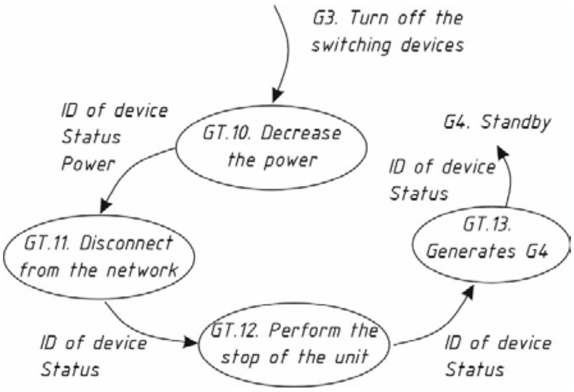


**Fig. 14.** DFDA object "Generating station" status "Turn off switching devices"

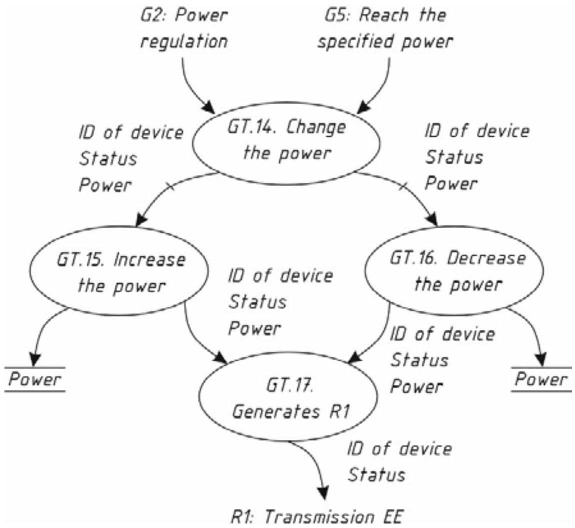


**Fig. 15.** DFDA object "Generating station" status "Power regulation"

**Table 2**

State processes for the object "Generating station"

| Process identifier | Type | Process name |
|---|---|---|
| GT.1 | Accessor | Standby |
| GT.2 | Generator | Generates G1 |
| GT.3 | Generator | Generates G3 |
| GT.4 | Generator | Generates G5 |
| GT.5 | Accessor | Measure power and frequency |
| GT.6 | Accessor | Set status to "On" |
| GT.7 | Generator | Start the installation |
| GT.8 | Generator | Synchronize with the network |
| GT.9 | Generator | Power regulation |
| GT.10 | Accessor | Reduce power |
| GT.11 | Generator | Disconnect from the network |
| GT.12 | Generator | Stop the installation |
| GT.13 | Generator | Generates G4 |
| GT.14 | Accessor | Change power |
| GT.15 | Accessor | Increase power |
| GT.16 | Generator | Reduce power |
| GT.17 | Generator | Generates R1 |

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The DFDA for the “Transmission line” object is shown in Fig. 16 – 19.

