DOI: https://doi.org/10.15276/hait.05.2022.17
UDC 004.621.34.052.2

Developing of functioning algorithm of information-control system for phase-shifting devices in power lines

Artem A. Savieliev
ORCID: https://orcid.org/0000-0002-6949-5959; savieliev.a.a@op.edu.ua. Scopus Author ID: 57202208787
Odessa National Polytechnic University, 1, Shevchenko Ave. Odessa, 65044, Ukraine

ABSTRACT

The article is devoted to development of a functioning algorithm of the control system of phase-shifting devices in double-circuit overhead power lines, as well as to the formulation of the main tasks of this system. Based on these, functional schemes for controlling phase-shifting devices were developed. The developed system will allow, through the use of phase-shifting transformers, which belong to the flexible alternating current transmission system (FACTS) technology, to change the value of phase shift angle of the voltage and current vectors of one circuit relative to another that. This will lead to a change in the value of the wave impedance of double-circuit lines, due to the emergence of new electromagnetic connections between the conductors of the two circuits. The main task of the developed system is to support the operation of power lines in the matched load mode, when the value of the wave impedance is equal to the value of the load impedance. It follows from the analysis that this mode provides the lowest losses in the transmission of electricity through power lines. The implementation of this control system is planned by using the Internet of Things information technology, that is, the formation of a wireless connection between the main elements of the system for data transmission. The developed system can be attributed to information systems, as well as the current concept of Smart Grid. Thus, a method has been proposed to increase efficiency by reducing losses during the transmission of electricity through double-circuit power lines through the use of the concept of Smart Grid.

Keywords: Controlled high-voltage power lines; wave impedance; matched load mode; information-control system; Smart Grid; Internet of Things; FACTS-devices

***For citation*: Savieliev A. A. "Developing of functioning algorithm of information-control system for phase-shifting devices in power line". *Herald of Advanced Information Technology.* 2022; Vol. 5 No. 3: 220–228. DOI: https://doi.org/10.15276/hait.05.2022.17**

INTRODUCTION

In today's realities of Ukraine, the problem of increasing the energy efficiency of functioning of power supply systems is very relevant one. At the same time, one of the scientific and practical tasks for solution of this problem is reducing of losses in the transmission and distribution of electricity. Largely such losses depend on the transmission lines state.

According to data given in the plan for the development of transmission systems of national power company "Ukrenergo" [1], in 2018, 70 % of all overhead transmission lines in Ukraine have been in operation for more than forty years, and are subject to reconstruction or modernization.

One of the effective measures to reduce losses in the transmission and distribution of electricity is Concept of implementation of the Smart Grid, which was adopted recently [2] by the Cabinet of Ministers of Ukraine. As a result of introduction of the action plan for the implementation of this Concept until 2035, it is expected to reduce losses of electricity in the power grids in Ukraine as a whole from 11.6 % to 7.5 %, or by six billion kWh.

Thus, today, to solve the scientific and practical task of reducing losses in the transmission and distribution of electricity, it is necessary to reconstruct and modernize the power lines to increase their energy efficiency on the one hand, and to introduce of the concept of Smart Grid – on the other.

LITERATURE REVIEW

The analysis carried out in [3] showed that the main methods, which are used to reduce losses of electricity in transmission lines, are transfer of the line to a higher class of rated voltage, or increasing the cross-section of conductors.

The common disadvantage of these methods is the necessity to modernize power grids, its equipment, cables or wires. Such changes are associated with economic costs, which in a crisis economy is not acceptable and is not in the first place in terms of priority.

Also, according to review of the literature, it follows [3] that such a type of losses as losses due to inconsistency between the load and the line impedance fell out of the consideration of scientists and was insufficiently studied.

So, one of the new ways to reduce losses during power transmission appears which has not been considered previously, namely maintaining the operation of the power line in the mode of matched load, when the wave impedance is equal to the load impedance.

In [4], study was made of the effect of a matched load on the efficiency of power transmission lines (which was measured by the ratio of the active power value at the end and at the beginning of line) and evidence was obtained for reducing losses in the transmission of electricity by using the matched load mode.

