ISSN 2664-5289

ELECTRO

SCIENTIFIC-INDUSTRIAL JOURNAL

ENERGETICS
TECHNICS
MECHANICS
+ CONTROL

Volume 12, No.1

BAKU 2022

Azerbaijan State Oil and Industrial University

Azerbaijan Scientific-Research & Design Prospecting Power Engineering Institute

Azerbaijan Technical University

ELECTROENERGETICS, ELECTROTECHNICS ELECTROMECHANICS + CONTROL

Scientific – Industrial Journal

UDC 621.311

LOAD BALANCING TASKS IN THE AZERBAIJAN ENERGY SYSTEM

YUSIFBAYLI N.A.[1], NASIBOV V.Kh.[2], ALIZADE R.R.[2]

[1]Azerbaijan Technical University, 25, H. Cavid Avenue, Baku, Azerbaijan
[2]Azerbaijan Research and Design–Prospecting Power Engineering Institute, 94, Zardabi, Baku, Azerbaijan

ABSTRACT

The article provides a comparative analysis of the main indicators of the load curves of Azerbaijan's energy system with the energy systems of some neighboring states. As the analysis showed, there is a significant potential for improvement in load profile indicators such as the unevenness factor and the fill factor for the Azerbaijani power system. Based on the technical and economic indicators of the main generating capacities of Azerbaijan, the positive effects of leveling the load curves of our energy system in the management of power consumption of three characteristic modes of operation of the energy system: normal mode, peak modes and minimum load modes have been studied.

KEYWORDS: power consumption, load curve, active consumer, technical and economic indicators, peak power

ЗАДАЧИ ВЫРАВНИВАНИЯ ГРАФИКА НАГРУЗКИ В АЗЕРБАЙДЖАНСКОЙ ЭНЕРГОСИСТЕМЕ

ЮСИФБЕЙЛИ Н.А.[1], НАСИБОВ В.Х.[2], АЛИЗАДЕ Р.Р.[2]

[1]Азербайджанский Технический Университет, проспект Г. Джавида 25, Баку, Азербайджан
[2]Азербайджанский Научно-Исследовательский и Проектно-Изыскательский Институт Энергетики, Зардаби 94, Баку, Азербайджан

АННОТАЦИЯ

В статье произведен сравнительный анализ основных показателей графиков нагрузки энергосистемы Азербайджана с энергосистемами некоторых соседних государств. Как показал анализ, имеется существенный потенциал для улучшения таких показателей графиков нагрузки, как коэффициент неравномерности и коэффициент заполнения для азербайджанской энергосистемы. Исходя из технико-экономических показателей основных генерирующих мощностей Азербайджана исследованы положительные эффекты выравнивания графиков нагрузки нашей энергосистемы при управлении электропотреблением трех характерных режимов работы энергосистемы: нормального режима, пиковых режимов и режимов минимальных нагрузок.

КЛЮЧЕВЫЕ СЛОВА: электропотребление, график нагрузки, активный потребитель, технико-экономические показатели, пиковая мощность.

INTRODUCTİON

The efficiency of the power system is largely determined by the nature of the daily load schedule of consumers.

Managing power consumption and thus balancing load curves is one of the key trends in the development of the electric power industry in the world. The transition of electricity consumers to the status of active consumers is fully consistent with the innovative transformation of the electric power industry based on the concept of intellectualization of the energy system. The basis of the concept of transformation of the electric power industry in the world is the Smart Grid concept, where power systems should be controlled in real time by a network of information and control devices and systems. At the same time, management covers not only all generating sources, transmission and distribution networks, but also all types of consumers of electrical energy.

SMART GRID CONCEPT

In the last decade, Smart Grid technology (intelligent network) has been developing in the advanced countries of the world.

In the Smart Grid concept, the consumer acts as a full-fledged participant in the electricity market. At the same time, both the active consumer and the power system can benefit from the readiness of the consumer to change its load.

Currently, there are two types of programs for changing the load of consumers. Some of these programs are incentive based, while others are time based. Among the programs based on incentives, one can note the program with direct load control (Direct load control - DLC). Its essence lies in the fact that an agreement is concluded between the supplier and the consumer of electricity, according to which the supplier can remotely control some of the consumer's devices.

Unlike a direct load management program, an Interruptible Curtailable (I/C) Service program is typically used in the industrial sector or large commercial sectors. In this case, when the power system is overloaded, consumers are asked to reduce their load for a certain time. With the consent of the consumer, he can receive a discount on the tariff or on bills, but if he refuses, he can be fined.

The Demand bidding buyback (DB) program is suitable for both large customers and small customers who are integrated by the system operator and act as a single consumer. The essence of this method is that the supplier, depending on demand and production, announces the amount of electricity that needs to be reduced. The consumer reduces the volume of electricity consumption, based on his situation and the wholesale market. Consumers then provide the specified constraint, otherwise they receive a penalty.

With the help of the Emergency Demand Response Program (EDRP), the system operator stimulates consumers to reduce power consumption in case of unexpected situations. Under this program, consumers are not penalized for non-compliance.

When the system lacks reserve, the Capacity Market Program (CAP) obliges consumers to reduce their predetermined consumption. These announcements are usually published a day in advance. If the consumer proves his ability to reduce electricity consumption, he can receive a reservation payment, and by providing a discount, receive an incentive. If they do not provide a discount, then they can be fined.

Similar to on-demand trading, the Ancillary Service Market Programs (A/S) program also provides for power outages. These abbreviations are used as operational redundancy. Reduction proposals are offered to the independent system operator/regional transmission organization. After accepting the offer, consumers must comply with the reservation. In this situation, the reservation is paid according to the market price. The consumer is paid for both the willingness to reduce and the reduction of electricity consumption itself.

Time-based disaster recovery programs include Time of Use (TOU), Real Time Pricing (RTP), and Critical Peak Pricing (CPP). In the use time program, the electricity tariff is set for the entire time, including the peak. Real Time Pricing Programs The RTP is the same as the TOU program, the only difference is that the electricity price is generated on an hourly basis.

The CPP Critical Peak Pricing Program is used on a limited number of days and is divided into four groups:

- Pricing at critical peaks with a fixed time. In this case, only the time of the price increase is known, but when and at what time it will be applied is not known.
- Critical peak pricing with variable application times. In this case, unlike fixed-time critical peak pricing, neither the time nor the day of the price increase is known.
- Variable pricing. In this program, the time of price increases may vary.
- Critical peak discounts. In this program, during critical peak hours, when their load decreases, consumers receive discounts.

The energy management program is divided into incentive program and time program. In turn, incentive programs can be voluntary (with direct load control, with power consumption control under special conditions), forced (interrupted/reduced service, capacity market program) and market relations (bidding on demand, ancillary services market program). Time programs are categorized into time of use, real-time pricing, and critical peak pricing.

The use of energy management programs for the power system can lead to the following positive effects:

- reduction of power losses in electrical networks,
- reduction of peak power,
- equalization of load curves,
- reduction of transmitted power, increase in network throughput,
- improved stability
- reduction of environmental pollution,
- improvement of voltage profiles,
- reduction or postponement of capital investments in network development,
- reduction or postponement of capital investments in the development of generating capacities.

The use of energy management programs for the consumer can lead to the following positive effects:

- the possibility of transferring power consumption to cheaper watches,
- increase in energy efficiency,
- the possibility of earning income,
- reduction of environmental pollution,
- increasing the reliability of power supply and reducing the problems of complete disconnection from the network,
- reduction of the diktat of electricity market participants.

Here, the effects of leveling the load curve will be considered.

It should be noted that the positive effect of leveling the load curve includes several components:

- Savings associated with the postponement of the construction of power plants (mainly peak),
- Reduction of fuel overburning due to minimum and partial loads,
- Reducing fuel consumption for starting and stopping power system units
- Decreased costs associated with an increase in accidents, repairs, etc. due to frequent start-stops.
- Reducing the unloading of economical power plants in order to keep the blocks of the Azerbaijan TPP in operation.
- Reduction of other losses associated with the growth of expenses for own needs, losses of electricity during the transmission and distribution of electrical energy.

Daily schedules of electrical loads

In 2021, Azerbaijan adopted the Law on the Use of Renewable Energy Sources in the Production of Electricity, which specifies the rights and obligations of an active consumer of electricity. An active consumer can use only a part of the electricity he produces, while selling the other part to the supplier of electricity. At the same time, the consumer, like other electricity producers, can participate in filling the load schedule for the day ahead and receive economic benefits.

Daily graphs of electrical loads are uneven and have several alternating characteristic sections: morning rise, daytime decline, evening peak, deep night dip. The nature of the change in the daily load schedule, in addition to daily rhythms, is also influenced by such parameters as weekly (working and non-working days) and seasonal (winter, spring, summer, autumn) changes in power consumption.

As can be seen from Figures 1-5, daily load schedules differ from each other in the level of load and nature.

As a rule, the highest load is most often observed on working days, in contrast to non-working days, as well as the load in summer and winter compared to the load in spring and autumn.

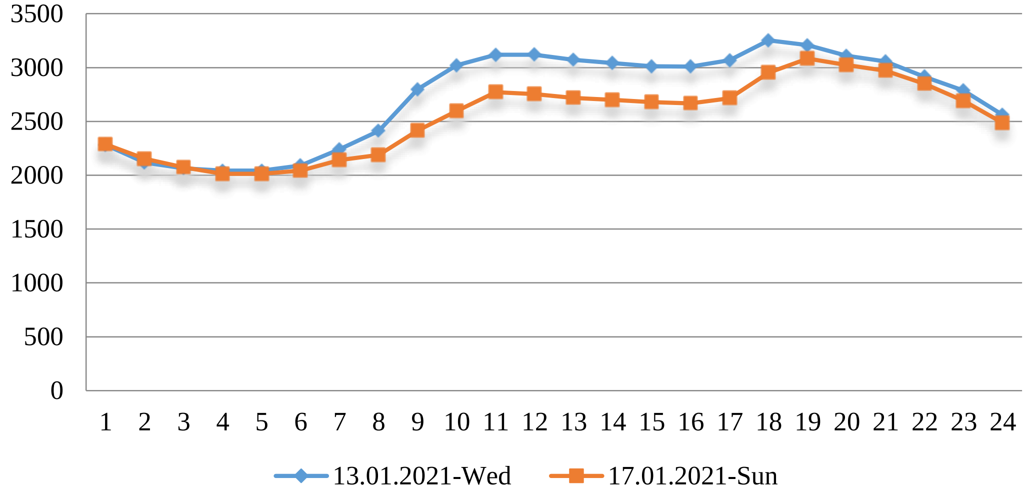


Figure 1. Load schedule for typical winter days

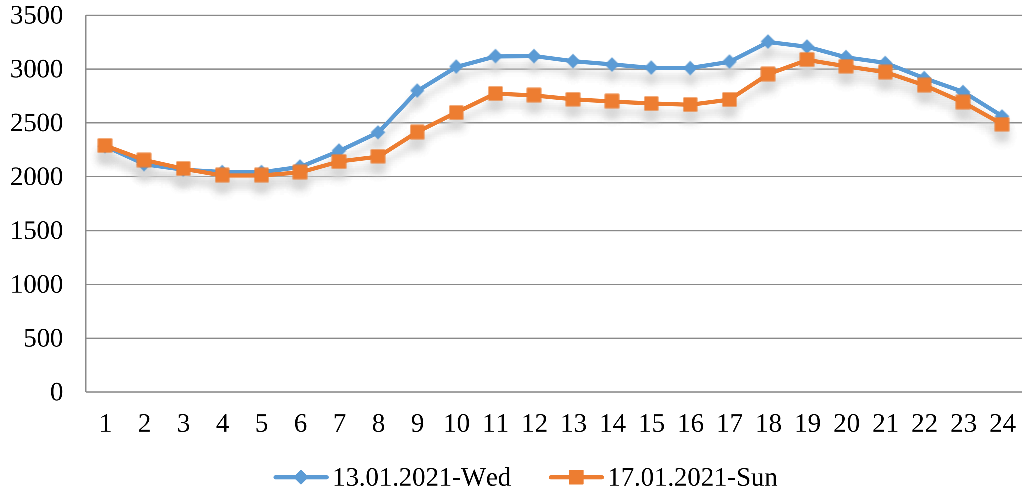


Figure 2. Load schedule for typical spring days

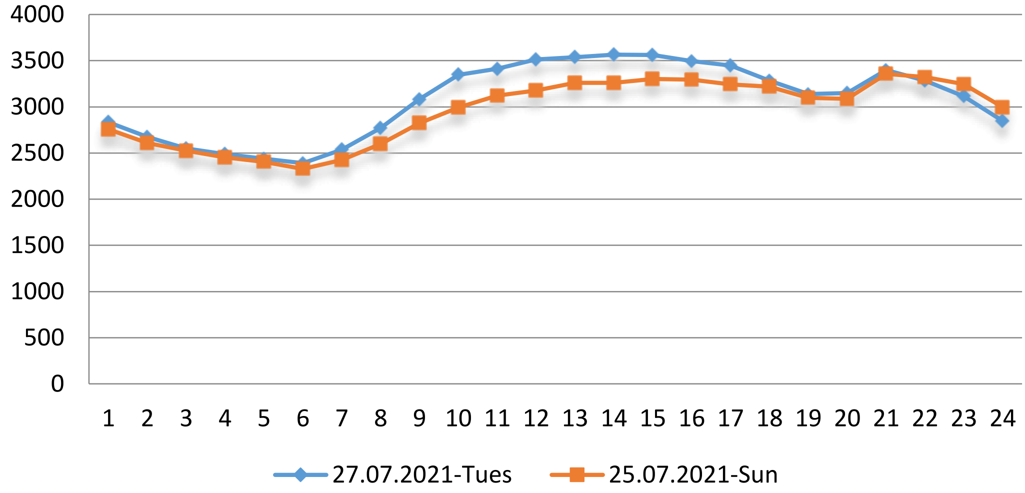


Figure 3. Load schedule for typical summer days

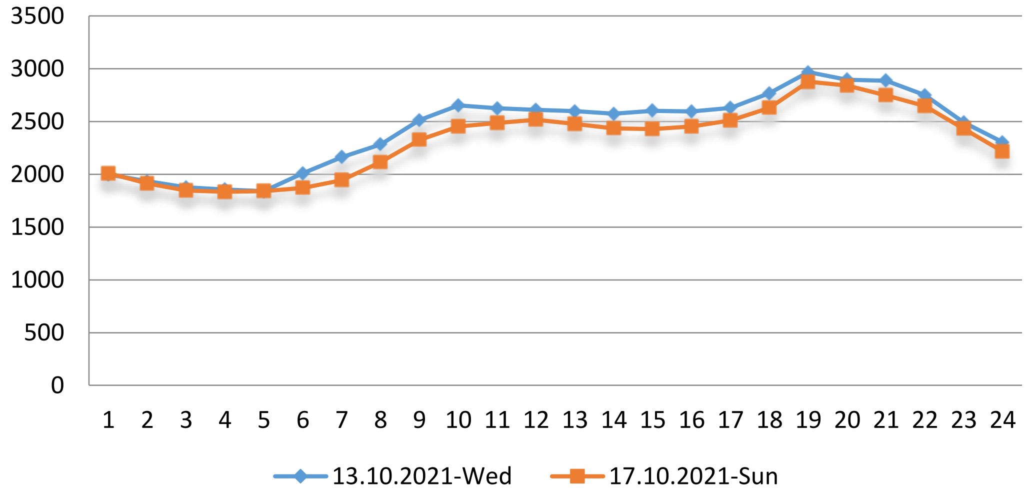


Figure 4. Load schedule on typical autumn days

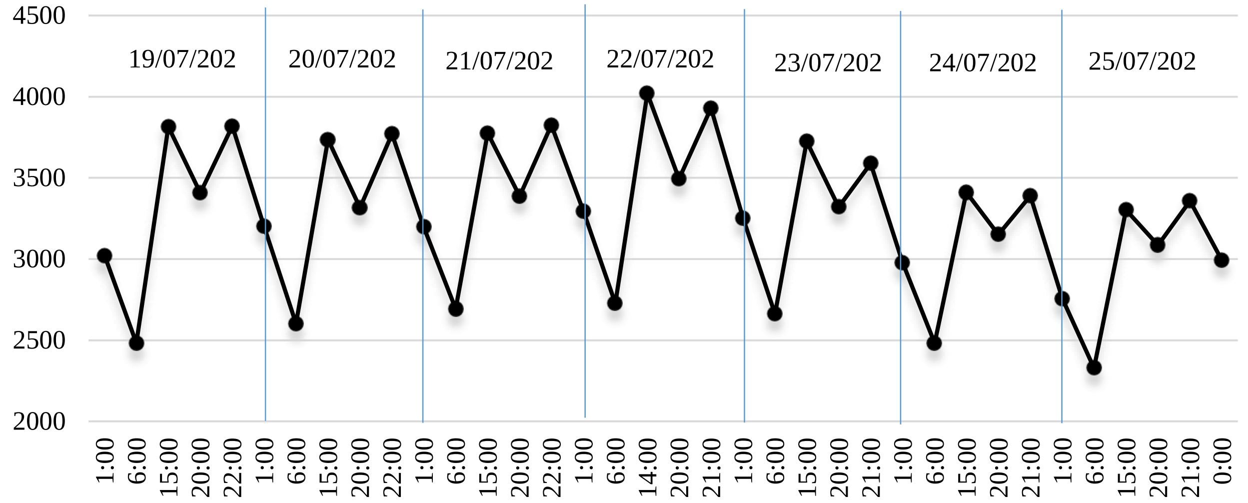


Figure 5. Weekly load schedule

Analyzing the load graphs of Azerbaijan over the past few years, we can come to the conclusion that the maximum load falls on the summer, while the load is highly dependent on the ambient temperature. To evaluate the characteristics of the daily load curve, parameters such as the coefficient of unevenness, the duty cycle, the maximum control range, etc. are used. The lower the coefficients of unevenness and filling, the worse the uniformity of the load curve, and the worse the technical and economic indicators of covering the load curve.