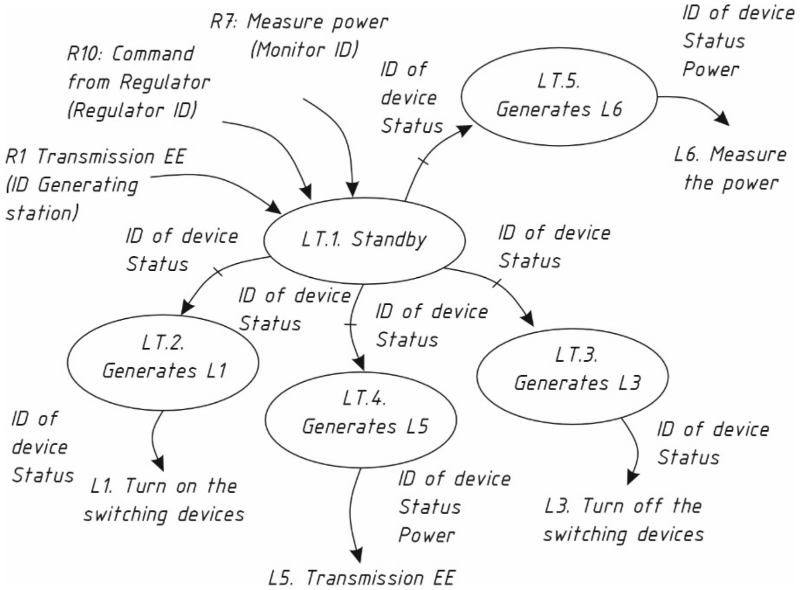


**Fig. 16.** DFDA object “Transmission line” status “Standby”

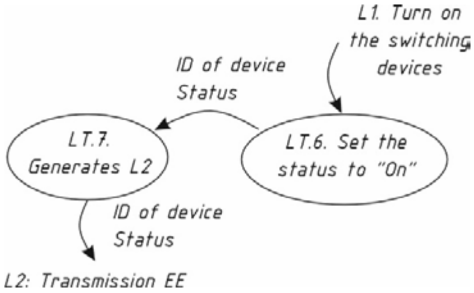


**Fig. 17.** DFDA object “Transmission line” status “Turn on switching devices”

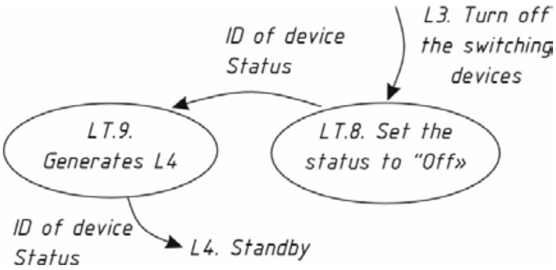


**Fig. 18.** DFDA object “Transmission line” status “Turn off switching devices”

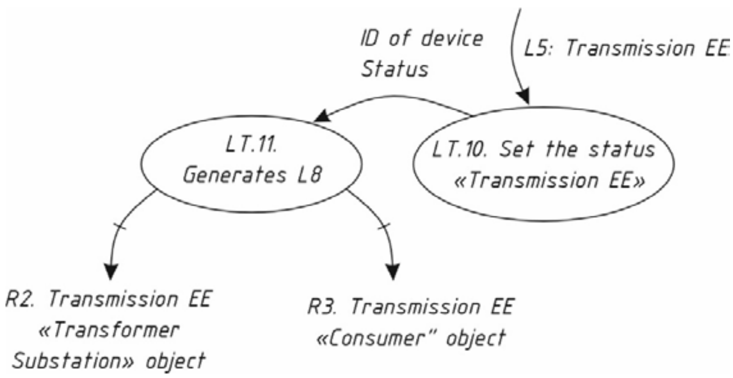


**Fig. 19.** DFDA object “Transmission line” status “Transfer EE”

The list of state processes for the “Transmission line” object is given in Table 3.
The DFDA for the “Transformer substation” object is shown in Fig. 20 – 23.
The list of state processes for the “Transformer substation” object is given in Table 4.
The DFDA for the “Consumer” object is shown in Fig. 24 – 26.
The list of state processes for the “Consumer” object is given in Table 5.

**Table 3**

State processes for the object “Transmission line”

| Process identifier | Type | Process name |
|---|---|---|
| LT.1 | Accessor | Standby |
| LT.2 | Generator | Generates L1 |
| LT.3 | Generator | Generates L3 |
| LT.4 | Generator | Generates L5 |
| LT.5 | Generator | Generates L6 |
| LT.6 | Accessor | Set status “On” |
| LT.7 | Generator | Generates L2 |
| LT.8 | Accessor | Set status “Off” |
| LT.9 | Generator | Generates L4 |
| LT.10 | Accessor | Set status “EE transmission” |
| LT.11 | Generator | Generates L8 |
| LT.12 | Accessor | Measure power |
| LT.13 | Generator | Generates R7 |