In [5], the authors consider the possibility of operating overhead power lines in the mode of matched load. According to results of calculations of parameters with using developed mathematical models of real lines of the unified energy system of Ukraine, they come to conclusion that using of this mode of operation gives the maximum value of line efficiency in transmission of electricity. The calculation results show that using of matched load mode makes it possible to transfer more energy along the same line (with an efficiency in the range of 97-99 %), in contrast to the normal mode of operation.

Here the question arises how to achieve this matched load mode, what needs to be done for this.

Ensuring mode of matched load is possible only in the case when the wave impedance of the line is equal to the impedance of its load [6]. Here we are faced with a significant and at first sight insurmountable difficulty. The wave impedance of the line is a constant value, which depends only on primary parameters of the line and on the frequency. The voltage frequency in the network is determined by the standard and cannot be changed. Primary parameters of the line depend on its design, which can be changed only if the value of the cross section of the conductors is changed or the length of the line itself is increased. There is a contradiction, expressed in the following. To ensure high energy efficiency, the wave impedance of the line must change, tracking the changing load impedance. But at the same time, changing the wave impedance is possible only by changing the geometric parameters of the line, which is essentially impossible. So, it is impossible to overcome these contradictions within the framework of the traditional representation and construction of power lines.

However, in the Laboratory of Controlled Power Transmissions of the Energy Institute of the Republic of Moldova, the so-called controlled power transmission lines have been developed and tested. The work on these lines was carried out by a large team of authors led by academician Vitaly Postolaty. The idea and theoretical foundations of controlled power high-voltage lines are described in detail in the monograph [7].

The design and circuit differences of power high-voltage lines from conventional power lines are described. Namely: power high-voltage lines consist of two or more three-phase AC circuits and differ from conventional overhead power lines in that their circuits are brought together by a distance that is the minimum allowable under the conditions of phase-to-phase overvoltage. And the systems of three-phase voltages applied to the circuits are shifted relative to each other by a certain angle, depending on the amount of transmitted power. The convergence of phases of different circuits creates a pronounced increased mutual electromagnetic influence of the circuits, the nature of which depends on the angular shift between the applied voltage vectors. That is, from the shift angle θ of the three-phase system of voltage vectors of one circuit with respect to another. The main parameter that is influenced in power high-voltage lines is the wave impedance. Controlling magnitude of wave impedance is possible only by controlling the angular shift θ. The value of the angle θ can vary depending on the load overhead power lines within 0-120º or 0-180º.

Thus, the only way to significantly increase the efficiency of power transmission lines is to abandon their traditional construction in the form of unconnected single lines and switch to power high-voltage lines.

The changing of the angle θ is carried out thanks to phase-shifting transformers, devices that belong to the FACTS technology [8]. Devices of this technology transform the electrical network from a passive element of electricity transportation and distribution into an active one, which is equipped with modern high-speed power electronics devices, which are designed to control processes in the electric power system in real time. In paper [9] presents an overview of phase-shifting transformers, their technical characteristics, a description of the principle of operation and their current use in power transmission networks.

One of the possible methods for adjusting the value of the shift angle θ between the input and output current and voltage vectors is performed using thyristor switches. According to the analysis carried out in [10], using of thyristor switches as part of the phase-shifting devices will increase the reliability and service life of the switching thyristor device, will increase the switching speed taps of electromagnetic elements of phase-shifting transformers, which generally improves the dynamic stability of the entire system. In the article [11], authors analyze the problems of power supply systems that can be solved through the use of FACTS devices. These devices are key components of the Smart Grid concept and are used to improve the reliability of power systems and ensure power quality in line with today's requirements.

Smart Grid is a digital technology [12] that is used to create energy networks that can automatically track energy flows and adapt accordingly to changes in energy supply. So, with this technology, it is possible to create a two-way connection between generating capacities and consumers, as well as provide monitoring of power lines. Smart Grid is made up of controls, computers, new technologies and equipment all working together to form one global control network.

Thus, our analysis showed that there is an alternative way to reduce losses in the transmission and distribution of electricity. The essence of the proposed method is to maintain the operation of line in matched load mode, which will increase the efficiency of lines. This effect can be achieved by upgrading existing lines using FACTS technology devices. Also, from analysis, it should be noted that the question of developing an information control system for phase-shifting devices to change the power high-voltage lines parameters remained relevant. The development of such a system should be based on the concept of Smart Grid.