Table 1 shows the indicators of the load graph of the Azerbaijan energy system on typical working and non-working days at different times of the year.

Table 1.

Load curve indicators, MW	**Winter**		**Spring**		**Summer**		**Autumn**	
	Working day	**Non-working day**	**Working day**	**Non-working day**	**Working day**	**Non-working day**	**Working day**	**Non-working day**
Maximum load (P_{max})	3252	3085	2957	2857	3566	3358	2967	2877
Minimum load (P_{min})	2042	2013	1993	1929	2390	2329	1839	1834
Morning maximum ($P\ m_{min}$)	3120	2772	2801	2532	3538	3259	2652	2517
Evening maximum ($P\ e_{max}$)	3252	3085	2957	2857	3566	3358	2967	2877
Average load (Rav)	2727	2541	2496	2350	3077	2954	2434	2327
Irregularity coefficient (Kirreg)	0,63	0,65	0,67	0,68	0,67	0,69	0,62	0,64
Fill factor (K_{fill})	0,84	0,82	0,84	0,82	0,86	0,88	0,82	0,81
Difference between maximum and average load (P_{max}-P_{av})	525	544	461	507	489	404	533	550
Load regulation range (P_{max}-P_{min})	1210	1072	964	928	1176	1029	1128	1043
Regulation coefficient (K_{reg})	0,37	0,35	0,33	0,32	0,33	0,31	0,38	0,36

Table 2 compares the indicators of the daily load curves of the Azerbaijan energy system with similar characteristics of other countries.

Table 2.

Load curve indicators, MW	Azerbaijan		Turkey		Ukraine		Russia	
	Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
Maximum load (Pmax)	3566	3252	39131	41590	21572	28435	110851	142381
Minimum load(Pmin)	2390	2042	28882	29521	16011	20597	89812	122162
Roughness Coefficient (Kner)	0,67	0,63	0,73	0,70	0,74	0,72	0,81	0,85
Fill factor (Kzap)	0,86	0,84	0,89	0,87	0,89	0,87	0,92	0,94
Regulation coefficient (Kreg)	0,31	0,37	0,26	0,29	0,25	0,27	0,18	0,14
Ratio (Plet.min/Pwinter.min)	1,17		0,97		0,77		0,73	
Ratio (Plet.mak/Pwinter.mak)	1,10		0,94		0,75		0,77	

As can be seen from tables 1 and 2, the characteristics of the daily load curves of the Azerbaijan energy system are noticeably worse compared to similar characteristics of other countries, and there is significant potential in the Azerbaijan energy system to improve the characteristics of the daily load curves.

In the energy system of Azerbaijan, the basic part of the daily load schedule is mainly covered by thermal power plants, regardless of the day of the week or season. TPPs covering the base part - Dzhanub PP - 780 MW with specific fuel consumption (SFC) 233 gr/kWh, Shimal PP - 800 MW, with specific fuel consumption 214 gr/kW.h and Sumgait PP -525 MW, with fuel consumption 224 g/kWh, have good technical and economic indicators. Half peaks and peaks of the daily load schedule of the Azerbaijan energy system are mainly covered by the Azerbaijan TPP - 2400 MW and relatively small modular power plants.

As can be seen from fig. 6, the Azerbaijan energy system itself fully covers its own demand for electricity. The energy system exports some electricity to neighboring states, mainly to Georgia and Turkey.

The technical and economic indicators of covering the daily schedule of the Azerbaijan energy system mainly depend on the operation mode of the Azerbaijan TPP with a specific fuel consumption of 330-337 g/kWh.

The mode of coverage of the load schedule mainly depends on how many units of Azerbaijan TPP with a capacity of 300 MW participate in the coverage of the schedule. The number of connected blocks can be 2-block, 3-block, 4-block and 5-block (no more than 10 days a year you have to include the 6th block in operation). At night, due to a decrease in consumption, it is necessary to unload the included units of the Azerbaijan TPP to a technical minimum, and modular power plants also stop. In the morning, with the growth of electricity consumption, modular stations are put into operation, if necessary, the capacity of the Azerbaijan TPP is increased.

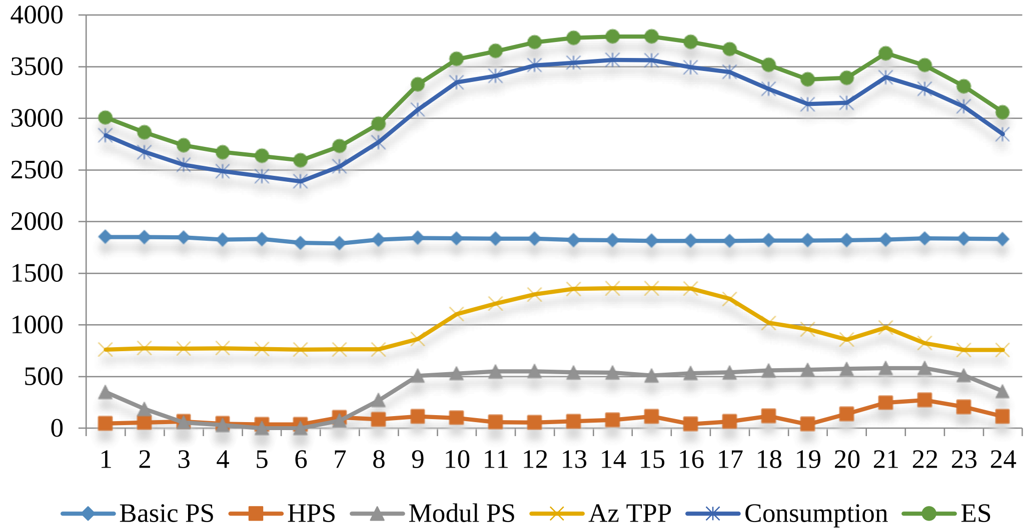


Figure 6. Coverage of the daily load curve

The following are the components of the effect of leveling the load curve:

 The construction of a 410 MW power plant (corresponding calculations and negotiations with suppliers and builders are being carried out) would cost 450 million dollars, while the cost of 1 kW of power is 1,100 dollars. If we accept the effect of postponing construction to a later date (9-10 years), we will get an annual effect of $47 million.

 Burnout of fuel associated with the partial load of the Azerbaijan TPP is calculated from the operating modes of this TPP. In 2021, the blocks of the Azerbaijan TPP were in operation: 5 blocks - 87 days, 4 blocks - 73 days, 3 blocks - 45 days, 2 blocks - 160 days.

 Based on the typical daily load schedules, when 5 units are in operation, the overrun is calculated in such a way that the units carried minimal loads for 10 hours with an overrun of 21 g/kWh, while 7651 MW/h of electricity was generated. For 8 hours, the units of the Azerbaijan TPP operated at close to nominal capacity with an overrun of 2.7 g/kWh, while 10,273 MWh were generated. During the remaining 6 hours, the units operated with an average power consumption of 14.3 g/kWh, while 5501 MWh of electricity was produced. The total overexpenditure for one day of operation of the Azerbaijan TPP with 5 units is approximately 21 g/kWh * 7651000 kWh + 2.7 g/kWh* 10273000kWh + 14.3 g/kWh * 5501000kWh = 267 t.e.

Table 3.

Number of units turned on	**Number of days**	**Excessive fuel consumption associated with partial load, t.f.e.**
5	87	23229
4	73	16644
3	45	8478
2	160	22310
Total		**70661 t.f.e.**

Considering that there were 87 such days in 2021, then in the annual context, the overrun from the operation of the Azerbaijan TPP with 5 units is 267 tons of fuel equivalent * 87 days = 23229 tons of fuel equivalent. in a year. Similar calculations were made for other modes of the Azerbaijan TPP, and the results are summarized in the table.

As shown above, modular power plants stop at night and start working in the morning, in order to regulate the load schedule, the blocks of the Azerbaijan TPP are also sometimes stopped and then turned on (start-stop can be carried out both in weekly and seasonal regulation of the load schedule). Considering that approximately 130,000 m3 of gas is consumed during the start-up of a block of the Azerbaijan TPP from a cold state, 60 m3 of gas at modular low-capacity power plants, and 130 m3 of gas at modular power plants of medium capacity, the overrun associated with the start-up shutdown of the units is approximately 7 million m3 of gas per year.

In order to prevent shutdown of units of the Azerbaijan TPP, it is often necessary to operate more economical power plants with partial loads, which leads to excessive fuel consumption due to partial loads of economical power plants. The table shows the values of excessive fuel consumption at economical power plants.

Table 4.

Power plant	**Excessive fuel consumption in 2021, t.f.e.**
Canub PP – 780 MW	42000
Sumgayit PP – 525 MW	10000
Shimal PP – 800 MW	8800
Total	**60800**

If we bring the above values of the cost overruns of standard fuel into the volumes of natural gas (natural gas is used at the power plants of Azerbaijan), we will get 115 million m3. Taking into account the excessive consumption of gas for the start-stop of the units, we will get 122 million m3 of natural gas.

We are conducting special studies to determine the costs associated with an increase in accidents, repairs, etc. due to frequent start-ups, as well as losses associated with the growth of expenses for own needs, losses of electricity during the transmission and distribution of electrical energy. Without taking into account these components, the annual effect of leveling the load schedule (at current prices for a thousand cubic meters of natural gas at $1,740), taking into account the effect of postponing the construction of a peak station, can be estimated at $260 million per year. More than 80% of this amount falls on the share of natural gas, the price of which has recently been characterized by great instability, and therefore it is possible to operate with the amount received conditionally.

Azerbaijan has adopted a strategic direction for the development of the electric power industry, which provides for the widespread introduction of renewable energy sources. Modular power plants will make it possible to cover the electrical load of the power system when introducing renewable energy sources in the amount of up to 500 MW, covering large volumes will be accompanied by significant problems, primarily the need to build peak power and large electric energy storage capacities.

Thus, at current natural gas prices, the amount that can be used to equalize the load schedule can be estimated at $260 million. The main means of leveling the load schedule is the use of hourly rates. To do this, it is necessary to introduce modern electricity meters with appropriate functions.

Currently, the two-part tariff applied in Azerbaijan for continuous production (production of aluminum, steel, etc.) does not contribute to leveling the load curve (their share in total consumption is not significant). In order to equalize the load schedule, it is necessary to stimulate the development of industry with continuous automatic production.

CONCLUSIONS

1. Power consumption management is one of the main components of the concept of modern development of the electric power industry.
2. Currently, in countries with developed market relations in the electric power industry, there are two types of programs for changing the load of consumers: programs based on incentives and programs based on time.
3. The characteristics of the daily load curves of the Azerbaijan energy system are noticeably worse compared to similar characteristics of other countries and there is significant potential in the Azerbaijan energy system to improve the characteristics of the daily load curves.
4. Characteristics of load coverage modes mainly depend on the number of connected units with a capacity of 300 MW of the Azerbaijan TPP.
5. The effect of equalizing the load schedule of the Azerbaijan energy system at current natural gas prices can be $260 million, which can be directed to the introduction of hourly tariffs for electricity, the development of storage systems and continuous automatic production with uniform power consumption.

REFERENCES

1. Md Rahat Hossain, Amanullah Maung Than Oo, A B M Shawkat Ali Smart Grid, p. 24
2. Воропай Н.И., Стенников В.А. Активные потребители в интеллектуальной электроэнергетической системе, http://energystrategy.ru/projects/Energy_21/3-6.pdf
3. Гуртовцев А.Л., Забелло Е.П Выравнивание графика электрической нагрузки энергосистемы. Энергетика и ТЭК. 2008. № 7/8., с.13-20
4. Волкова И.О., Шувалова Д.Г., Сальникова Е.А. Активный потребитель в интеллектуальной энергетической системе: возможности и перспективы, https://publications.hse.ru/mirror/pubs/share/folder/xnto5eu7bd/direct/71899800
5. Eid, C. Time-Based Pricing and Electricity Demand Response: Vxisting Barriers and Next Steps C.Eid, E.Koliou, M. Valles [et al.] Elsevier Utilities Policy 2016. Volume 40, p. 15-25
6. Pazouki, S., Mohsenzadeh, A., Haghifam, M. R. Optimal planning of parking lots and DLC programs of Demand Response for enhancing distribution networks reliability. IEEE Pes General Meeting Conference & Exposition, National Harbor, MD, USA: 27-31 July, 2014, p. 1-5

7. Robertson, G., Harrison, G.P. , Robin Wallace, A. OPF Techniques for Real-Time Active Management of Distribution Networks. IEEE Power & Energy Society General Meeting, Chicago, IL, USA: 16-20 July, 2017, p. 3529-3537

8. Насибов В.Х., Ализаде Р.Р. Исследование характерных графиков нагрузки Азербайджанской энергосистемы для определения нагрузочного резерва мощности, 85-ое заседание Международного научного семинара им. Ю.Н. Руденко «Методические вопросы исследования надежности больших систем энергетики», Надежность либерализованных систем энергетики», 30 июня-4 июля 2013, Иркутск, Россия, с. 119-124

9. Папков Б.В. Активные элементы потребителей в электроэнергетической системе, Методические вопросы исследования надежности больших систем энергетики. Вып. 66., Минск, Иркутск: ИСЭМ СО РАН, 2015, с. 218-224.

10. Hayder O. Alwan Compass Load Scheduling with Maximum Demand and Time of Use pricing for Microgrids, Virginia Commonwealth University VCU Scholars, p. 154, 2019

11. Jun Du, Zongnan Zhang, MenghanLi ,JingGuo&Kongge Zhu Optimal scheduling of integrated energy system based on improved grey wolf optimization algorithm, Scientifc Reports 2022

12. Jia, H. et al. Research on some key problems related to integrated energy systems. Autom. Electr. Power Syst. 39(7) 2015, p. 198–207

13. Dunnan, L., Guangyu, Q. & Qi, Li. Research on optimization operation of integrated energy microgrid considering multi-type energy conversion and storage. South. Power Grid Technol. 12(3) 2018, p. 105–115.

14. Li, W. et al. Optimal dispatch model considering environmental cost based on combined heat and power with thermal energy storage and demand response. Energies 12(5) 2019, p. 817.

15. Zhang, X. et al. Hourly electricity demand response in the stochastic day-ahead scheduling of coordinated electricity and natural gas networks. IEEE Trans. Power Syst. 31(1) 2015, p.592–601

Li, W. et al. Optimal dispatch model considering environmental cost based on combined heat and power with thermal energy storage and demand response. Energies 12(5), 817 (2019).

Zhang, X. et al. Hourly electricity demand response in the stochastic day-ahead scheduling of coordinated electricity and natural gas networks. IEEE Trans. Power Syst. 31(1), 592–601 (2015).

Nurali Yusifbayli was born on March 28, 1963. He attended Kiev Technical Academy from 1980 to 1986 and graduated on the specialty of "Electrical systems cybernetics" from the Power Engineering faculty. He received his degrees of Candidate of Technical Sciences in 1995 and Doctor of Technical Sciences in Azerbaijan Scientific-Research and Design-Prospecting Power Engineering Institute in 2004. In 2011 he became a professor. Since 2021 he is a vice-rector of Azerbaijan Technical University.
He has been awarded honorary titles "Honored engineer", "Honored Scientist" of the Republic of Azerbaijan and "Honored Power Engineer" of CIS member countries.
E-mail:yusifbayli.n@gmail.com

Valeh Nasibov was born in Djebrail region of Azerbaijan Republic on April 18, 1964. He graduated from the Moscow Energy Institute in 1987. In 2005 he was awarded a PhD's degree, in 2016 he became an assistant professor. Since 1987 to the present he has been working in Azerbaijani Scientific – Research Designed–Prospecting Institute of Energetics. From 2009 to 2012 he worked as the head of "Energy security" laboratory. Currently he is head of "Perspective development the electricity" Department.
E-mail: nvaleh@mail.ru

Rana Alizade was born in Baku of Azerbaijan Republic. She graduated from the Azerbaijan State Oil Academy in 1999 with being given a Bachelor's degree, and in 2001 – a Master's degree. Since 2001 to the present she has been working in Azerbaijani Scientific–Research and Designed–Prospecting Institute of Energetics. In 2012 she was awarded a PhD's degree, in 2016 she became an assistant professor. Currently she is Leading Researcher of "Perspective development the electricity" Department.
E-mail:rena_alizade@mail.ru

SIMULATION OF AN ANTENNA ARRAYS OPERATING IN THE FREQUENCY BAND 1574-1610 MHz

[1]ISLAMOV I.J., [2]HUNBATALIYEV E.Z.
[1]Azerbaijan Technical University, Baku, Azerbaijan, icislamov@mail.ru
[2]Azerbaijan Technical University, Baku, Azerbaijan, elmarzulfugar59@gmail.com

ABSTRACT. The process of modeling a seven-element antenna array in the range 1574-1610 MHz, which can be used in receivers of GPS navigation systems with adaptive noise suppression algorithms, is considered. The design features of the manufactured sample of the antenna array are noted. The material of the common dielectric base and the mutual position of the antenna elements are chosen, which make it possible to minimize the slope of the frequency dependences of the arguments characterizing the mutual connections between neighboring elements. The results of numerical calculations of the S-parameters are in good agreement with the measurement results.
Keywords: antenna array, numerical calculations, radiation pattern, navigation system, receiving device.