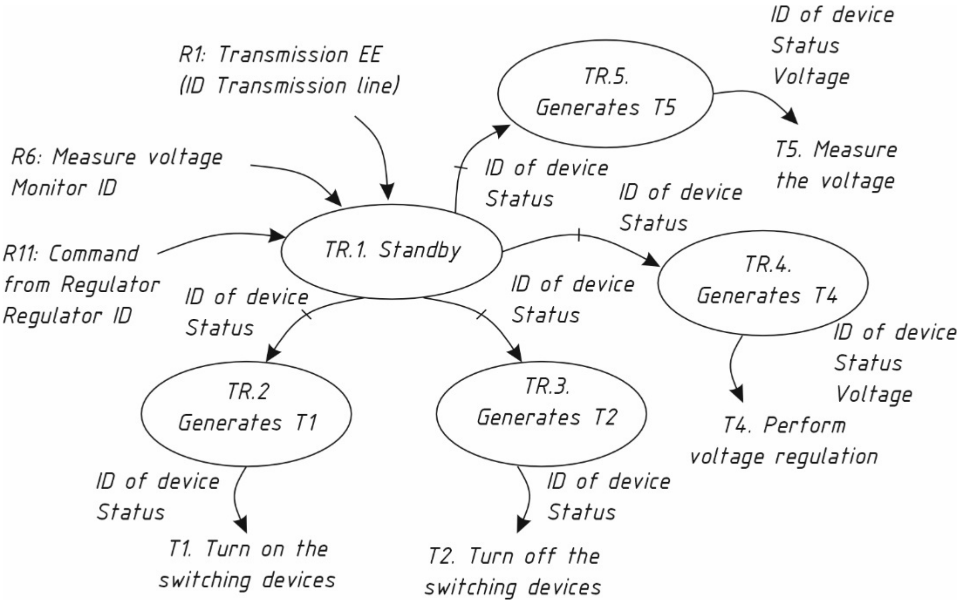


**Fig. 20.** DFDA object “Transformer substation” status “Standby”

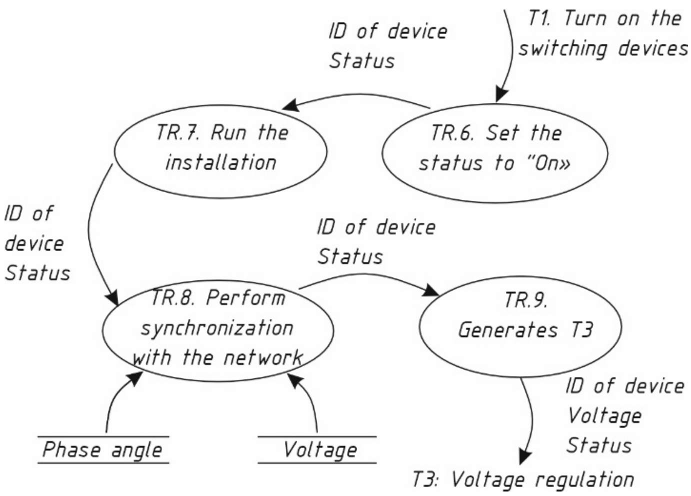


**Fig. 21.** DFDA object “Transformer substation” status “Turn on switching devices”

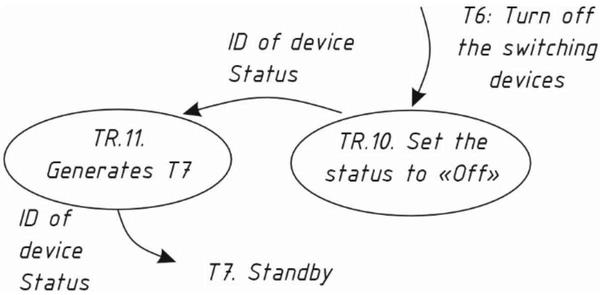


**Fig. 22.** DFDA object "Transformer substation" status "Turn off switching devices"

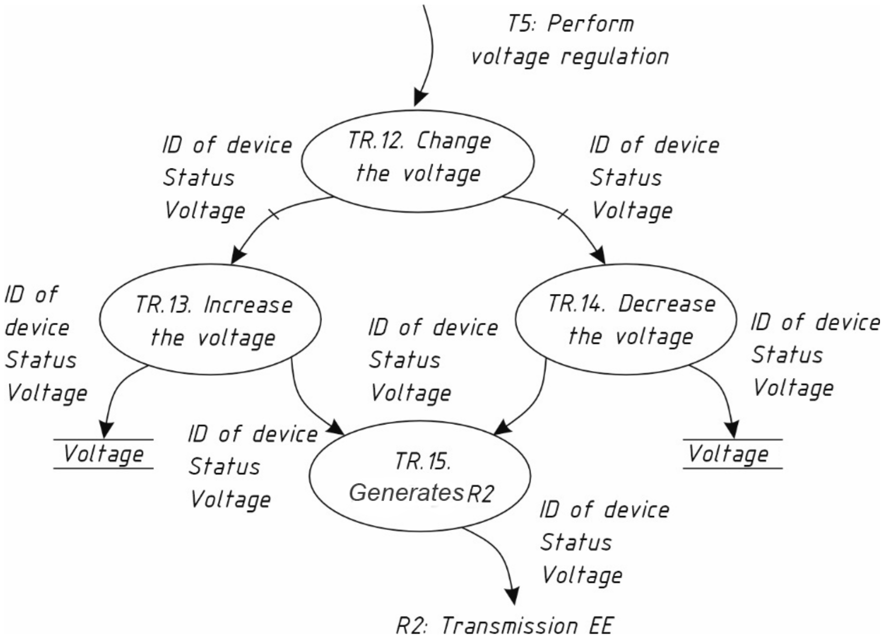


**Fig. 23.** DFDA object "Transformer substation" Status "Voltage regulation"

**Table 4**

State processes for the object "Transformer substation"

| Process identifier | Type | Process name |
|---|---|---|
| TR.1 | Accessor | Standby |
| TR.2 | Generator | Generates T1 |
| TR.3 | Generator | Generates T2 |
| TR.4 | Generator | Generates T4 |
| TR.5 | Accessor | Generates T5 |
| TR.6 | Accessor | Set status "On" |
| TR.7 | Generator | Start the installation |
| TR.8 | Generator | Synchronize with the network |
| TR.9 | Generator | Generates T3 |
| TR.10 | Accessor | Set status "Off" |
| TR.11 | Generator | Generates T7 |
| TR.12 | Accessor | Change voltage |
| TR.13 | Generator | Increase voltage |
| TR.14 | Generator | Decrease voltage |
| TR.15 | Generator | Generates R2 |
| TR.16 | Accessor | Measure voltage |
| TR.17 | Generator | Generates R6 |