2. PURPOSE AND OBJECTIVES OF THE RESEARCH

The purpose of this work is to develop functioning algorithm for information-and-control system (ICS) of phase-shifting devices to ensure maximum efficiency of a power transmission line. To achieve it, analysis was carried out of the main tasks and functions that ICS will have to perform.

3. INFORMATION CONTROL SYSTEM FOR PHASE-SHIFTING DEVICES

3.1. Functioning algorithm and information processes in the information control system for phase shifting devices

As a rule, control systems for any technological processes are based on information technology. They are of various types, but they have similar functions, namely: search and collection, processing, storage of necessary data, generation of new information, solution of optimization problems.

The ICS for phase shifting devices must perform certain tasks and functions. The main tasks of this system are:

- measurement of network parameters, namely the value of current and voltage across the load, as well as phase angle between them;
- calculation of complex of load impedance;
- comparison of the values of load impedance complex and the value of wave impedance complex of overhead power lines at a given time;
- analysis in which direction it is necessary to change the value of the value of wave impedance complex of overhead power lines (increase or decrease relative to the value at a given time);
- creation and sending to the executive device of the control signal;
- storage of information about the values of load impedance and wave impedance OPL.

On basis of these main tasks, was developed diagram of information processes (Fig. 1.), which structures stages of operation of ICS for phase-shifting devices, describes the procedure for performing processes in this system, and also shows which instrument-tools are used to perform certain actions.

The principle of operation of the algorithm is presented it in the form of a block diagram (Fig. 2.). The operation of algorithm begins with obtaining measurement results of devices, namely, with readings of voltmeter, ammeter and phasemeter. Based on these values, the value of load impedance Z_L is calculated. Next is taken data on current value of the angle θ from control unit of phase-shifting devices. Based on this value, the wave impedance Z_C. is calculated Further, in the comparison block, the values are compared $Z_L$and Z_C.

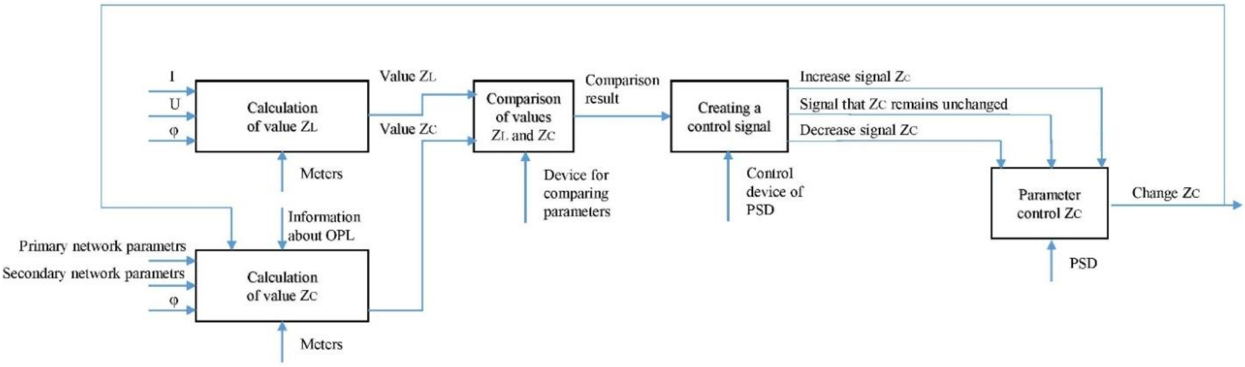

Fig. 1. **Information process diagram for phase-shifting devices**
Source: **compiled by the author**