1574-1610 MHs TEZLİK DİAPAZONUNDA İŞLƏYƏN ANTENA QƏFƏSİNİN MODELLƏŞDİRİLMƏSİ

[1]İSLAMOV İ.C., [2]HÜNBƏTƏLİYEV E.Z.
[1]Azərbaycan Texniki Universiteti, Bakı, Azərbaycan, icislamov@mail.ru
2Azərbaycan Texniki Universiteti, Bakı, Azərbaycan, elmarzulfugar59@gmail.com

XÜLASƏ. Məqalədə adaptiv səs-küyün qarşısının alınması alqoritmləri ilə GPS naviqasiya sistemlərinin qəbuledicilərində istifadə olunan 1574-1610 MHs tezlik diapazonlu yeddi elementli antena qəfəsinin modelləşdirilməsi məsələsinə baxılmışdır. Antena qəfəsinin hazırlanmış nümunəsinin konstruktiv xüsusiyyətləri müəyyənləşdirilmişdir. Antena qəfəsinin materialı kimi dielektrik əsaslı material və antena elementlərinin qarşılıqlı mövqeyi seçilmişdir ki, bu da qonşu elementlər arasındakı qarşılıqlı əlaqələri xarakterizə edən arqumentlərin tezlik asılılığını minimuma endirməyə imkan vermişdir. Müəyyən edilmişdir ki, S-parametrlərinin ədədi hesablamalarının nəticələri ölçmə nəticələri ilə yaxşı uyğunlaşır.
Açar sözlər: antena qəfəsi, ədədi hesablamalar, istiqamətlənmə diaqramı, naviqasiya sistemi, qəbuledici qurğu.

МОДЕЛИРОВАНИЕ АНТЕННОЙ РЕШЕТКИ, РАБОТАЮЩЕГО В ЧАСТОТНОМ ДИАПАЗОНЕ 1574-1610 МГц

[1]ИСЛАМОВ И.Дж., [2]ГУМБАТАЛИЕВ Э.З.
[1]Азербайджанский технический университет, Баку, Азербайджан, icislamov@mail.ru
[2]Азербайджанский технический университет, Баку, Азербайджан, elmarzulfugar59@gmail.com
АННОТАЦИЯ. Рассмотрен задача моделирования семиэлементной антенной решетки диапазона 1574-1610 МГц, которая может использоваться в приемниках навигационных систем GPS с адаптивными алгоритмами подавления помех. Отмечены конструктивные

особенности изготовленного образца антенной решетки. Выбран материал общего диэлектрического основания и взаимное положение антенных элементов, позволяющие минимизировать наклон частотных зависимостей аргументов, характеризующих взаимные связи между соседними элементами. Результаты численных расчетов S-параметров достаточно хорошо согласуются с результатами измерений.

Ключевые слова: антенная решетка, численные расчеты, диаграмма направленности, навигационная система, приемная устройства.

1. INTRODUCTION

To the radio technical characteristics of antennas operating in GPS navigation systems are subject to a number of specific requirements. They must ensure the reception/transmission of waves with right-hand circular polarization, have close to uniform radiation patterns in the upper half-space, and ensure the systems operability in the required frequency ranges. In this area of antenna technology, microstrip antennas [1], which is mainly due to their planar structure, relative cheapness and ease of manufacture, high repeatability, and the possibility of minimizing the size of the antenna due to the use of a substrate with a high dielectric constant.

Today, much attention is also paid to the development of antenna arrays for signal receivers of satellite navigation systems. In particular, a number of specific applications [2, 3] require antenna systems with a relatively high gain with a fixed amplitude-phase distribution in the aperture. But the most widely used antenna arrays for receiving navigation signals are found in adaptive noise protection systems with digital beamforming of the required shape [4, 5]. This direction is relevant for both military and civilian facilities. Note that the maximum number of interference that can be suppressed by a digital array is one less than the number of array antenna elements [6, 7].

The simplest antenna arrays designed for adaptive noise protection systems include a small number of elements $N \leq 10$ and consist of microstrip antenna elements. In this case, the characteristic interelement distances are half the wavelength or less, which, together with the weak directivity of the radiation patterns of the antenna elements themselves, does not allow us to neglect the mutual influence of the antennas on each other. As a result, in order to obtain an adequate theoretical estimate of the radio technical characteristics, it is necessary to carry out an electrodynamic calculation of the entire model of antenna arrays as a whole. The close location of the boundaries of antenna arrays to peripheral elements and the possibility of making antenna elements in the form of three-dimensional planar structures that do not have a common dielectric substrate, in turn, limits the possibility of using numerical two-dimensional methods for analyzing flat layered structures to solve such problems.

A priori, it may seem that modern software packages for three-dimensional electrodynamic modeling make it possible to analyze and synthesize (using parametric optimization) microstrip antenna arrays with a small number of elements even on non-modern personal computers, because the characteristic dimensions of such problems do not exceed several wavelengths. However, in practice, to analyze such structures, rather significant hardware resources are required, as well as significant computer time due to the need to divide each of the array elements into a sufficiently large number of grid cells, especially if the antenna elements used are small in size, for example, due to the use of radiators of complex indented shape and/or the use of materials with high dielectric constant.

In the proposed work, we consider the simulation of a seven-element planar antenna array in the L1 range (1574-1610 MHz), which consists of commercially available small-sized ceramic antenna elements and can be used in receivers with adaptive noise reduction algorithms. In the first part of the article, the characteristics of the antenna elements used are given, a solitary element is calculated, and the layout of the antenna elements in the array is described. In the second part, the results of modeling the entire antenna arrays are described, the material of the common dielectric base and the relative position of the antenna elements are selected. There is a difference between the characteristics of the radiation field in the far zone and the reflection coefficients for antennas in the composition of antenna arrays and one solitary antenna element. For numerical calculations, the method of finite differences in the time domain was used. Special attention is paid to recommendations on the use of manual settings for partitioning the lattice model into cells. In the third part of the work, the results of measuring the elements of the scattering matrix of the manufactured sample of antenna arrays are presented.

2. DESCRIPTION OF THE LAYOUT OF ELEMENTS AND THEIR CHARACTERISTICS

Modeling of antenna arrays was carried out using microstrip antenna elements. They consist of a silver emitting element, a ceramic substrate and an excitation pin. An integral part of such a microstrip antenna is a metal “screen” with a standard size of 70x70 mm, which is not supplied by the manufacturer along with these antennas.

Note that circular polarization of the radiation field of a microstrip antenna can be achieved in the case when two orthogonal modes with a phase shift of 90° are excited in the formed antenna resonator. In our case, to obtain a field polarization close to circular, asymmetry is used, namely, a cut of two edges of a square element. This also makes it possible to separate the resonant frequencies of the two excited modes. The single-point excitation system used is quite simple to implement, but it is inferior to the two-point excitation system in terms of the operating frequency band [8-12] and, often, the value of the maximum achievable coefficient of ellipticity.

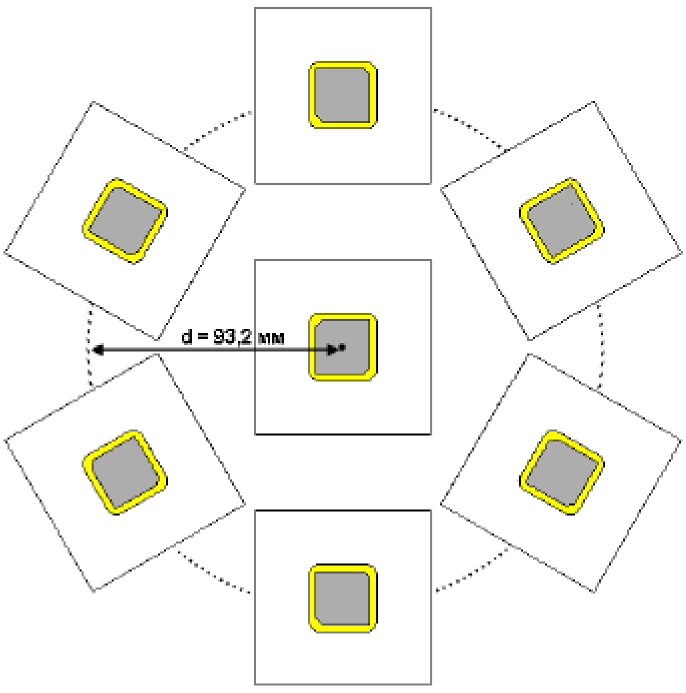


Figure 1. Layout of elements in the developed antenna arrays.

Neighboring elements of the developed antenna arrays should be at a distance of half a wavelength from each other, which for the center frequency of the L1 range is d = 93,2 mm. In the center of the antenna arrays is its central element, the remaining six antenna elements are located at the vertices of a regular hexagon. On Figure 1 schematically shows the arrangement of the elements of such a lattice. Due to the need to locate the centers of six peripheral antenna elements on a circle of radius d relative to the center of the central element, the dimensions of the sides of square metal screens are chosen to be 65 mm (instead of the standard 70 mm according to the documentation, at which the edges of adjacent screens will intersect), as a result of which, as computer simulation showed that the resonant frequencies of one solitary antenna element are shifted by several megahertz towards higher frequencies.

3. MODELING A SINGLE ISOLATED ELEMENT

To check the adequacy of numerical calculations and determine of the required “quality” of the mesh of the model partition, we simulated one solitary microstrip antenna in the CST Microwave Studio environment [13-15] using the finite integration in the time domain [16, 17], which is nothing more than the more widely known method of finite difference time domain [18-21].

The constructed model is shown in Figure 2. Dimensions of the metal screen are 65x65x5 mm, ceramic substrate - 25x25x4 mm. For excitation, an air 50-Ohm coaxial line was used, located inside the screen. As the material of the radiating element and the excitation pin were set to silver, the screen material was aluminum, the parameters of the ceramic substrate were set as follows: dielectric constant ε=20,5 (average value according to the specification for the antenna) and dielectric loss tangent tanδ=0,002.

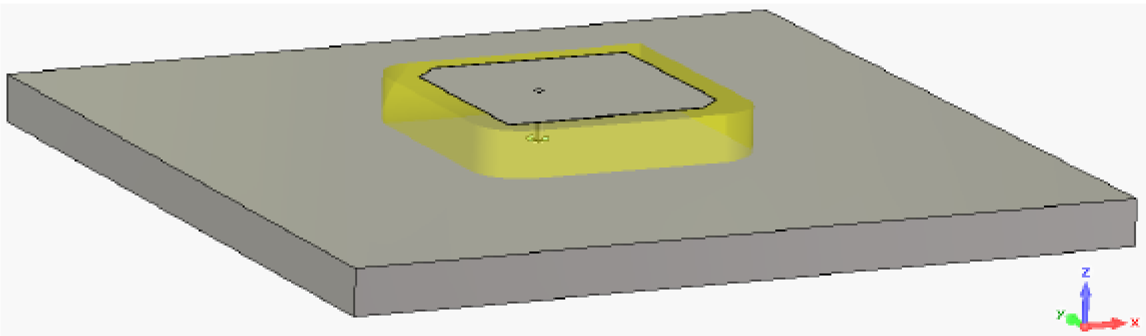
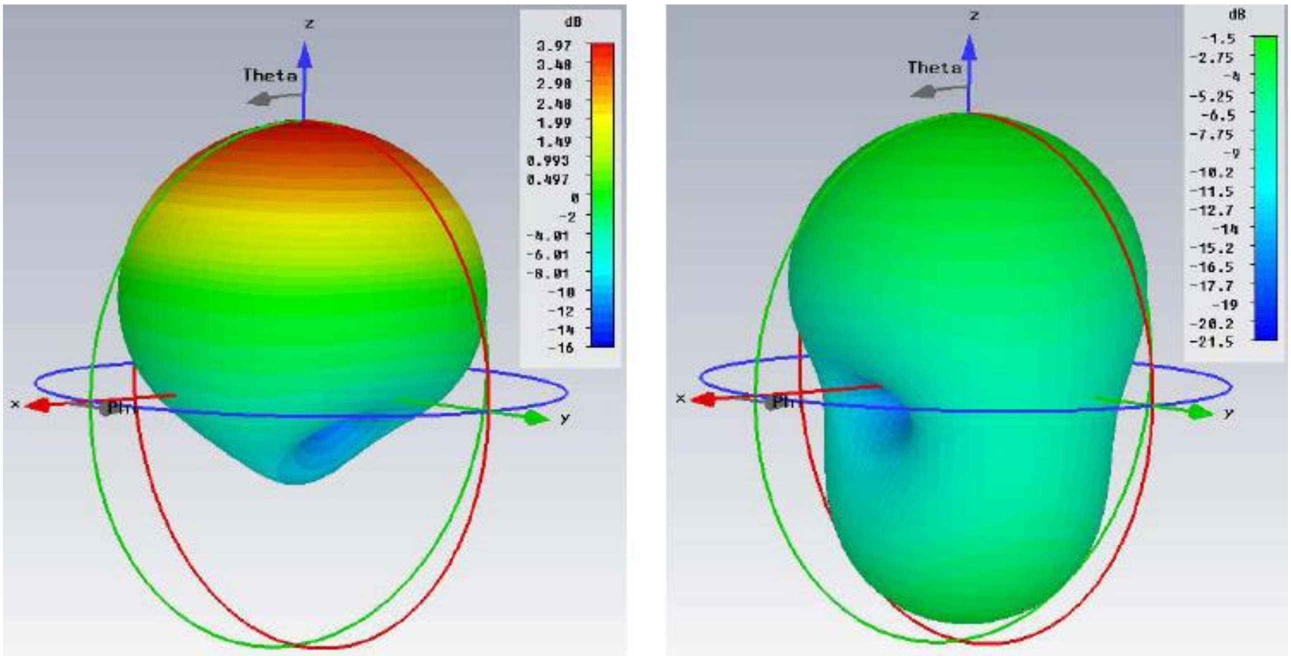


Figure 2. Microstrip antenna model

On Figure 3 shows the calculated right-hand circular polarization and cross-polarization (left-hand circular polarization) radiation patterns of the antenna elements. The antenna gain is about 4 dB. The calculated frequency characteristics of the reflection coefficient have two characteristic minima and, taking into account the possible spread of the parameters of the antenna elements, are in good agreement with the measurement data (for a model with a metal screen with dimensions 70x70) given in the documentation for the antenna elements.



a) b)

Figure 3. Spatial radiation patterns of antenna elements at a frequency of 1,6 GHz: right circular polarization (a) and cross-polarization (b) components

4. FEATURES OF ANTENNA ARRAY MODELING

In order to reduce the possible effect of multipath (interference from metal surfaces), it was decided to place the elements of the antenna system on a common supporting dielectric substrate with no metallization on any of its sides.

One of the requirements for the designed antenna arrays was to minimize the slope of the phase-frequency characteristics arg(Sij) of the scattering matrix elements corresponding to neighboring array elements in the operating frequency band. Or otherwise, minimizing the group delay time of the interconnection coefficients Sij. The preliminary numerical studies of the antenna arrays design under consideration showed that the slope angle of the phase-frequency characteristics increases with increasing permittivity of the reference dielectric. As a result, fluoroplast was chosen as the material of the latter, the dielectric constant of which is low (ε=2…2,1). The sheet thickness was 5 mm.

To obtain the results of calculating the matrix of S-parameters, which are closer to the real antenna arrays, the excitation circuit of the antenna elements was slightly modified relative to that used above for one solitary element. Thus, the pin that excites the antenna elements, which is the central residential supply coaxial line in the cross section of the screen, changes its stepwise radius at the border of the aluminum screen and the ceramic substrate. On Figure 4 shows the power supply circuit of the antenna elements used in the manufacture of antenna arrays, as well as a section of the corresponding area of the electrodynamic model. The air-filled coaxial line still has a characteristic impedance of 50 Ohm. Note that a more significant complication of the excitation circuit was not carried out due to the lack of information about the internal structure of the used TNC connectors. As we show below, this, however, did not prevent us from obtaining a fairly good agreement between the results of calculation and measurements of the matrix of S-parameters.

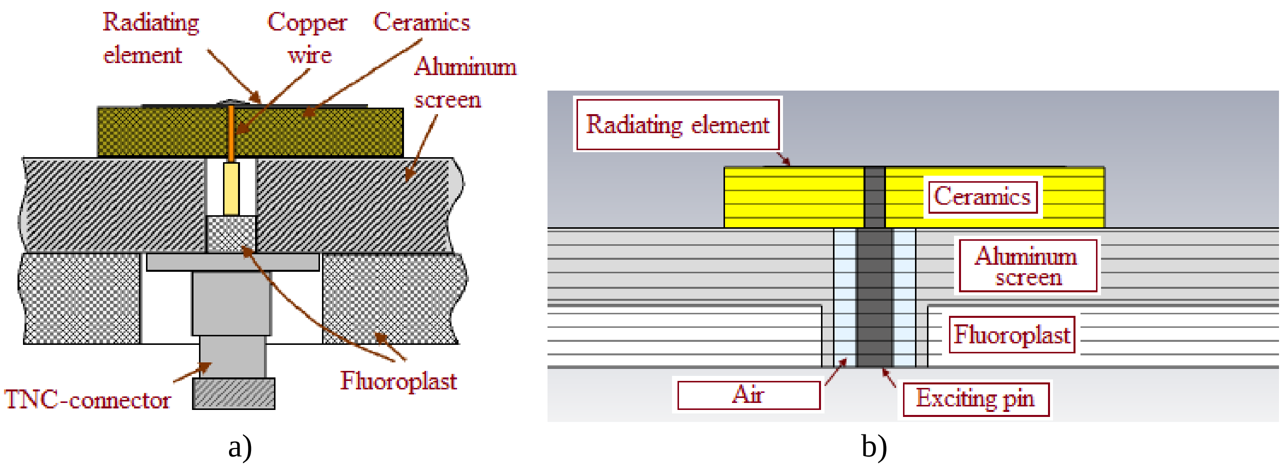


Figure 4. The power supply circuit of antenna elements during manufacture (a) and the power supply model used for modeling (b)

The mutual arrangement of elements in the composition of antenna arrays also has a certain effect on the frequency characteristics arg(Sij) of interest to us. As a result of modeling, from several possible options for the location of peripheral antenna elements, the structure shown in Figure 5. This option is characterized by the maximum remoteness of the power points of the peripheral elements from the central antenna element and allows, among other things, to minimize the mutual connections |Sij| between antennas.