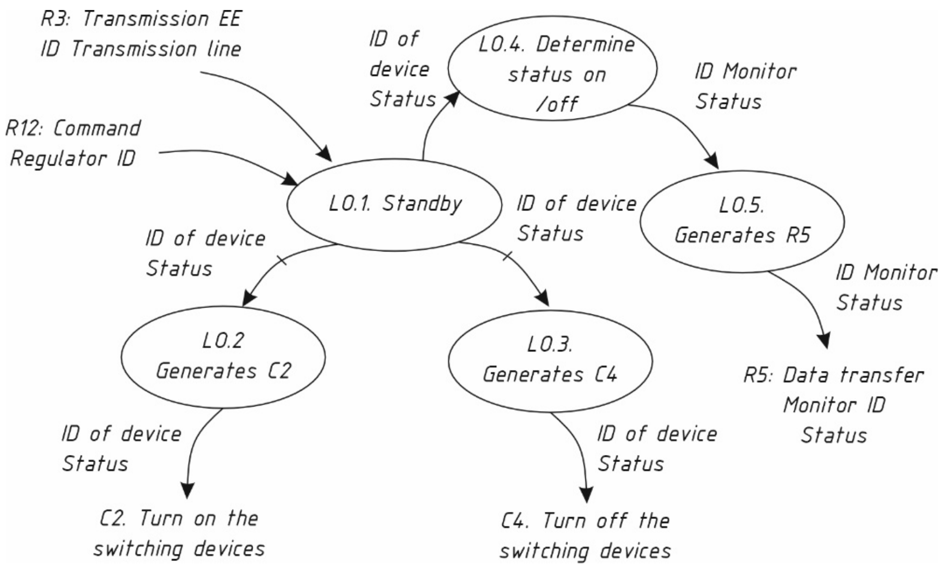


**Fig. 24.** DFDA object "Consumer" status "Standby"

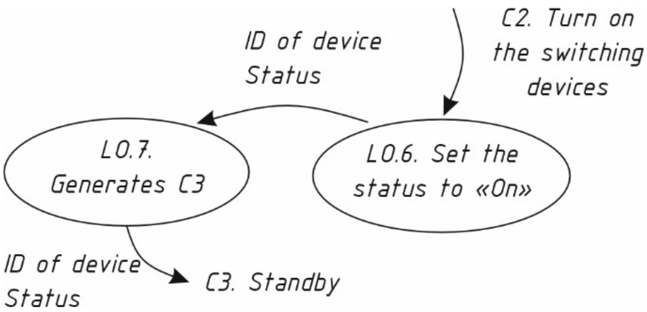


**Fig. 25.** DFDA object "Consumer" status "Turn on switching devices"

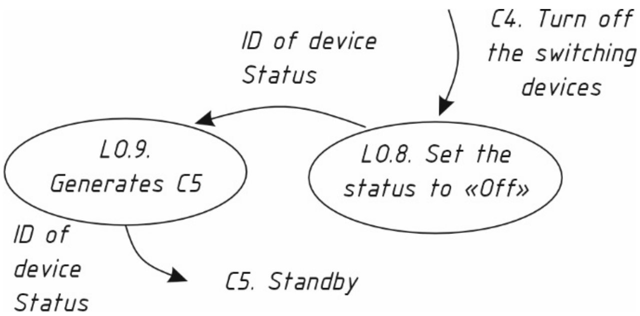


**Fig. 26.** DFDA object "Consumer" status "Turn off switching devices"

**Table 5**

State processes for the object "Consumer"

| Process identifier | Type | Process name |
|---|---|---|
| LO.1. | Accessor | Waiting for command |
| LO.2. | Generator | Generates C2 |
| LO.3. | Generator | Generates C4 |
| LO.4. | Accessor | Determine on/off status |
| LO.5. | Generator | Generates R5 |
| LO.6. | Accessor | Set status "On" |
| LO.7. | Accessor | Generates C3 |
| LO.8. | Accessor | Set status "Off" |
| LO.9. | Accessor | Generates C5 |

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### 4.4 Analysis of Process Flow in the EPS Based on Object-Oriented Models

Description of the process of increasing electricity generation. In the case of a request to increase the generating capacity, the "Regulator" object receives the request "Increase generation". The event H.8 "Perform calculations" is triggered, followed by a transition to the process HO.14 "Parameter calculation", after which the process HO.15 "Perform power calculation" is executed, meaning that the existing generating power is compared to the consumption power. In case of a deficit in generating power, the process HO.1 "Object search" is performed, which ensures an increase in generating power. Then, the process HO.3 is executed, leading to the state H4 "Change power". The process HO.8 "Change power" is carried out by selecting the conditional flow HO.9 "Increase power". The "Regulator" object sends a command to the "Generating station" object via the connection R4 "Increase power". The "Generating station" object performs the process G.5 "Reach specified power", triggering GT.14 "Change power" and then GT.15 "Increase power".

In the same way, events and processes in the EPS develop depending on the command from the "Regulator" object.

## 5. Results of Modeling the EPS

As a result of changing the design power values in the power system, the "Regulator" object performs a power balance analysis. Information about generation and consumption power is received by the "Regulator" object from the "Monitor" object. Based on the comparison of generation and consumption power, the "Regulator" object sends a command to the "Generating station" object to either increase or decrease generating power. In the absence of generating power reserves, the "Regulator" object sends a command to disconnect the "Consumer" object. Similarly, the voltage regulation of the "Transformer substation" object is performed. The "Regulator" object controls and regulates the voltage to ensure the stable operation of the "Transformer substation".

In the event of disturbances or emergency situations, the "Regulator" object coordinates the operation of system objects, specifically by turning on or off the "Generating station", "Transmission line", "Transformer substation" and "Consumer" objects as needed. The integration of the "Regulator" actions improves the system's adaptability to disturbances and imbalances. The proposed model allows for a quick response to power imbalances, promoting reliable and efficient electricity supply to consumers. This energy system model ensures reliable and effective power supply, as it takes into account the specifics of the interaction between objects and processes within the system, adapting it to changing internal and external events.