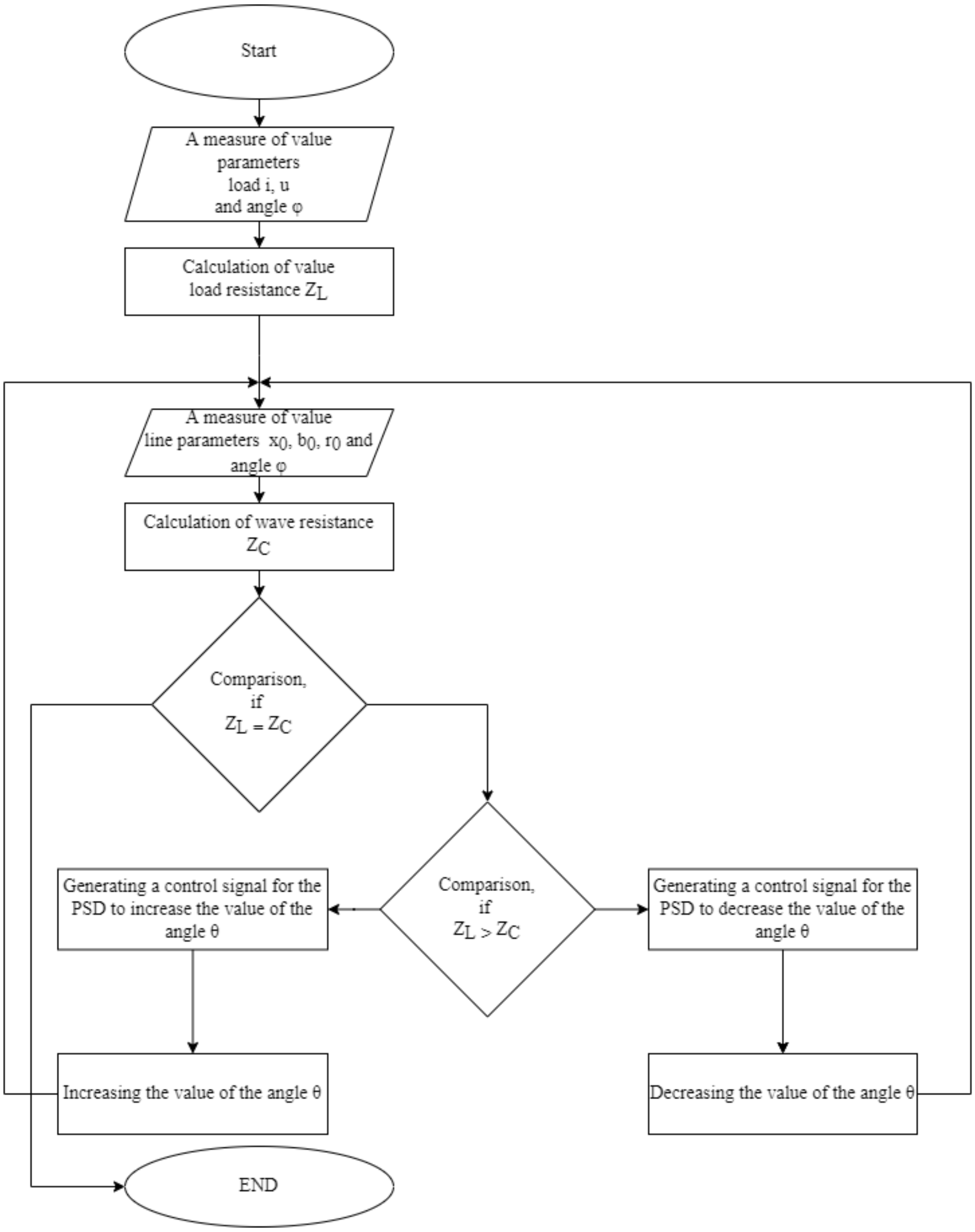

Fig. 2. **Algorithm flowchart for phase-shifting devices in the information-and-control system**
Source: **compiled by the author**

After comparison, there are three possible scenarios for the development of event:

- $Z_L = Z_C$, then the cycle ends and after a certain period of time starts again
- $Z_L > Z_C$, then is formed signal for the phase-shifting devices control unit to increase the value Z_C by increasing the angle θ;
- $Z_L < Z_C$, then is formed signal for the phase-shifting devices control unit to decrease the value Z_C by decreasing the angle θ

For the second and third options, after changing the value of the angle θ, data about new angle is sent to the calculation block, where new values of Z_C are calculated.

The main task of the executive part of ICS for phase shifting device is formation of logical signals for controlling valves in static mode of operation of semiconductor phase-shifting devices switch.

3.2. Functional diagram of the information-and-control system for phase-shifting devices

Considering entire set of functions that ICS for phase shifting devices must perform during their operation, this system can be divided into two subsystems:

1) Subsystem of regulation, diagnostics, automation phase-shifting devices.

2) Thyristor switch (TS) control subsystem.