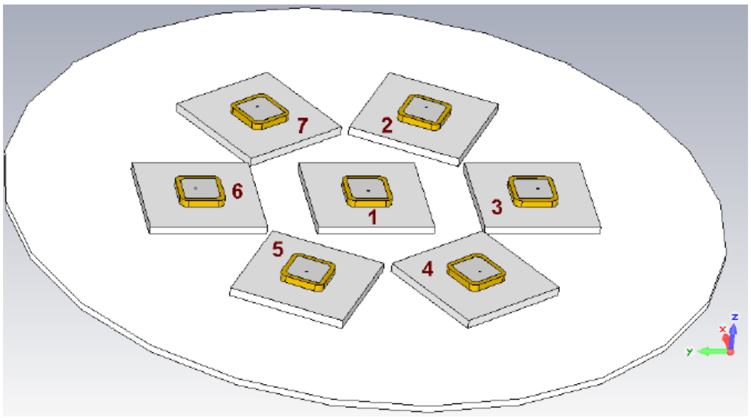
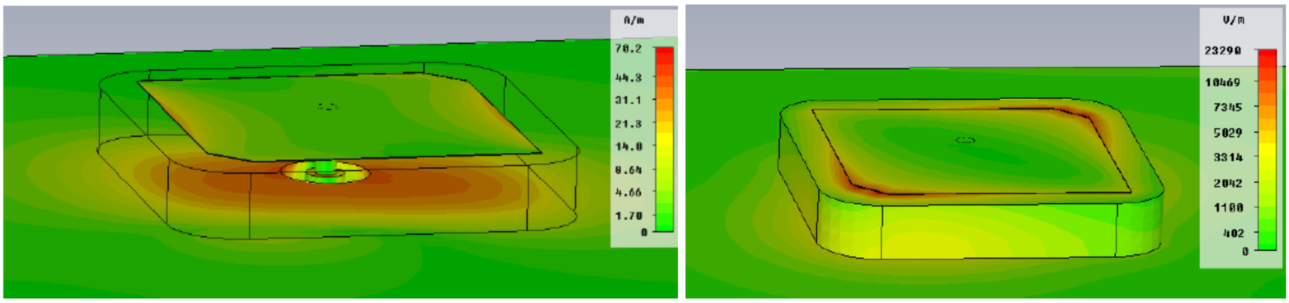


Figure 5. Model a in Microwave Studio with antenna element numbering used

Let us dwell on some issues related to the modeling process itself. When using the finite difference method in the time domain to calculate a multiport device (2N-terminal), it is necessary to carry out N calculations of the transient propagation of the input signal, one for each port. In our case, we have N=7. As a result, when using an adaptive algorithm for partitioning an electrodynamic model into cells, which involves several steps of the iterative procedure for compacting the mesh, the time spent on calculating the considered antenna array can be significant. To reduce the time required to calculate the lattice, the possibility of manually setting the model partitioning parameters was used.

The highest energy density of the electromagnetic field of the antenna elements is observed in the space between the radiating elements and the screen, as well as near the edges of the radiating element (Figure 6). Therefore, it is precisely near these areas that it is first of all necessary to condense the mesh of the model partition with respect to some rough initial partition. In addition, to obtain a more accurate result of calculating the matrix of S-parameters, it is also necessary to densify the grid inside the coaxial power line. On Figure 7 shows the partition mesh used for the entire model in the lattice plane. The total number of partition elements - rectangular parallelepipeds - was more than 1,2 million. A preliminary check of the “quality” of the resulting grid can be carried out using the example of calculating one solitary antenna element.



a) b)

Figure 6. Calculated distributions of surface currents (a) and electric field vector (b) averaged over a period for one solitary antenna element when a power of 1 Wt is applied to its input

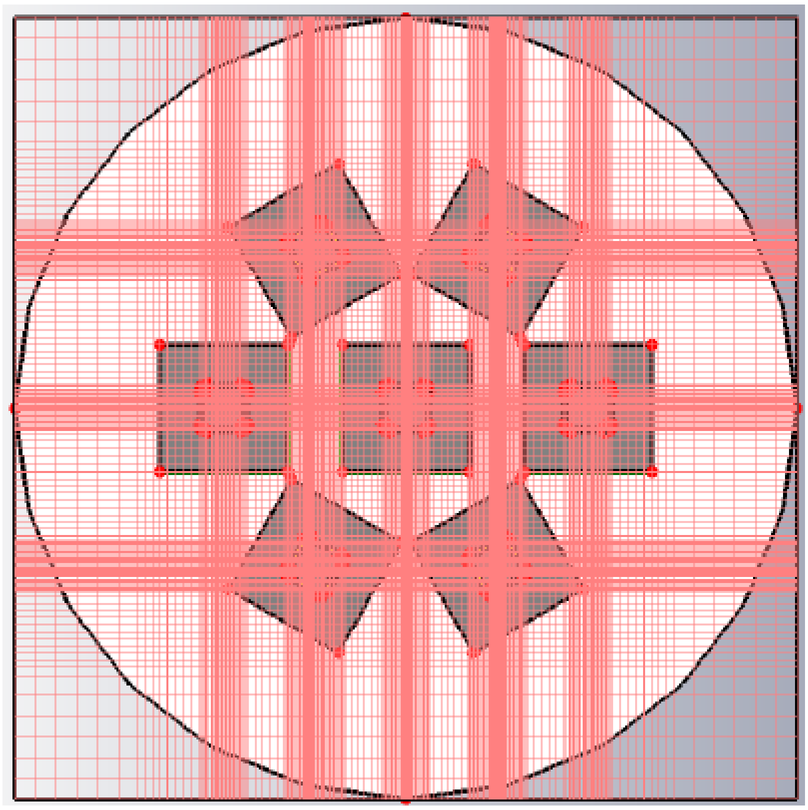


Figure 7. Cell division of the antenna array model

We also note the following feature of the numerical calculation method used. The disadvantage of the classical finite difference method in the time domain in three-dimensional space using Cartesian orthogonal grids (Figure 8, a) is the lack of “flexibility” when it is required to discretize complex curved structures. As a result, the real structure along the curved boundaries is approximated by orthogonal elements of rectangular parallelepipeds, and to improve the accuracy of the calculation, it may be necessary to make the mesh step along these boundaries very small. However, the presence in the mesh of the partition element with excessively small dimensions compared to the wavelength will inevitably lead to an increase in the calculation time, since to maintain the stability of calculations, it will be necessary to reduce the calculation step of the time process [22-24]. Moreover, the numerical complexity of the problem also increases due to the growth in the number of partition elements themselves.

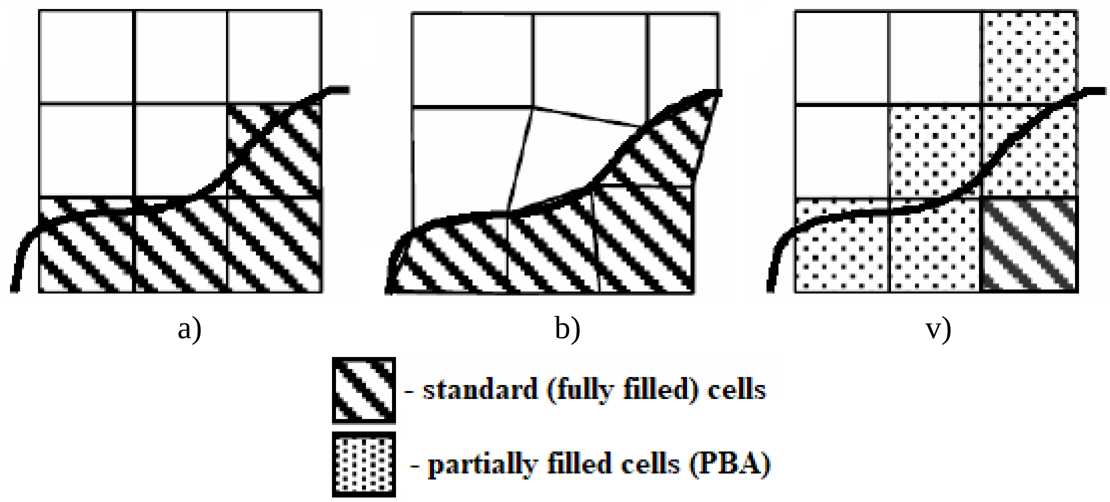


Figure 8. Grid approximation of curved boundaries in the finite difference method in the time domain: standard (a), using a non-orthogonal grid (b) and PBA (v)

The most general approach to taking into account curved boundaries is to using generalized conformal non-orthogonal grids (Figure 8, b). But the use of a non-orthogonal algorithm is sometimes limited by the increase in the numerical complexity of the problem and the need to create a tight-fitting boundary of a structured non-orthogonal mesh.

As a more efficient approach, the technique of ideal boundary approximation was proposed [10]. With this approach, there is no need to match the orthogonal computational grid with rounded boundaries (Figure 9, v). Instead, additional information about the contents of the cells in the space is taken into account, resulting in a second-order accurate algorithm for free-form boundaries. When calculating the considered antenna array in the Microwave Studio program, the option of using the technique of ideal approximation of the PBA boundary was forcibly set, which made it possible to fairly accurately take into account the presence in the array model of geometry elements whose faces are curved or do not coincide with the directions of the axes of the Cartesian coordinate system, and also take into account the finite thickness of the metal layer of the radiating elements.

Thus, when setting adequate partitioning parameters, taking into account the features of the structure of the electromagnetic field in the device and the features of the numerical finite difference method itself in the time domain, it is possible to reduce the time for analyzing the model of a particular device compared to the case of using adaptive mesh compaction while maintaining a comparable level of calculation accuracy. In the Microwave Studio environment, you can use a similar design approach when solving problems using the finite integration method in the frequency domain, which also uses an orthogonal mesh. This approach seems to be especially effective at the stage of optimizing the device model.

The experience of modeling microstrip antennas with circular polarization shows that such a calculated antenna characteristic as the ellipticity factor is often more sensitive to the accuracy of the partition grid compared to the matrix of S-parameters and radiation patterns. Therefore, in order to be completely confident in the accuracy of the results obtained, the final (optimized) device model should still be calculated using a finer mesh, the parameters of which are set manually, or an automatic adaptive meshing algorithm.

5. SIMULATION RESULTS

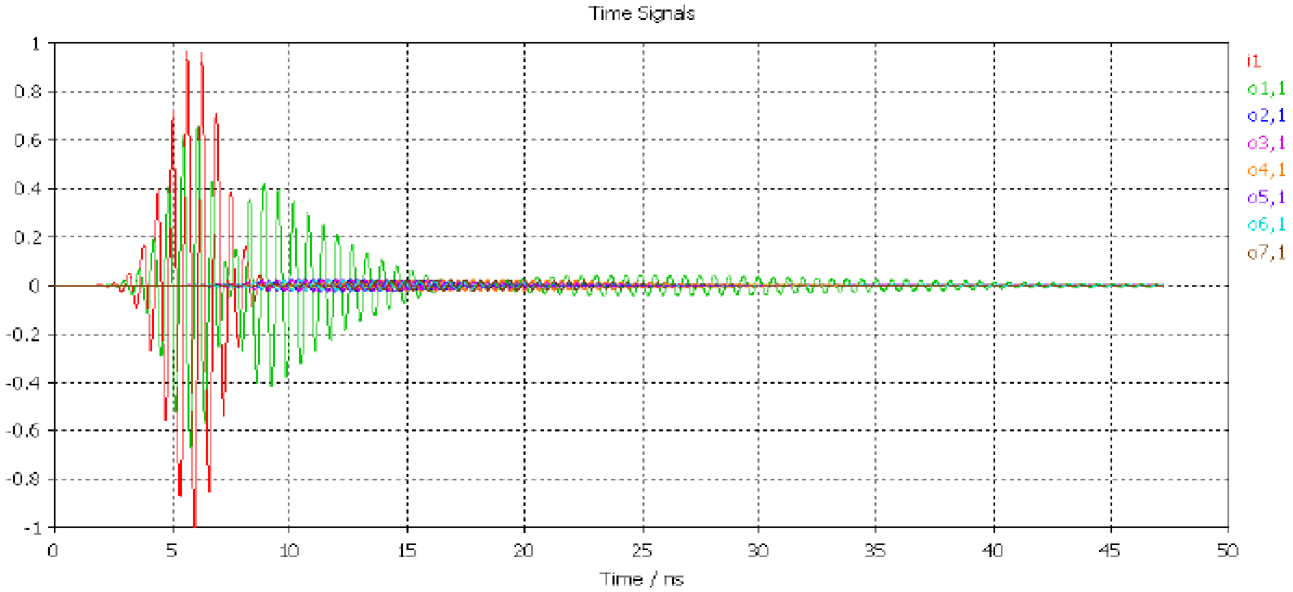


Figure 9. The signal (i1) applied to the input of the central element and the signals reflected from the inputs of all antenna elements

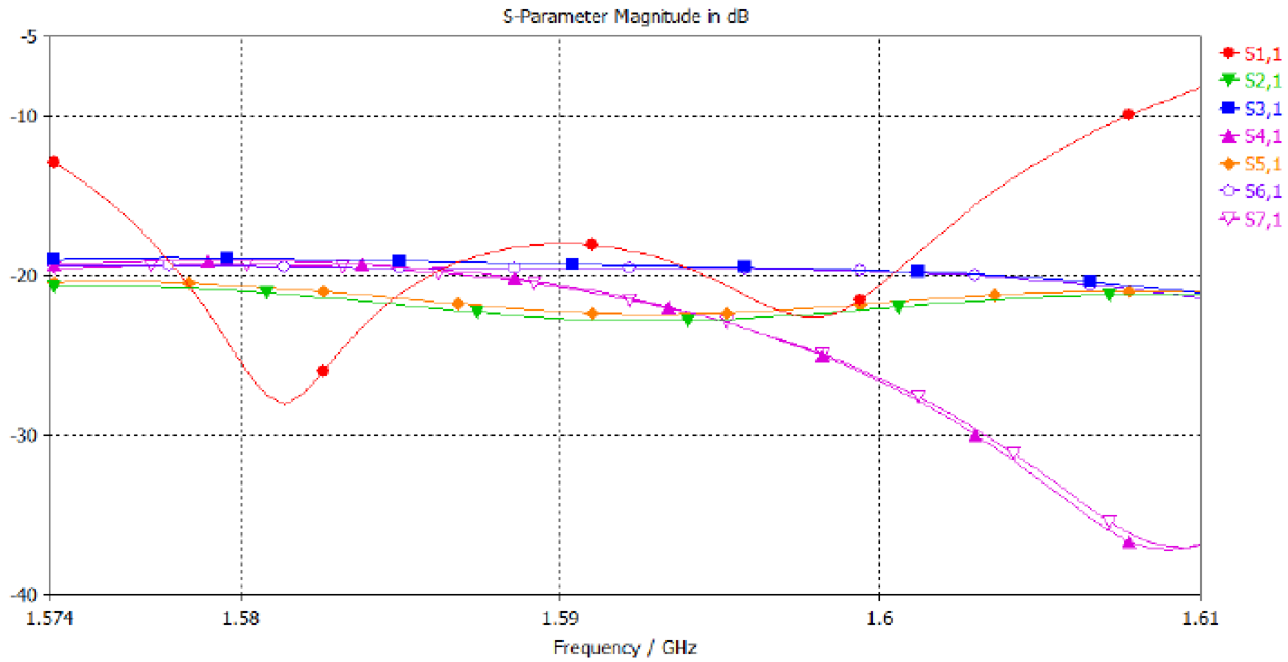


Figure 10. Calculated modules of the elements of the 1st row of the matrix of S-parameters.

Consider the results of the electrodynamic modeling. On Figure 9 shows the calculated time dependence of the transient when the first port of the antenna array is excited. Figures 10 and 11 show the calculated frequency dependences of the modules and arguments of the elements of the first row of the lattice S-parameter matrix in the operating frequency range. Note that, in order to reduce the time of analysis of the array model by the finite difference method in the time domain, the calculation was carried out in a frequency band several times wider than the width of the operating band L1 (1574-1610 MHz).