## Conclusions

In the process of writing the article, a simulation model of the power system was developed based on OOA. The developed information model identifies key objects such as the "Regulator", "Monitor", "Generating Station", "Transmission Line", "Transformer Station" and "Consumer", as well as the relationships between them.

The proposed state models reflect the lifecycle of objects as a result of events occurring in the power system. The state models are universal and can be applied to all instances of the corresponding objects, allowing for the analysis of object transitions into different states.

The developed DFDA reflect the functional nature of the actions of objects, enabling the analysis of key processes occurring during the execution of these actions.

The analysis of processes in the power system shows that the use of object-oriented models allows for the depiction of the sequence of process execution, contributing to a better understanding of their interaction and dynamics. The application of such models not only visualizes the processes and states of objects but also allows for assessing the impact of disturbances on the system's performance. This will facilitate the prompt identification of potential problems, forecast their development, and optimize the operation of individual elements of the power system, increasing the system's efficiency and reliability.

## Література

1. Журахівський А.В., Казанський С.В., Матеєнко Ю.П., Пастух О.Р. Надійність електроенергетичних систем і електричних мереж: підручник. Київ : КПІ ім. Ігоря Сікорського, Вид-во "Політехніка", 2017. 456 с.

2. Kryvda V. I., Suvorov V. O., Zubak V. V. Modeling and method for assessing the efficiency of the power system. *Herald of Advanced Information Technology*. 2023. Vol. 6, No. 3. P. 240–249. DOI: https://doi.org/10.15276/hait.06.2023.16.
3. Бардик Є.І., Бондаренко О.Л., Заклюка І.В. Аналіз методів і алгоритмів дослідження режимної надійності енергосистем в умовах каскадного розвитку відмов. *Відновлювана енергетика*. 2023. №3 (74). С. 6–17.
4. Bevrani H., Watanabe M., Mitani Y. Power System Monitoring and Control. Hoboken, NJ, USA : Wiley, 2014. 288 p.
5. Кириленко О.В., Денисюк С.П. Сучасні тенденції побудови та керування режимами електроенергетичних мереж. *Енергозбереження. Енергетика. Енергоаудит.* 2016. № 4. С. 35–42.
6. Distributed and decentralized control of residential energy systems incorporating battery storage / Worthmann K., Kellett C.M., Braun P., Grüne L., Weller, S.R. *IEEE Transactions on Smart Grid*. 2015. 6(4). P. 1914–1923. DOI: 10.1109/TSG.2015.2392081.
7. Li X. The Analysis and Design of the Object-Oriented System. Shijiazhuang Vocational Technology Institute, Department of Electrical & Electronic Engineering. Hebei, Shijiazhuang, China, 2006. DOI: 10.2991/meita-15.2015.4.
8. Шлеер С., Меллор С. Объектно-ориентированный анализ: моделирования мира в состояниях: Пер. с англ. Київ : Диалектика, 1993. 240 с.
9. Booch G. Object-Oriented Analysis and Design with Applications (Third Edition). Addison-Wesley, 2007. 720 p.
10. Максименко І.М. Об'єктно-орієнтований підхід до аналізу автоматизованих систем теплопостачання зі змінною структурою. *Автоматика та інформаційно-вимірювальна техніка. Вісник Вінницького політехнічного інституту*. 2006. №6. С. 123–129.
11. Кокол Е.А. Объектно-ориентированный анализ АСУ мощностью для повышения маневренных возможностей энергоблока с ВВЭР–1000. *Автоматизація та комп'ютерно-інтегровані технології – 2016*: III Міжнар. наук-практ. конф. молодих вчених, аспірантів та студентів (АКІТ – 2016), 20–21 квітня 2016 р., м. Київ, НТУУ "КПІ". С. 108–109.
12. Тодорцев Ю.К., Максименко І.Н. Об'єктно-орієнтована модель системи теплозабезпечення. Інформаційні моделі. Праці Одеського політехнічного університету. 2005. Вип. 2(24). С. 160–164.
13. Давыдов В.О., Максимова О.Б. Объектно-ориентированая модель системы теплоснабжения с распределенной структурой теплотехнического оборудования. *Автоматика-2008* : тез. докл. XV міжнар. конф. з автомат. упр., 23-26 верес. 2008 р. О. : ОНМА, 2008. Ч. 2. С. 629–631.
14. Максимов М.В. Применение объектно-ориентированного анализа для проектирования систем управления технологическими процессами. *Автоматика-98* : Труды пятой украинской конф. по автоматическому управлению. Киев : 1998. Часть 1. с. 262–265.