Subsystem of regulation, diagnostics, automation phase-shifting devices comprises:

- Measuring device systems – collecting information about overhead power lines and load parameters, as well as transmitting them to main control unit.
- Overhead power lines parameters analysis unit – receives network parameter value from main control unit, performs analysis.
- Information Storage Unit about the current state of the thyristor switch – receives information status on the TS control unit from the main control unit. It also acts as part of the database, stores information about control signals in accordance with overhead power lines parameters in certain period of time.
- Information storage unit about the overhead power lines parameters – acts as part of the database, stores information about overhead power lines parameters.
- Main control unit – forms a decision about type of the thyristor switch control signal based on the data received from the overhead power lines parameters analysis unit and the Information storage unit about the current state of the thyristor switch, Namely, the need to increase the value Z_C пby increasing the angle value Θ_{PFD};
- the need to decrease the value Z_C by decreasing value of angle Θ_{PFD}.

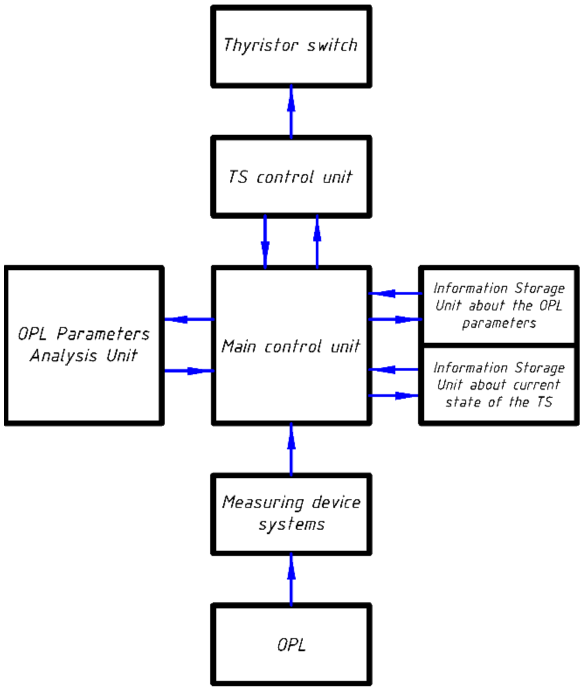

Fig. 3. **Functional diagram of the information-and-control system**
Source: **compiled by the author**

Thyristor switch control subsystem generates control signals and consists of a thyristor switch Control Unit and the thyristor switch itself. This subsystem cooperates with the main control unit and receives signals to control the control stage, generates logical gate control signals in the static operation mode of the semiconductor switch phase-shifting devices and gives feedback on the current degree of regulation to main control unit.

In [13], a schematic diagram of the control subsystem of a phase-shifting device using bridges of TS was developed. They allow to change the angle of shift Θ_{PFD} of the voltage and current vectors at the input and output of the phase-shifting devices in the range of ±60° in steps of 4°. In total, there are thirty-one steps for adjusting the positions of thyristor switches.

Also, a mathematical (simulation) model of the ICS was developed in software “Matlab & Simulink” for a double-circuit line. Choice of the main parameters of the elements of this model is given. The simulation results are presented in the form of diagrams of currents and voltages, they

 ISSN 2663-0176 (Print)
ISSN 2663-7731 (Online)

confirmed the operability of the developed thyristor switch control subsystem of the ICS. That is, by changing the step of adjusting the positions of the thyristor switches, to obtain the value of the shift angle in the range of 0-120 °, and thereby changing the value of the wave impedance.

3.3. Functional diagram ICS for phase-shifting devices for double-circuit overhead power lines

Fig. 3 shows functional diagram of ICS with one phase-shifting device. A controlled power high-voltage lines system with two phase-shifting devices can be based on this scheme. The main control unit of phase shifting devise No. 1 will be located at the end of the line, i.e., at the distribution substation. There it will receive up-to-date information from the measuring devices installed on the underside of the transformer, about the nature and values of the current and voltage of load, which is transmitted via overhead power lines. But the circuit needs to be supplemented with phase-shifting devices, which will be installed at the beginning of line. This phase-shifting devices also need to be controlled, meaning it becomes necessary to add secondary control unit (SCU) to control the thyristor switches No. 2. The general functional diagram of ICS of two phase-shifting devices s is shown in Fig. 4.