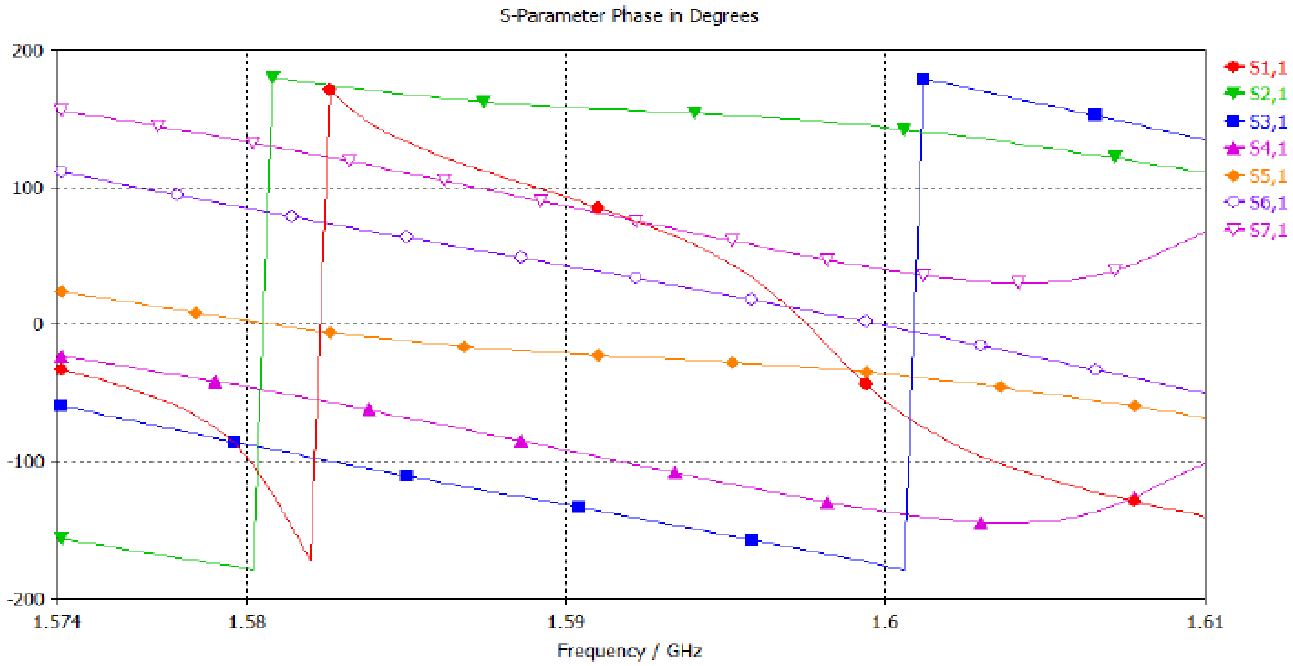


Figure 11. Calculated arguments of the elements of the 1st row of the matrix of S-parameters

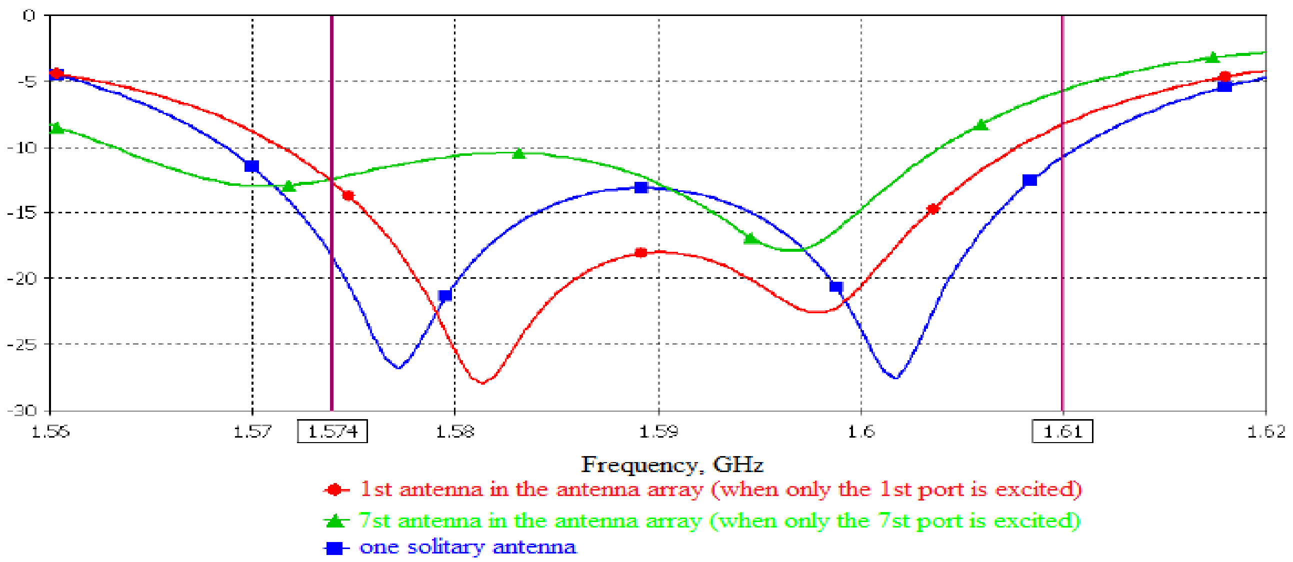


Figure 12. The reflection coefficients of one solitary antenna element and two separate antenna elements in the antenna array (in dB)

Let us compare the calculated characteristics of the reflection coefficients and radiation fields of one solitary antenna element and two antenna elements in the antenna array. On Figure 12 shows the frequency dependences of the reflection coefficients. A comparison of the graphs shows that the bandwidth of the central antenna element in terms of the modulus of the reflection coefficient - 10 dB is narrower compared to the bandwidth of the solitary antenna element. The frequency band of the peripheral element is comparable to that of the solitary element, but it is shifted to lower frequencies and is characterized by “floating” of the first minimum of the reflection coefficient.

The graphs shown in Figures 13 and 14 show the modification of the radiation patterns and the final element when moving from a single antenna element to elements in the array. It can be seen that in the two presented planes, the radiation patterns of the central element differ from the radiation patterns of a solitary antenna element insignificantly, at the same time, the radiation patterns of the peripheral element of the lattice is asymmetric and “jagged”. Finite element graphs differ to a greater extent. We note a significant difference in the finite elements in two orthogonal planes for the central antenna element: in directions close to the sliding angles $\theta=\pm90°$, in the plane passing through the feed point, the finite element is close to 1, while in the perpendicular plane of the finite element decreases to the level of 0,2.

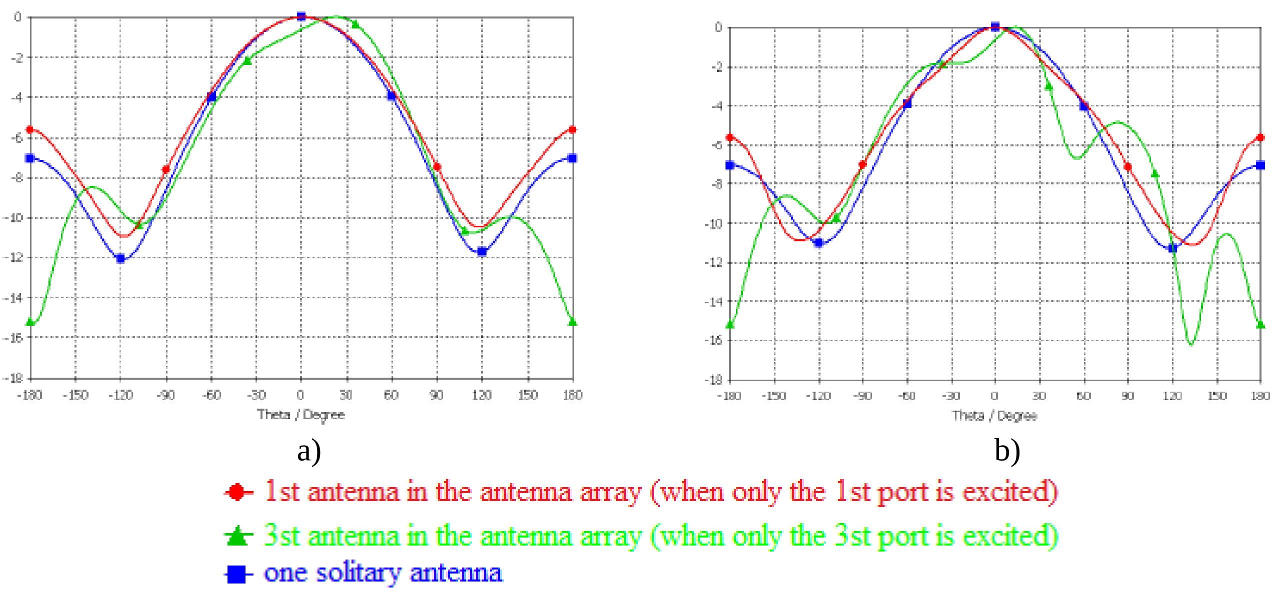


Figure 13. Normalized radiation patterns of one solitary antenna element and two separate antenna elements as part of an antenna array in the plane of the feed point (a) and orthogonal to it plane (b) on a logarithmic scale

Thus, the radiation patterns of the elements in the considered antenna array differ from each other. Knowledge of the characteristics of the radiation field of all elements can be taken as the basis for calculating the complex vector of weight coefficients for the formation of the required radiation patterns of the entire array, for example, for the synthesis dip in the direction of arrival of interference signals in the presence of a priori information about the angular coordinates of targets and interference.

In cases where the direction of interference arrival is unknown, approaches to constructing adaptive algorithms are widely used, which are based on the element-by-element principle of searching for the optimal vector of weight coefficients according to the criteria for minimizing the signal-to-noise ratio or other target functional. The disadvantages of such methods include the minimal use of a priori information about the structure of the antenna array, as well as a sharp increase in the computational complexity of the algorithms with an increase in the number of antenna elements.

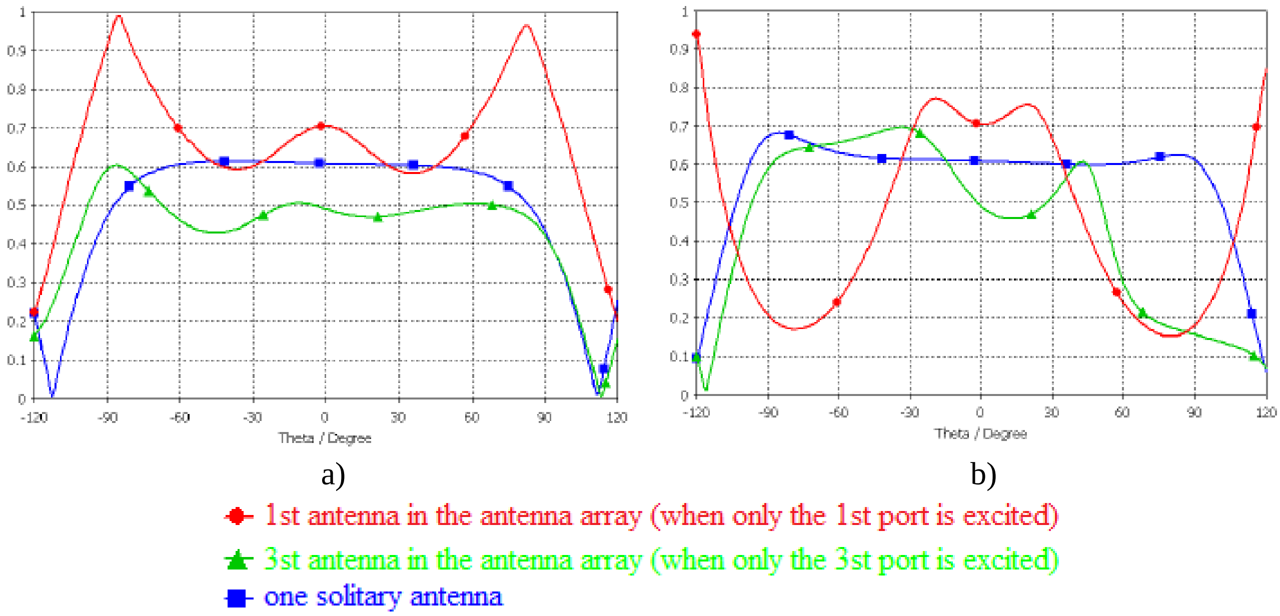


Figure 14. The finite element of one solitary antenna element and two separate antenna elements as part of an antenna array in the plane of the feed point location (a) and the plane orthogonal to it (b)

The so-called “group” adaptation method [25], the essence of which consists in successive scanning of dips in predetermined directions of directional diagrams (for example, in the direction of side lobes) using the method of aperture orthogonal polynomials [26], by means of which it is possible to synthesize the required distribution the vector of weight coefficients at once on the entire opening of the antenna array. In this case, it is important to know the radiation patterns of each array element. However, the relevance of such an approach for the case of an antenna array with a small number of elements N (in our case N=7) is beyond dispute.

6. FABRICATED ANTENNA ARRAY. COMPARISON OF MEASUREMENTS AND NUMERICAL CALCULATIONS

On Figure 15 shows a photograph of an antenna array made in accordance with the design features noted above. Due to lack at the time of the measurements of the technical base necessary to determine the characteristics of the radiation field of the antenna array in the far zone, the tests were limited to measuring the elements of the matrix of S-parameters. The corresponding measurements were carried out using a vector network analyzer, while the antenna array itself was placed in an anechoic chamber.

Below are the results of measurements of S-parameters: in Figure 16 - frequency dependences of the modules of several diagonal elements of the scattering matrix (in dB), in Figures 17 and 18 - frequency responses of modules (in dB) and arguments of S-parameters (in degrees) characterizing mutual relations between antenna array elements. These dependencies allow us to conclude that in the range of operating frequencies, the levels of mutual connections (expressed by the modules of S-parameters) are less than minus 17 dB. The corresponding differences in the levels of the phase-frequency characteristics at the boundaries of the range L1 are on average about 180 degrees (Figure 18), which corresponds to a linear relationship with a slope of 5 degrees per megahertz.

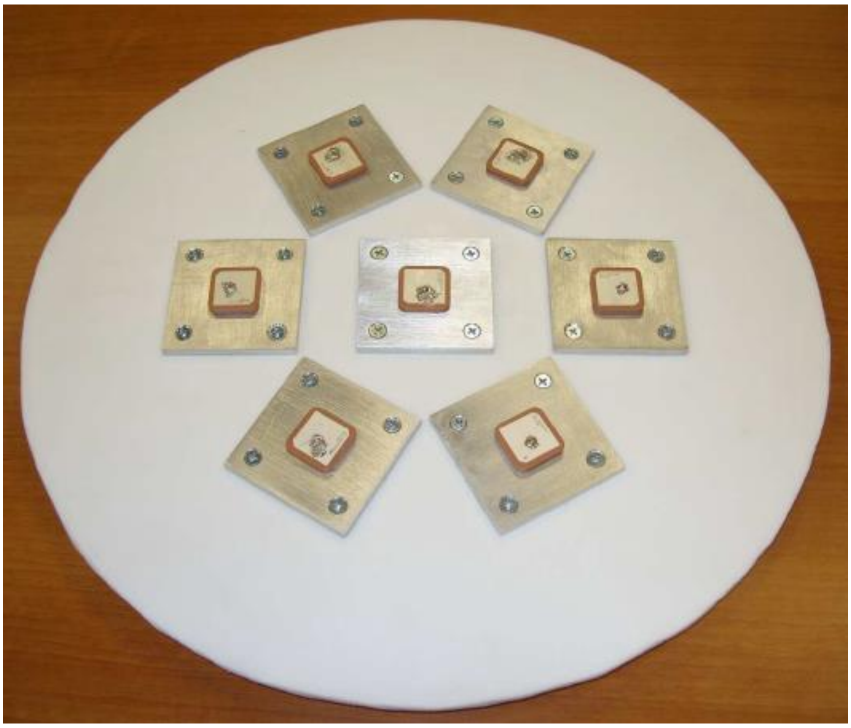


Figure 15. Photo of the manufactured antenna array

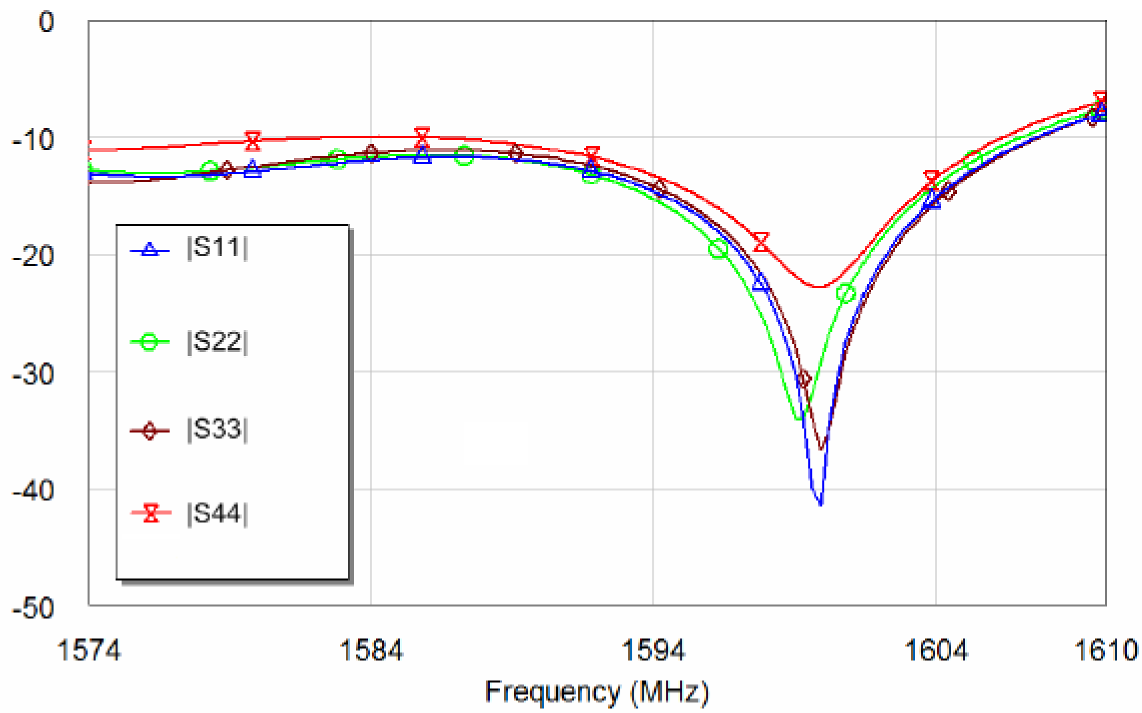


Figure 16. Measured moduli of the diagonal elements of the matrix of S-parameters