### References

1. Zhurakhivskyi, A. V., Kazanskyi, S. V., Mateienko, Y. P., & Pastukh, O. R. (2017). *Reliability of Power Systems and Electrical Grids*: Textbook. Kyiv: Igor Sikorsky KPI, Publishing House "Politechnika".
2. Kryvda, V. I., Suvorov, V. O., & Zubak, V. V. (2023). Modeling and method for assessing the efficiency of the power system. *Herald of Advanced Information Technology*, 6, 3, 240–249. DOI: https://doi.org/10.15276/hait.06.2023.16.
3. Bardyk, Y. I., Bondarenko, O. L., & Zakliuka, I. V. (2023). Analysis of Methods and Algorithms for Investigating the Reliability of Power Systems under Cascading Failures. *Renewable Energy*, 3(74), 6–17.
4. Bevrani, H., Watanabe, M., & Mitani, Y. (2014). *Power System Monitoring and Control*. Hoboken, NJ, USA: Wiley. 288 p.
5. Kyrylenko, O. V., Denysiuk, S. P. (2016). Modern trends in the construction and control of power system regimes. *Energy Saving. Energy. Energy Audit*, 4, 35–42.
6. Worthmann, K., Kellett, C.M., Braun, P., Grüne, L., & Weller, S.R. (2015). Distributed and decentralized control of residential energy systems incorporating battery storage. *IEEE Transactions on Smart Grid*, 6(4), 1914–1923. DOI: 10.1109/TSG.2015.2392081.
7. Li, X. (2006). *The Analysis and Design of the Object-Oriented System. Shijiazhuang Vocational Technology Institute, Department of Electrical & Electronic Engineering*. Hebei, Shijiazhuang, China, 2006.
8. Shleer, S., & Mellor, S. (1993). *Object-Oriented Analysis: Modeling the World in States* (Translated from English). Kyiv: Dialectica.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

9. Booch, G. (2007). *Object-Oriented Analysis and Design with Applications* (Third Edition). Addison-Wesley.
10. Maksymenko, I. M. (2006). Object-Oriented Approach to Analyzing Automated Heat Supply Systems with a Variable Structure. *Automation and Information-Measuring Technology. Bulletin of Vinnytsia Polytechnic Institute*, 6, 123–129.
11. Kokol, E. A. (2016). Object-Oriented Analysis of Power Control Systems for Improving the Maneuverability of VVER-1000 Energy Units. *Automation and Computer-Integrated Technologies – 2016: III International Scientific-Practical Conference of Young Scientists, Postgraduates, and Students* (ACIT – 2016), April 20–21, (pp. 108–109). Kyiv.
12. Todortsev, Y. K., & Maksymenko, I. N. (2005). Object-Oriented Model of Heat Supply Systems. Information Models. *Proceedings of Odessa Polytechnic University*, 2(24), 160–164.
13. Davydov, V. O., & Maksymova, O. B. (2008). Object-Oriented Model of a Heat Supply System with a Distributed Structure of Thermal Equipment. *Automation-2008: Abstracts of the XV International Conference on Automatic Control*, September 23–26, Part 2. (pp. 629–631). Odesa: ONMA.
14. Maksimov, M.V. (1998). Application of Object-Oriented Analysis for Designing Process Control Systems. *Automation-98: Proceedings of the Fifth Ukrainian Conference on Automatic Control,* Part 1. (pp. 262–265). Kyiv.

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