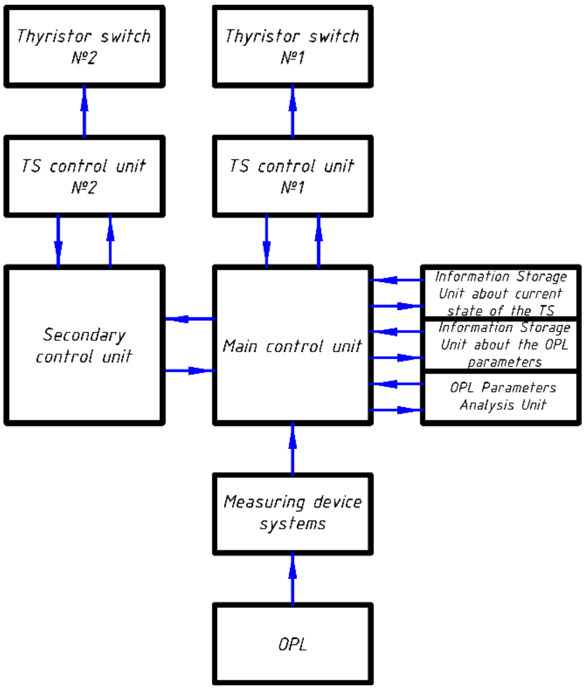

Fig. 4. **General functional diagram of the ICS of two phase-shifting devices in one circuit of a double circuit controlled power high-voltage lines**
Source: **compiled by the author**

The SCU performs the same functions as TS control unit, but receives information about necessary to change the value of angle θ from the main control unit.

The complexity of implementing such a system also lies in fact that phase-shifting devices will be located at a distance of hundreds, and possibly thousands of kilometers from each other. Here one question arises: how will they interact, and what will be the speed of response to changes in the load value at the end of the line.

Due to the possible long distance between phase-shifting devices No.1 and phase-shifting devices No. 2, the connection between SCU and main control unit cannot be done by wires. There is a need to use information technology, such as Internet of Things (IoT), to provide communication between ICS for phase shifting devices.

3.4. Software for control subsystem of phase shifting devices

For the operation of the phase-shifting devices control device, a program code based on the C++ programming language has been developed. The code consists of three main parts: an initialization block, a function block, and a main program block.

In the initialization block are announced complexes of currents, load voltage (these values are obtained by the main control unit from the corresponding measuring instruments, which read the load value in real time), as well as complexes of impedance, equivalent and wave impedance.

Further, in the block of functions, a translation is performed from one form of writing complex numbers to another to perform calculations. The next step is to calculate values of load impedance and wave impedance. The functions of controlling the value of the angle θ are also given to ensure the matched load mode, that is, when the wave impedance is equal to the load impedance. One function is to decrease the angle θ to decrease wave impedance, and the other is to increase the angle θ.

In the main part, using the "If…else if…else" cycle, the values of the complexes of the total wave and impedance of the load are compared.

3.5. Using devices on the IoT platform to monitor and control the operation modes of power lines

Devices working with the IoT information technology can be involved in the controlled power high-voltage lines system, namely in ICS for phase-shifting device.

They will be responsible for the following functions:

- Collection and analysis of overhead power
- lines parameters;
- Create and send to control signals;
- storage data of parameters EPS;
- Interaction between Main Control Unit and SCU of phase-shifting devices.

The concept of IoT [14] is to create a network of various devices, sensors connected to the global network.

So-called "smart meters" can be responsible for collecting data on overhead power lines parameters in real time – smart meters [15] have microprocessor that reads data from the meters and transmits them through the network to the device for collecting, storing and processing information.

Devices for collecting, storing and processing information are included as components in the Main Control Unit phase-shifting devices and perform certain tasks. Physically, they are a board with a processor.

The microprocessor in the Main Control Unit is responsible for creating and sending control signals to the thyristors. This may be the same processor that is responsible for collecting information, or another, depending on its power.

Taking into account the tasks assigned to the ICS of phase-shifting devices, a diagram has been developed that describes the information processes occurring in the ICS for phase-shifting devices, with the help of which the change in the value of the phase shift angle θ is performed.