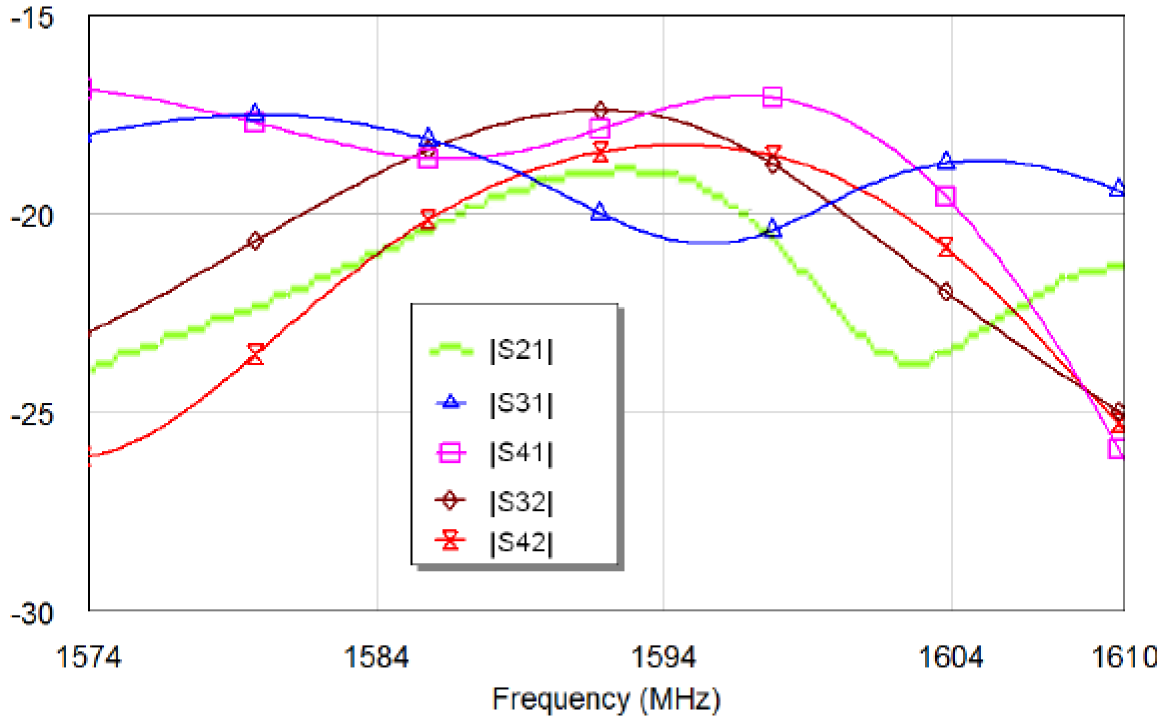


Figure 17. Measured modules of coupling coefficients between antenna elements

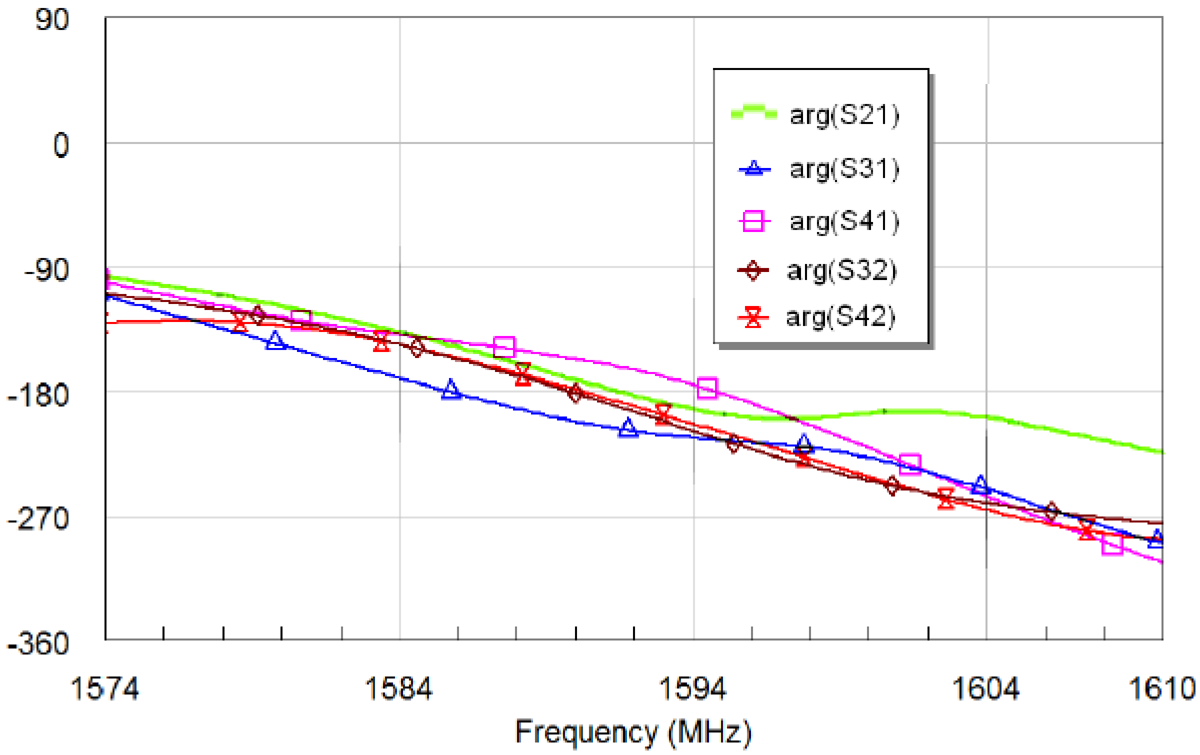


Figure 18. Measured arguments of the coupling coefficients between antenna elements

Let us compare the results obtained with modeling, and measurements. On Figures 19 and 20 show the corresponding dependences of the modules and arguments of the S-parameters; in this case, the simulation results are displayed as solid curves, and the measurement results are displayed as hollow symbols. Note that in order to adequately measure/calculate the levels of the arguments of the S-parameters, it is necessary to count the phases relative to the position points of the phase centers (radiation centers) of the antenna elements (which is not taken into account in the simulation results, shown in Figure 11).

Due to the spacing of neighboring antenna elements by half the wavelength corresponding to the center frequency f_0 = 1592 MHz of the L1 band, at the frequency f_0 one should expect a phase difference of the S-parameters corresponding to neighboring elements of about 180 degrees. Note that this was taken into account when processing the measurement results shown in Figure 18, where for a visual comparison of the slope of the graphs, the curve corresponding to the argument S_{42} was similarly shifted. On the graphs of Figure 20, the noted fact was also taken into account for the simulation results, which allows an adequate comparison of the calculations and measurements of the arguments of the S-parameters.

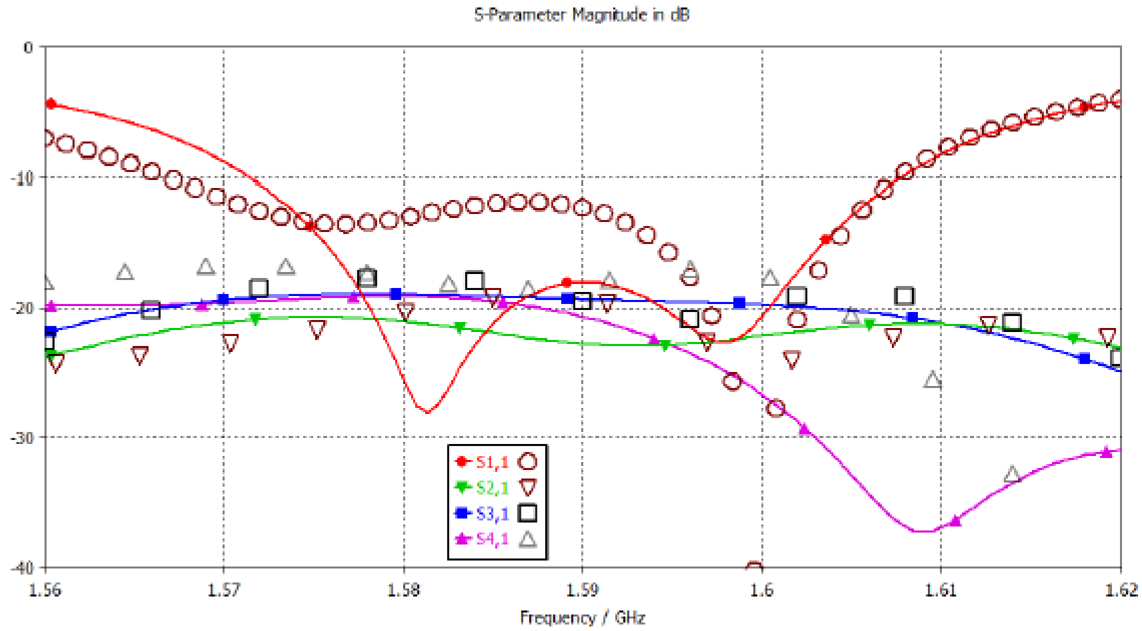


Figure 19. Comparison of S-parameter modules: solid curves are numerical calculations, hollow symbols are measurements

Sufficiently significant differences are observed between the curves corresponding to the modules of the coefficient S_{11}, as well as the modules and arguments of the coefficient S_{41}. However, the reasons for the occurrence of these differences include errors in the manufacture of the antenna array, a possible spread in the parameters of the used ceramic microstrip antennas. All this should have a greater effect on the diagonal elements of the S-matrix, which characterize the degree of matching of the antenna elements with the power line. Thus, the presented results of calculations and measurements corresponding to the parameters S_{21} and S_{31} are in good agreement with each other. Not very good correspondence in the dependencies of the modulus and argument S_{41}, apparently, is due to insufficiently high accuracy manufacturing of the 4th antenna element, which also affected the deterioration of the parameter $|S_{44}|$ (Figure 16).

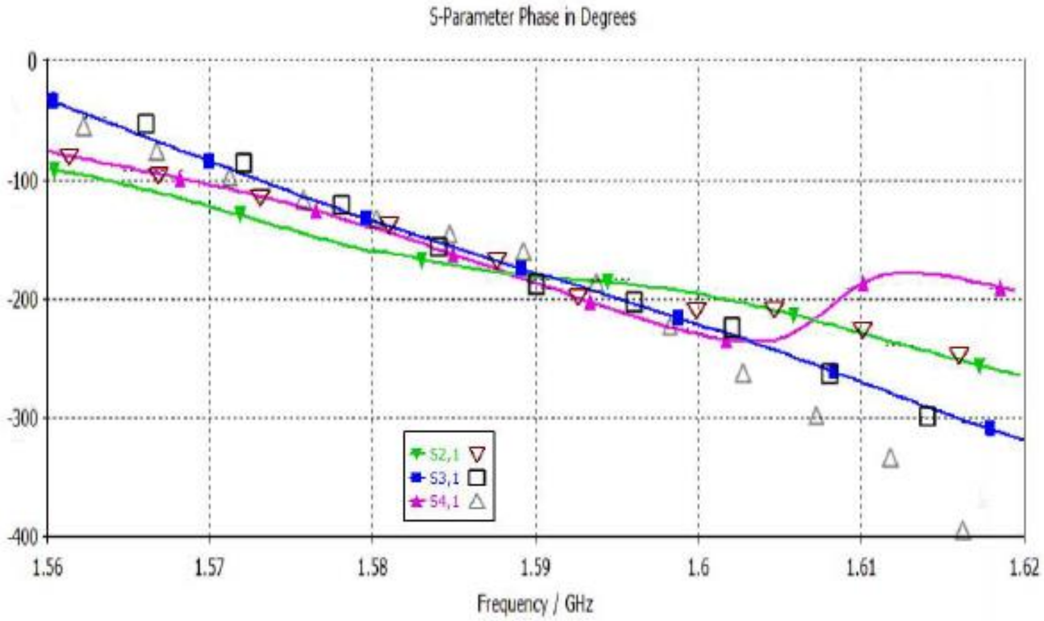


Figure 20. Matching S-parameter arguments: solid curves are numerical calculations, hollow symbols are measurements

7. CONCLUSIONS AND RECOMMENDATION

The process of modeling a seven-element antenna array of the range 1574-1610 MHz, which can be used in receivers of GPS navigation systems with adaptive noise suppression algorithms, is considered. The design features of the manufactured sample of the antenna array are noted. Selected the material of the common dielectric base and the mutual position of the antenna elements, which make it possible to minimize the slope of the frequency dependences of the arguments arg(S_{ij}) of the scattering matrix elements characterizing the mutual relations between neighboring elements. The difference between the characteristics of the radiation field in the far zone and the coefficients of the scattering matrix for antennas in the composition of an antenna array and one solitary antenna element is noted. Numerical calculations were carried out by the finite difference method in the time domain. Special attention is paid to the process of manually partitioning the antenna array model into cells, and the characteristic features of the numerical finite difference method itself in the time domain are noted. The results of numerical calculations of the elements of the matrix of S-parameters are in good agreement with the measurement results.

ACKNOWLEDGEMENT

The authors would like to thank the editor and anonymous reviewers for constructive, valuable suggestions and comments on the work.

REFERENCES

[1] Lina, D.; Xueming, L.; Dong, M.; Leiran, W.; Guoxi, W.: Experimental observation of dissipative soliton resonance in an anomalous-dispersion fiber laser. Optics Express, **20**(1), 2012, 265-270.

[2] Jun, L.; Yu, C.; Pinghua, T.; Changwen, X.; Chujun, Z.; Han, Z.; Shuangchun, W.: Generation and evolution of mode-locked noise-like square-wave pulses in a large-anomalous-dispersion Er-doped ring fiber laser. Optics Express, **23**(5), 2015, 6418-6427.

[3] Shestopalov, Y.V.: Complex waves in a dielectric waveguide. Wave Motion, **82**(2018), 16-19.

[4] Shestopalov, Y.V.; Kuzmina, E.A.: On a rigorous proof of the existence of complex waves in a dielectric waveguide of circular cross section. Progress In Electromagnetics Research, **82**(2018), 137-164.

[5] Mazur, M.; Mazur, J.: Operation of the Phase Shifter Using Complex Waves of the Circular Waveguide With Periodical Ferrite-Dielectric Filling. Journal of Electromagnetic Waves and Applications, **25**(7), 2011, 935-947.

[6] Smirnov, Y.G.; Valovik, D.V.: Guided electromagnetic waves propagating in a plane dielectric waveguide with nonlinear permittivity. Phys. Rev. A 91, **91**(1), 2015, 345-354.

[7] Kusaykin, O.P.; Melezhik, P.N.; Poyedinchuk, A.E.; Provalov, S.A.; Seleznyov, D.G.: Surface and leaky waves of a planar dielectric waveguide with a diffraction grating. IET Microwaves, Antennas & Propagation, **10**(1), 2016, 61-67.

[8] Calignanoa, F.; Peverini, O.A.; Addamo, G.; Paonessa, F.; Manfredi, D.; Galati, M.; Salmi, A.; Atzeni, E.; Minetola, P.; Iuliano, L.: High-performance microwave waveguide devices produced by laser powder bed fusion process. Procedia CIRP, **79**(2019), 85-88.

[9] Caballero, E.D.; Esteban, H.; Belenguer, A.; Boria, V.: Efficient Analysis of Substrate Integrated Waveguide Devices Using Hybrid Mode Matching Between Cylindrical and Guided Modes. IEEE Transactions on Microwave Theory and Techniques, **60**(2), 2012, 232-243.

[10] Nair, D.; Webb, J.P.: Optimization of microwave devices using 3-D finite elements and the design sensitivity of the frequency response. IEEE Transactions on Magnetics, **39**(3), 2003, 1325-1328.

[11] Belenguer, A.; Esteban, H.; Boria, V.E.: Novel Empty Substrate Integrated Waveguide for High-Performance Microwave Integrated Circuits. IEEE Transactions on Microwave Theory and Techniques, **62**(4), 2014, 832-839.

[12] Fang, K.; Matheny, M.H.; Luan, X.; Painter, O.: Optical transduction and routing of microwave phonons in cavity-optomechanical circuits. Nature Photonics, **10**(2016), 489-496.

[13] Liu, W.; Zhang, Y.; Triki, H.; Mirzazadeh, M.; Ekici, M.; Zhou, Q.; Biswas, A.; Belic, M.: Interaction properties of solitonics in inhomogeneous optical fibers. Nonlinear Dynamics, **95**(2019), 557-563.

[14] Silveira, M.; Frizera, A.; Leal-Junior, A.; Ribeiro, D.; Marques, C.; Blanc, W.; Díaz, C.A.R.: Transmission–Reflection Analysis in high scattering optical fibers: A comparison with single-mode optical fiber. Optical Fiber Technology, **58**(2020), 123-131.

[15] Islamov, I.J.; Ismibayli, E.G.; Gaziyev, Y.G.; Ahmadova, S.R.; Abdullayev, R.Sh.: Modeling of the Electromagnetic Feld of a Rectangular Waveguide With Side Holes. Progress In Electromagnetics Research, **81**(2019), 127-132.

[16] Islamov, I.J.; Shukurov, N.M.; Abdullayev, R.Sh.; Hashimov, Kh. Kh.; Khalilov, A.I.: Diffraction of Electromagnetic Waves of Rectangular Waveguides With a Longitudinal. IEEE Conferences 2020 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), INSPEC Accession Number: 19806145.

[17] Khalilov, A.I.; Islamov, I.J.; Hunbataliyev, E.Z.; Shukurov, N.M.; Abdullayev, R.Sh.: Modeling Microwave Signals Transmitted Through a Rectangular Waveguide. IEEE Conferences 2020 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), INSPEC Accession Number: 19806152.

[18] Islamov, I.J.; Ismibayli, E.G.: Experimental Study of Characteristics of Microwave Devices Transition From Rectangular Waveguide to the Megaphone. IFAC-PapersOnLine, **51**(30), 2018, 477-479.

[19] Ismibayli, E.G.; Islamov, I.J.: New Approach to Definition of Potential of the Electric Field Created by Set Distribution in Space of Electric Charges. IFAC-PapersOnLine, **51**(30), 2018, 410-414.

[20] Islamov, I.J.; Ismibayli, E.G.; Hasanov, M.H.; Gaziyev, Y.G.; Abdullayev, R.Sh.: Electrodynamics Characteristics of the No Resonant System of Transverse Slits Located in the Wide Wall of a Rectangular Waveguide. Progress in Electromagnetics Research Letters, **8** (2018), 23-29.

[21] Islamov, I.J.; Ismibayli, E.G.; Hasanov, M.H.; Gaziyev, Y.G.; Ahmadova, S.R.; Abdullayev, R.Sh.: Calculation of the Electromagnetic Field of a Rectangular Waveguide with Chiral Medium. Progress In Electromagnetics Research, **84**(2019), 97-114.

[22] Islamov, I.J.; Hunbataliyev, E.Z.; Zulfugarli, A.E.: Numerical Simulation of Characteristics of Propagation of Symmetric Waves in Microwave Circular Shielded Waveguide With a Radially Inhomogeneous Dielectric Filling. Cambridge University Press: International Journal of Microwave and Wireless Technologies, **9**, 2021, 1-7.

[23] Islamov, I.J.; Hasanov, M.H.; Abbasov, M.H.: Simulation of Electrodynamic Processes in a Cylindrical-Rectangular Microwave Waveguide Systems Transmitting Information. 11th International Conference on Theory and Application of Soft Computing, Computing with Words, Perception and Artificial Intelligence, ICSCCW – 2021, 2021, 246-253.

[24] Alsuyuti, M.M.; Doha, E.H.; Ezz-Eldien, S.S.; Bayoumi, B.I.; Baleanu, D.: Modified Galerkin algorithm for solving multitype fractional differential equations. Mathematical methods in the Applied Sciences, **42**(5), 2019, 1389-1412.

[25] Duvigneau, R.: CAD-consistent adaptive refinement using a NURBS-based discontinuous Galerkin method. International Journal for Numerical Methods in Fluids, **92**(9), 2020, 1096-1117.

[26] Yusifbayli, N.A.; Nasibov V.; Guliyev H.B.; Aghaliyev N.: Assessment of penetration level of variable renewable generations on the flexibility of power system. Electroenergetics, Electrotechnics, Electromechanics + Control (EEEC), **11**(1), 2021, 31-44.

ABOUT THE AUTHORS

Islam Jamal oglu Islamov - Associate Professor of the Department of “Radio engineering and Telecommunication” of the Azerbaijan Technical University. He is author of over 270 scientific articles. Research interests: Digital signal processing; Microwave devices; Analysis and synthesis of radio engineering and telecommunication networks and systems.

Elmar Zulfugar oglu Hunbataliyev - Associate Professor of the Department of “Radio engineering and Telecommunication” of the Azerbaijan Technical University. He is author of over 45 scientific articles. Research interests: Digital signal processing; Microwave devices; Analysis and synthesis of radio engineering and telecommunication networks and systems.

RESEARCH OF RATIONAL ACTIVE AND REACTIVE POWER DISTRIBUTION ON DIFFERENT VOLTAGE POWER DISTRICT NETWORKS

[1]Ilyasov O.V., [2]Guliev H.B.
[1]OJSC "Azerenerji", Baku, Azerbaijan, ilyasov.osman@mail.ru
2Azerbaijan Technical University, Baku, Azerbaijan, huseyngulu@mail.ru

Abstract. Failure to take into account the inhomogeneity during the application of different voltage levels in the power grids of the energy system ultimately leads to irrational distribution of active and reactive powers. As a result, power transmission lines with low power transmission capacity are maximally loaded, and power transmission lines with high power transmission capacity are less or minimally loaded. Thus, in this case, the stability of the region of the considered system and the mode reliability decrease, and the probability of stability violation increases in post-accident modes.

For this purpose, the real energy region of the 220/110 kV power system was studied. In this case, since 110 kV lines are loaded by 80-90%, 220 kV lines by 20%, the justification of applying phase-changing transformers to equalize power distribution was considered. The obtained modeling results showed the effectiveness of the application of this type of transformers, which implement vectorial voltage regulation in the mentioned network region.

Key words: power system, energy district, active and reactive flow distribution, phase shift transformer, power losses, current profiles, normal, post-emergency and repair modes.

MÜXTƏLİF GƏRGİNLİKLƏRİN PAYLAŞMA ŞƏBƏKƏLƏRİ ÜZRƏ AKTİV VƏ REAKTİV GÜCÜN RASİL BAYLANISININ ÖDƏNİLMƏSİ.

[1]İlyasov O.V., [2]Quliyev H.B.
[1]"Azərenerji" ASC, Bakı, Azərbaycan, ilyasov.osman@mail.ru
[2]Azərbaycan Texniki Universiteti, Bakı, Azərbaycan, huseyngulu@mail.ru

Referat. Enerji sisteminin elektrik şəbəkələrində enerji verilişi zamanı müxtəlif gərginlik səviyyələrindən istifadə edərkən qeyri-bircinsliyin nəzərə alınmaması son nəticədə aktiv və reaktiv gücün qeyri-rasional paylanmasına gətirib çıxarır. Nəticədə, aşağı gücötürmə qabiliyyətli ötürücü xətlər maksimum, yüksək gücötürmə qabiliyyətli ötürücü xətlər isə az və ya minimal yüklənir. Belə ki, bu halda baxılan sistemin enerjirayonunun dayanıqlığı və rejim etibarlılığı azalır, qəzadansonrakı rejimlərdə dayanıqlığın pozulması ehtimalı artır.

Bunun üçün 220/110 kV-luk enerjisistemin real enerji rayonu tədqiq edilmişdir. Eyni zamanda, 110 kV-luq xətlər 80-90%, 220 kV-luq xətlər 20% yükləndiyindən güc paylanmasının bərabərləşdirilməsi üçün faza dəyişdirici transformatorlardan istifadənin əsaslandırılmasına baxılmışdır. Alınmış simulyasiya nəticələri şəbəkənin müəyyən edilmiş hissəsində gərginliyin vector tənzimlənməsini həyata keçirən bu tip transformatorlardan istifadənin səmərəliliyini göstərmişdir.

Açar sözlər: enerjisistem, enerji,rayonu aktiv və reaktiv güclər paylanması, faza dəyişdirici transformator, güc itkiləri, cərəyan profilləri, normal, qəzadan sonrakı və təmir rejimləri.

ИССЛЕДОВАНИЕ РАЦИОНАЛЬНОГО РАСПРЕДЕЛЕНИЯ АКТИВНОЙ И РЕАКТИВНОЙ МОЩНОСТИ В ПЕРЕДАЮЩИХ СЕТЯХ РАЗНОГО НАПРЯЖЕНИЯ

[1]Ильясов О.В., [2]Гулиев Г.Б.

[1]ОАО "Азерэнержи", Баку, Азербайджан, ilyasov.osman@mail.ru

[2]Азербайджанский технический университет, Баку, Азербайджан, huseyngulu@mail.ru

Аннотация. Не учет неоднородности при применении различных уровней напряжения в электрических сетях энергосистемы в конечном итоге приводит к нерациональному распределению активной и реактивной мощностей. В результате линии электропередачи с низкой пропускной способностью максимально загружены, а линии электропередачи с высокой пропускной способностью менее или минимально загружены. Таким образом, в этом случае снижается устойчивость области рассматриваемой системы и режимная надежность, а вероятность нарушения устойчивости в послеаварийных режимах возрастает.

Для этого исследовался реальный энергорайон энергосистемы 220/110 кВ. При этом, так как линии 110 кВ загружены на 80-90%, линии 220 кВ на 20%, рассмотрено обоснование применения фазоповоротных трансформаторов для выравнивания распределения мощности. Полученные результаты моделирования показали эффективность применения данного типа трансформаторов, реализующих векторное регулирование напряжения в указанном участке сети.

Ключевые слова: энергосистема, энергорайон, активное и реактивное потокораспределение, фазоповоротных трансформатор, потери мощности, профиль токов, нормальный, послеаварийный и ремонтный режимы.

INTRODUCTION

Optimizing the active and reactive power flows in the power grids of different voltage systems increases the reliability and stability of the system. Thus, it is possible to control the power distribution in adjacent networks by adjusting the reactive power flows in the system processing networks and, accordingly, the voltages at the nodes. Operational redistribution of electricity in the grid region becomes an important operational issue from the point of view of both mode optimization and power loss minimization.

Taking into account the above, various software tools and methods have been developed for the rational management of power distribution in the network region. So, from these methods, it is possible to show the breaking of the network from the weakest point [1-4]. However, this method is not justified, as in this case the reliability of the network decreases and consumers' poor supply of electricity is at risk.

Another way to eliminate uneven power distribution in district power grids is to change network parameters and provide a new power distribution configuration by applying FACTS devices [5-7]. The main essence of this approach is to reduce the inhomogeneity by adding longitudinal additional resistance to the power transmission line [8].

The reviewed or presented work consists of optimizing the power distribution by controlling the voltage phase angles at the ends of the lines due to the FACTS device in parallel between buses of different voltages in a closed heterogeneous network. As a result, active and reactive power flows are rationalized in the network, and in this case, power loss is also significantly reduced. An example of such a FACTS device is a phase shift transformer (PST) [9-15].

PST have been used in world practice since 1969. In 2009, for the first time in the history of the CIS, a 500/220 kV PST with a capacity of 400 MVA was installed at 500 kV Ulka SS in Kazakhstan. PST made it possible to regulate the phase shift in the range of 0-700 and the unit was designed and manufactured by the company "Zaparozhtransformator" [16].

In 2019, on April 18, the Volzhsky HPP of Russia put into operation PST with a voltage of 500/220 kV with a capacity of 195.26 MVA with the participation of JSC STC UES and JSC Institute Hydroproject. Evaluations of the financial indicators of the options excluding the generation limitations of the Volzhkaya HPP indicated that the use of PST in comparison with the installation of an additional 220 kV transmission line requires 2.5 times lower capital costs.

Taking into account the above, to eliminate the natural irrational flow distribution of active power in the Absheron 220/110 kV power region in the Azerenerji system, the question of installing a PST was raised, which should ensure the economic flow distribution of active power through the adjacent networks of the Shimal-1 and Shimal-2 power plants. It was justified to install the PST complex in normal, repair and post-emergency circuit-regime situations of this power district.

1. SCHEMATIC AND MATHEMATICAL APPARATUS EXPLAINING VOLTAGE PHASE ANGLE CONTROL IN NON-HOMOGENEOUS NETWORK REGION ON PST BASIS.

The angular phase between the voltage vectors at the beginning and end of the line is changed in order to redistribute the power in the electrical grid region. Thus, increasing the phase angle also increases the luminous flux. As a result, the load of the overloaded line decreases and the load of the underloaded high-voltage line increases. This angle can be changed only within a certain range on PST. Two types of regulation can be used here:

- module and phase adjustment of voltage at the end of the line;
- only the phase adjustment of the voltage vector (in other words, the angle between the voltage vectors is adjusted).

Figure 1 shows a typical circuit consisting of two lines. Here, the transmission of electricity from the source to the consumer is carried out with the help of PST with a closed network of different voltages. Consequently, the currents or powers will be distributed along the lines in proportion to their resistances as follows.

In this case, the currents I_1 and I_2 are determined [16]:

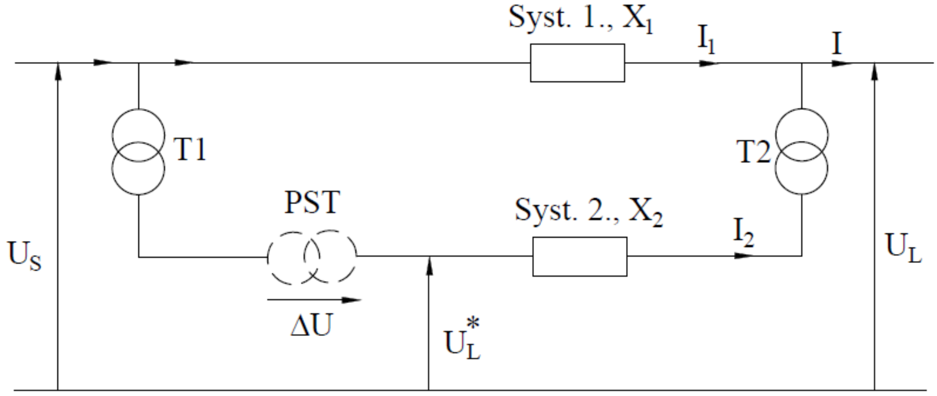


Figure 1. A typical electrical network with two lines connected in parallel

$$I_1 = \frac{X_2}{X_1 + X_2} \cdot I \qquad (1)$$

$$I_2 = \frac{X_1}{X_1 + X_2} \cdot I \qquad (2)$$

Since the power flow in line 2 (PP-2) is high, the voltage drop is also large, and additional voltage must be introduced to reduce it.

The power source can be connected to one of the parallel lines. Figure 2 shows the voltage vector diagram for different cases of PST connection.

This image is based on PP-2, which has a high resistance. The additional voltage introduced as a result of the compensation lowers the voltage drop across PP-2, thereby showing the difference in line loading.

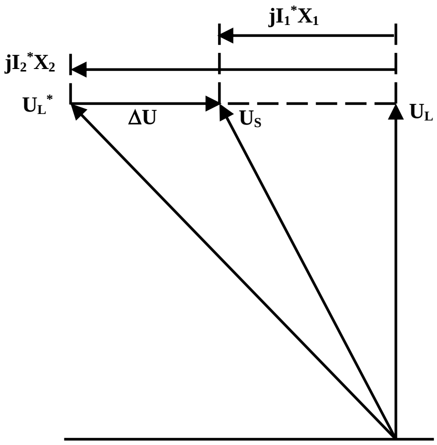


Figure 2. Vector voltage diagram when using PST (PTL 2 phase lead -U_L^* advances U_S

With the help of PST, the power flow between the two sources is controlled (Figure 3). Thus, by adjusting the phase angle, it is possible to control the power flow from PP-1 to PP-2.

$$U_S + \Delta U - I^* jX - U_L = 0 \qquad (3)$$

At $U_S = U_L = U$

$$\Delta U - I^* jX = 0 \qquad (4)$$

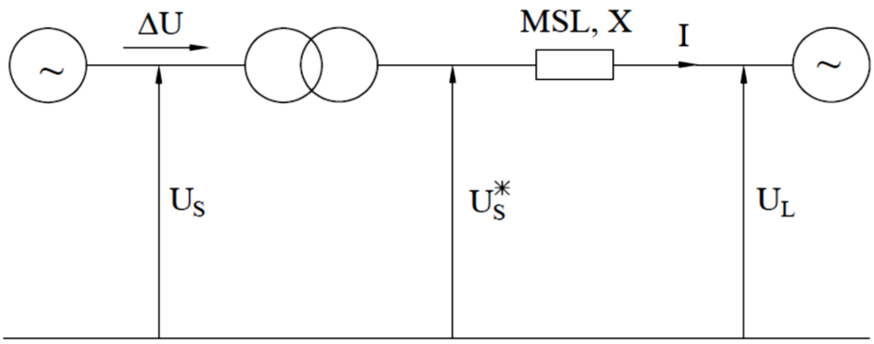


Figure 3. Intersystem communication

We consider aspects of the PST application as an innovative solution to the problem, which allows to exclude the forced restriction of the transmission load in the adjacent 220/110 kV electrical networks in repair and post-emergency circuit-regime situations of the Azerbaijani power system. Such a solution, due to the economical distribution of active power (and / or reactive power) between switchgears 220 and 110 kV, makes it possible to increase the throughput of electrical networks, transmission by all the power plants located at PP-1 and PP-2, of this power district, as well as the flexibility of managing the loading of 220-110 kV transmission lines.

In Figure 4 shows the equivalent circuits of a 220/110 kV network section and a vector diagram of voltages at the ends of the power transmission line, explaining the mechanism for the distribution of active power.