The possibility of implementing communication between phase-shifting devices at the ends of the line using the IoT platform is considered. It can provide the necessary connection of ICS elements of a double-circuit overhead power lines. It is also shown that devices working with IoT information technology can provide the implementation of the developed ICS.

CONCLUSIONS

In this article, a functioning algorithm of the ICS for phase-shifting devices was developed. The algorithm was developed taking into account its functions and tasks, that is, changing the shift angle θ between voltage vectors of circuits and, as a result, the wave impedance Z_C, in order to maintain a consistent network operation mode.

Thus, a method has been proposed to increase efficiency by reducing losses during the transmission of electricity through double-circuit power lines through the use of the concept of Smart Grid.

In further studies, it is necessary to perform a feasibility study for the implemented system in comparison with a conventional line. A large economic effect from the introduction of controlled energy systems will be noticeable on long and high-power transmission lines. On smaller lines, the effect will not be so significant. And it is also necessary to find the optimal dimensions and capacities of the power system, under which the creation and implementation of ICS for phase-shifting devices become economically justified

Also, one of the directions for further research will be the development of a simulation model for automatic control of the value of phase shift angle θ by an ICS.

REFERENCES

1. "Transmission system development plan for 2019-2028" (in Ukrainian). Ua.energy. 2018 [Online] – Available from: https://ua.energy/wp-content/uploads/2018/03/PROEKT-Planu-rozvytku-systemy-peredachi-na-2019-2028-roky.pdf. – [Accessed: Sep. 2020].

2. "The government approved the concept of implementation of "Smart Grids" by 2035. kmu.gov.ua. 2022 [Online] (in Ukrainian). – Available from: https://www.kmu.gov.ua/news/uriad-skhvalyv-kontseptsiiu-vprovadzhennia-rozumnykh-merezh-v-ukraini-do-2035-roku – [Accessed: Oct. 2021].

3. Savieliev, A. "Ways and methods of improving the efficiency of overhead power line". *Computational Problems of Electrical Engineering*. 2021; 11 (2): 18–25. DOI: https://doi.org/10.23939/jcpee2021.02.018.

4. Maevsky, D., Maevskaya, E., Savieliev, A., Semenyug, A. & Horokholynskyi, S. "Coefficient of efficiency of coupled electric power transmission lines." *14th International Conference on Advanced Trends in Radioelecrtronics, Telecommunications and Computer Engineering (TCSET).* 2018 DOI: https://doi.org/10.1109/TCSET.2018.8336215.

5. Maevsky, D., Besarab, O., Maevskaya, E., Berzan, V. & Savieliev, A. "Ways and reserves of increasing the efficiency of electric power transmission lines". *IEEE 15th International Conference on Ad-*

vanced Trends in Radioelectronics, Telecommunications and Computer Engineering (TCSET). Lviv-Slavske*:* Ukraine. 2020. p. 618–622. DOI: https://doi.org/10.1109/TCSET49122.2020.235506.

6. Bessonov, L. "Theoretical foundations of electrical engineering" (in Russian). *Textbook for energy and electrical engineering universities and faculties*. *Higher School Publishing House*. 4th ed. Moscow: Russian Federation, 1964.

7. Postolaty, V. M. "Compact controlled self-compensating high-voltage AC power lines" (in Russian) [Text]: (in three parts): [monograph]; Energy Institute of the Academy of Sciences of Moldova. Energy Institute of the ASM. Chisinau: Moldova. 2017. 731 p. ISBN 978-9975-62-404-6.

8. "FACTS – powerful systems for flexible power transmission". Library.e.abb.com. 1999 [Online]. – Available from: https://library.e.abb.com/public/b0f2c8c94b48a6bcc1256fda003b4d42/FACTS_%20eng.%20ABB%20Review.pdf. – [Accessed: Sep. 2020]

9. Belivanis, M. & Bell, K. R. "Coordination of phase-shifting transformers to improve trans-mission network utilization". *IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe).* DOI: https://doi.org/10.1109/isgteurope.2010.5638916.

10. Zharkin, A. F., Novsky, V. O. & Malakhatka, D. O. "Phase-shifting transformer devices with forced thyristor commutation for transversal and longitudinal-transversal voltage regulation" (in Ukrainian). Institute of electrodynamics National Academy of Science of Ukraine. 2014; 4: 38–40.

11. Tyll, H. & Schettler, F. "Power system problems solved by FACTS devices". *2009 IEEE/PES Power Systems Conference and Exposition*.

12. "Smart Grids and meters. Energy". Ec.europa.eu. [Online]. – Available from: https://energy.ec.europa.eu/topics/markets-and-consumers/smart-grids-and-meters_en. – [Accessed: Sep. 2021].

13. Savieliev, A. "Development and simulation of the information system for controlling the parameters of overhead power lines in SIMULINK" (in Ukrainian). *Electrical and Computer Systems.* 2022; 36 (112): 27–39. DOI: https://doi.org/10.15276/eltecs.36.112.2022.01.

14. Gillis, A. S. "What is IoT (internet of things) and how does it work?" – Definition from techtarget.com, IoT Agenda. TechTarget. – Available from https://www.techtarget.com/iotagenda/definition/Internet-of-Things-IoT. – [Accessed: Oct. 2021].

15. Carratu, M., Ferro, M., Pietrosanto, A. & Paciello, V. "Smart power meter for the IoT". *2018 IEEE 16th International Conference on Industrial Informatics (INDIN)*. 2018. p. 514-519. DOI: https://doi.org/10.1109/indin.2018.8472018.

Conflicts of Interest: the author declare no conflict of interest

Received 05.09.2022
Received after revision 11.10.2022
Accepted 19.10.2022

DOI: https://doi.org/10.15276/hait.05.2022.17
УДК 004. 621.34.052.2

Розроблення алгоритму функціонування інформаційно-керуючої системи фазозсувних пристроїв в лініях електропередачі

Савєльєв Артем Андрійович
ORCID: https://orcid.org/0000-0002-6949-5959; savieliev.a.a@op.edu.ua. Scopus Author ID: 57202208787
Odessa National Polytechnic University, 1, Shevchenko Ave. Odessa, 65044, Ukraine

АНОТАЦІЯ

Стаття присвячена розробці алгоритму функціонування системи керування фазозрушувальними пристроями у дволанцюгових повітряних лініях електропередачі, а також у постановці основних завдань цієї системи, на підставі яких були розроблені функціональні схеми управління фазозрушувальними пристроями. Розроблена система дозволить за рахунок використання фазозрушувальних трансформаторів, які належать до технології гнучкої системи передачі змінного струму (FACTS), змінювати значення кута зсуву фази векторів напруги і струмів одного ланцюга лінії відносно іншого ланцюга, що призведе до зміни значення хвильового опору дволанцюгових ліній, за рахунок виникнення нових електромагнітних взаємодій між провідниками двох кіл. Завданням системи є підтримка роботи ліній електропередачі в режимі узгодженого навантаження, коли значення хвильового опору дорівнює значенню опору навантаження. З проведеного аналізу випливає, що такий режим забезпечує найменші втрати при передачі електроенергії лініями електропередачі. Реалізація системи управління планується з використанням інформаційної технології «Інтернет Речей», тобто за рахунок формування бездротового зв'язку між основними елементами системи передачі даних. Розроблену систему можна віднести до інформаційних систем, а також до відомої актуальної концепції “Smart Grid”. Таким чином запропонований метод підвищення коефіцієнту корисної дії, за рахунок зменшення втрат при передачі електроенергії по дволанцюгових лініях електропередачі завдяки застосуванню концепції Smart Grid.

Ключові слова: керовані високовольтні лінії електропередачі; хвильовий опір; узгоджений режим навантаження; інформаційна система керування; концепція Smart Grid; Інтернет Речей; FACTS-пристрої

ABOUT THE AUTHOR

Artem A. Savieliev - PhD Student of Electromechanical Engineering Department. Odessa National Polytechnic
University, 1, Shevchenko Ave. Odessa, 65044, Ukraine
ORCID: https://orcid.org/0000-0002-6949-5959; savieliev.a.a@op.edu.ua. Scopus ID: 57202208787
***Research field*:** Coefficient of efficiency of power line; matched load mode; controlled high-voltage power lines; Smart Grid; Internet of Things

Савєльєв Артем Андрійович - аспірант кафедри Електромеханічної інженерії. Національний університет «Одеська політехніка», пр. Шевченка, 1. Одеса, 65044, Україна