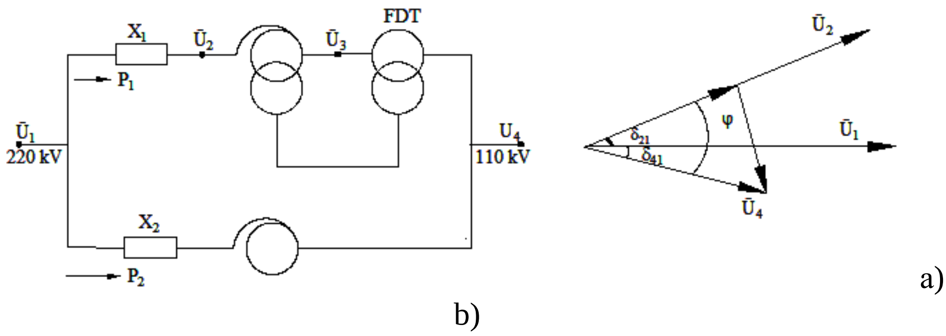


Figure 4. Equivalent circuit of the network section (a) and vector stress diagram (b)

In the absence of PST, when the power P_1 and P_2 is transmitted in the directions indicated in the figure, the voltage vector $\dot{U}_1$ is ahead of the voltage vectors $\dot{U}_2$ and $\dot{U}_3$, since the active power is directed from the leading vector to the lagging vector [7,12].

To increase and change the direction of the power P_1 transmitted towards the 220 kV switchgear through the AT autotransformer and reduce the power transmitted from the 110 kV switchgear bus to the adjacent 110 kV networks, it is necessary to ensure that the vector $\dot{U}_2$ is ahead of the system vector $\dot{U}_1$. This can be done by introducing an additional angle φ using the PST and observing the condition $|\varphi| > |\delta_{41}|$. For an arbitrary value of the angle φ, the active powers are expressed by the following formulas [4,15]:

$$P_1 = \frac{U_1 U_2}{X_\Sigma} \sin \delta_{21} = \frac{U_1 U_4}{X_{1TL} + X_{AT1} + X_{PST}} \sin(\delta_{41} - \varphi) \quad (1)$$

$$P_2 = \frac{U_1 U_4}{X_{2TL} + X_{AT2}} \sin \delta_{41} \quad (2)$$

where X_{TL}, X_{AT}, X_{PST} – inductive resistances of power lines, autotransformers and PST, respectively.

Thus, as can be seen from formulas (1) and (2), it is possible to choose such a range of the angle introduced by the PST in order to ensure an economical distribution of power in the 220/110 kV electrical networks of the power district of the system.

2. APPLICATION OF VOLTAGE PHASE ANGLE ADJUSTMENT TO PROVIDE FORCED POWER DISTRIBUTION FOR NON-PRIMARY POWER REGION

In Figure 5 shows the structure of the electrical connection for the non-homogeneous closed network region of the Azerenergy system. As can be seen from the picture, there are two power plants operating in the network district, namely Shimal-1 and Shimal-2. The power of Shimal-1 power station is 400 MW, the power of Shimal-2 power station is 400 MW, and the total power of the stations is 800 MW. An irregularity in the power distribution was noted when the Northern ES came into operation. The electricity generated from the station is transmitted to the system and consumers through 110 kV and 220 kV voltage transmission lines. 5 110 kV Shimal 1-5 lines, 2 double-circuit 220 kV Zabrat and Hovsani lines are operating here. But while 220 kV lines are usually loaded up to 30 percent, 110 kV lines are loaded up to the upper limit. In particular, Shimal-4 and Shimal-5 110 kV lines are in a worse condition from the point of view of operation. So, these lines normally have a load of 73 MW (390 A). In this case, the 220 kV Hovsani lines are loaded with a total of 103.8 MW (310 A) [15].

Therefore, in the post-accident mode or during planned shutdowns, one of the 110 kV northern lines 4 and 5 is suddenly loaded, and as a result, it is necessary to apply load limitation. This is not acceptable from the point of view of operation and economic point of view.

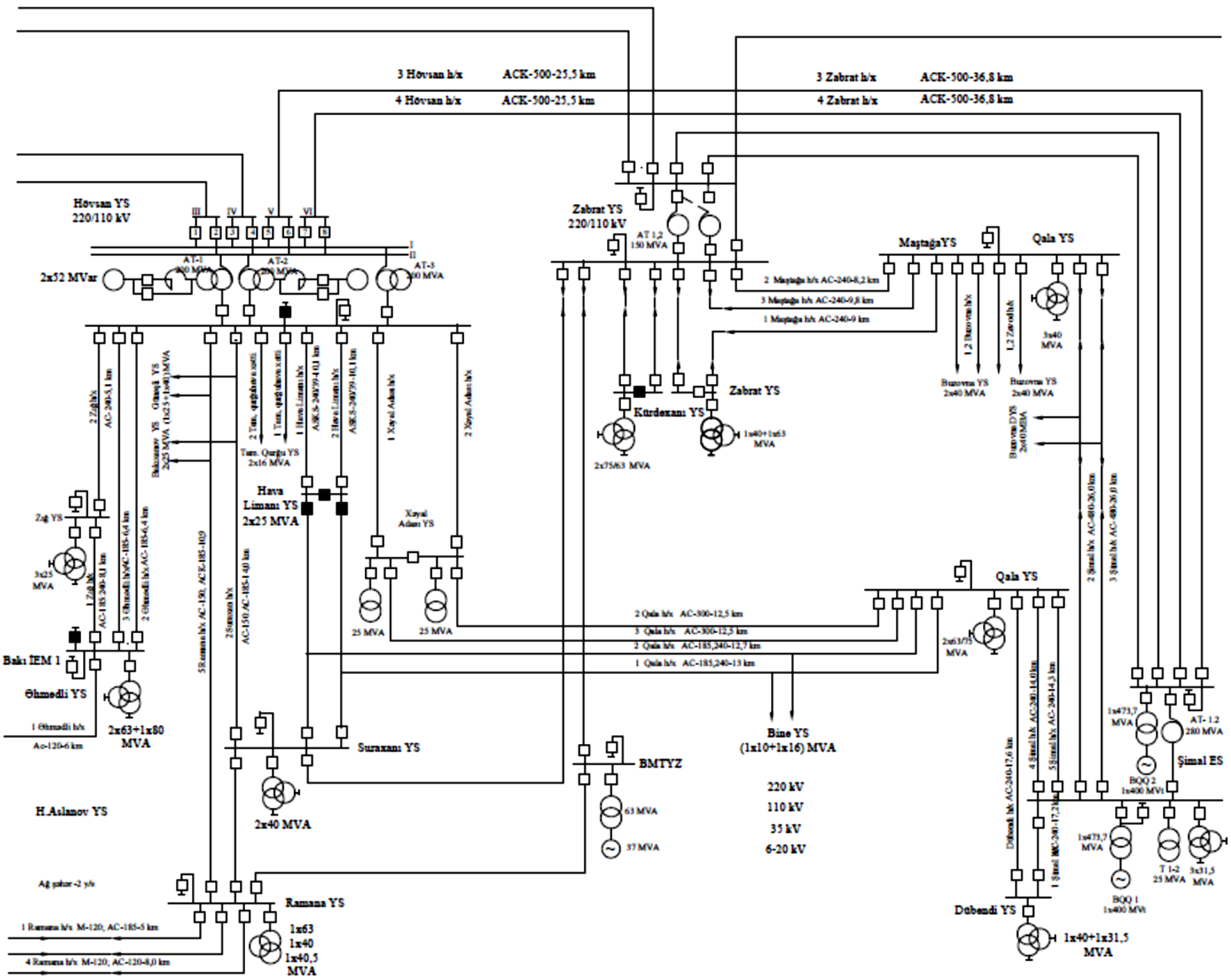


Figure 5. Scheme of a systemic site Azerenerji system networks 220/110 kV

Taking into account the above, it is necessary to ensure optimal loading of electric transmission lines by applying mandatory power distribution in the 110/220 kV-kug closed network with the application of PST in the considered network region. For this purpose, the connection of the PST to the circuit of the connection autotransformers between the 110 kV and 220 kV voltage station buses is considered. With the commissioning of the Shimal-2 power plant, this necessity became even more obvious. In the following sections, the issue of optimization of power distribution with the application of mandatory power distribution in the 110/220 kV.

3. ANALYSIS OF MODELING RESULTS ON POWER DISTRIBUTION IN THE ENERGY SYSTEM

Model reports were conducted to confirm the effectiveness of PST implementation for the considered power grid district. In order to provide a comparative analysis of the reports, two technical states of the network were considered: the case of no PST and the case of applying PST. In both cases, the regime reports were completed.

As mentioned, the Shimal-4 and Shimal-5 lines are more loaded in different scheme-mode conditions. As a result of the emergency opening of one of the lines, the remaining line is loaded to the limit and it is necessary to go to the load limit. Therefore, in order to simulate the scheme-mode conditions, model reports for the simultaneous opening of the Shimal-4 line, Shimal-1 and Shimal-4 lines, Shimal-1, Shimal-4 and Hovsani lines were performed. At this time, it was determined that the load of the 110 kV Shimal-5 line exceeds the permissible limit, taking into account the ambient air temperature. As a result, it is necessary to apply a power limit of up to 60 MW (6,25%).

The comparative model reports of settled modes for both scheme-mode cases showed that the power losses reduced from 65.73 MW (2.05%) to 64.62 MW (2.02%) by rationalizing the power distribution with the application of PST) has fallen.

In Figure 6 shows the profile curves of the current loads in both circuit-mode cases. It is clear from the figure that in the case of PST, the load of the Shimal-4 and North-5 110 kV lines decreases from 390 A to 260 A (1.7%). The loads of the adjacent 110 kV power transmission lines also decrease, and at the same time the loads of the 220 kV power transmission lines increase, in other words, the load of the Hovsan line increases from 320 A to 370 A.

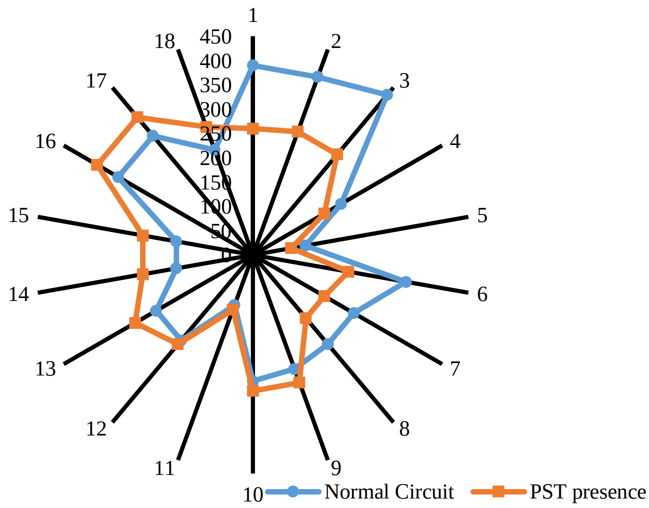


Figure 6. Profiles of currents for the branches of the energy region along the normal scheme in the presence and absence of PST

In Figure 7 shows the degree of power distribution dependingon the state of the PST converter. As it can be seen, by adjusting the position of the PST converter, the load of the 110 kV Shimal-4 and Shimal-5 lines can be reduced by 82.1 percent.

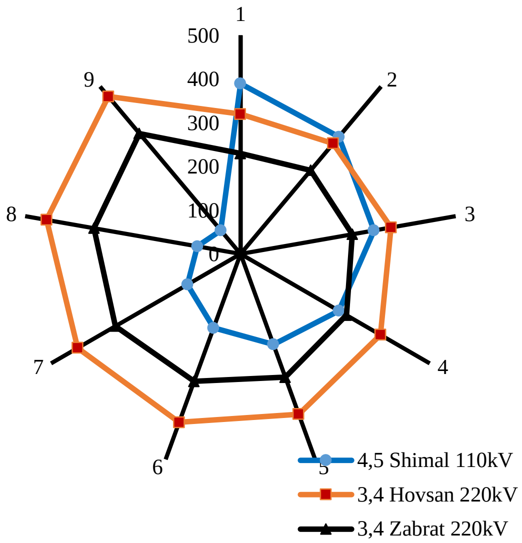


Figure 7. The pattern of variation of power line loads depending on the PST converter number

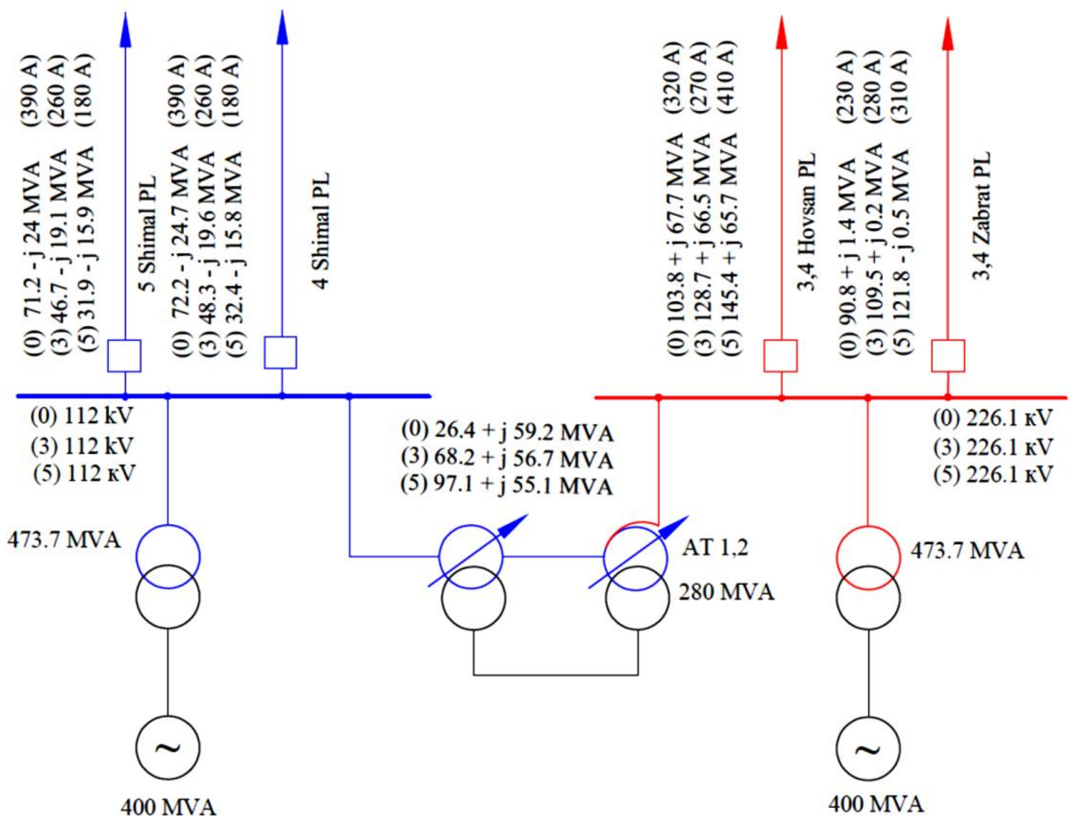


Figure 8. Structural scheme of power distribution in the network district

In Figure 8 shows the structure of power distribution in the considered network region schematically. In the figure, applying the forced distribution of powers on 110 and 220 kV lines and also in several cases of the converter, the mentioned regularity is satisfied. At the same time, it should be noted that in the absence of PST, due to the uneven loading of lines and load restrictions, the system was damaged by 4.5 million dollars, considering that the price of PST is on average 3-6 million dollars, the payback period of this application is 1-2 years happens.

4. STATEMENTS JUSTIFYING THE APPLICATION OF PST FOR VARIOUS SCHEME-MODE SITUATIONS

Studies on the effectiveness of PST in repair modes, numerous operating calculations were carried out according to the criteria N-1, N-2, and N-3. In order to substantiate the use of PST, studies were carried out in the absence and presence of PST for a comparative assessment of the results of computational experiments.

First, according to criterion N-1, the cases of shutdown of the Shimal-1 and Shimal-4 power lines were considered and the load of 110 and 220 kV power lines in the absence and presence of PST was investigated and the results of calculations in the form of current profiles along the branches of the electric networks of the power region are illustrated in Fig. 9 and Figure 10.

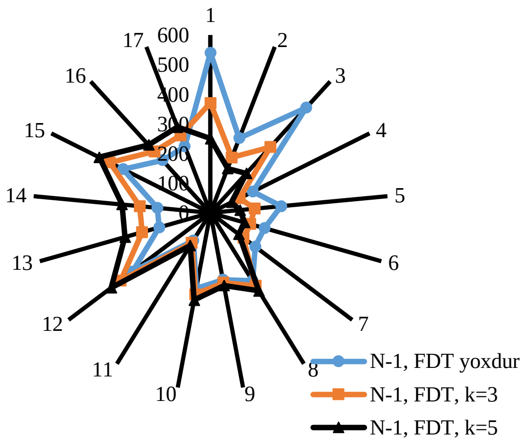


Figure 9. Profiles of currents along the branches of the circuit according to N-1 (disconnections TL Shimal-4)

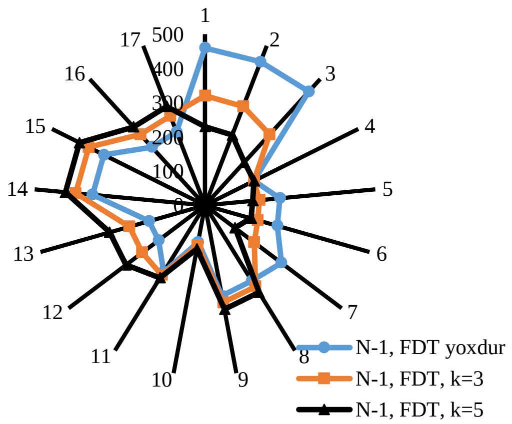


Figure 10. Profiles of currents along the branches of the circuit according to N-1 (disconnections Shimal-1 power transmission line) in the absence and presence of PST

As can be seen from both figures, in the cases considered, with the action of the PST, the unloading of 110 kV transmission lines and the loading of 220 kV transmission lines occur, and thus, an economical distribution of power arises over the adjacent electrical networks.

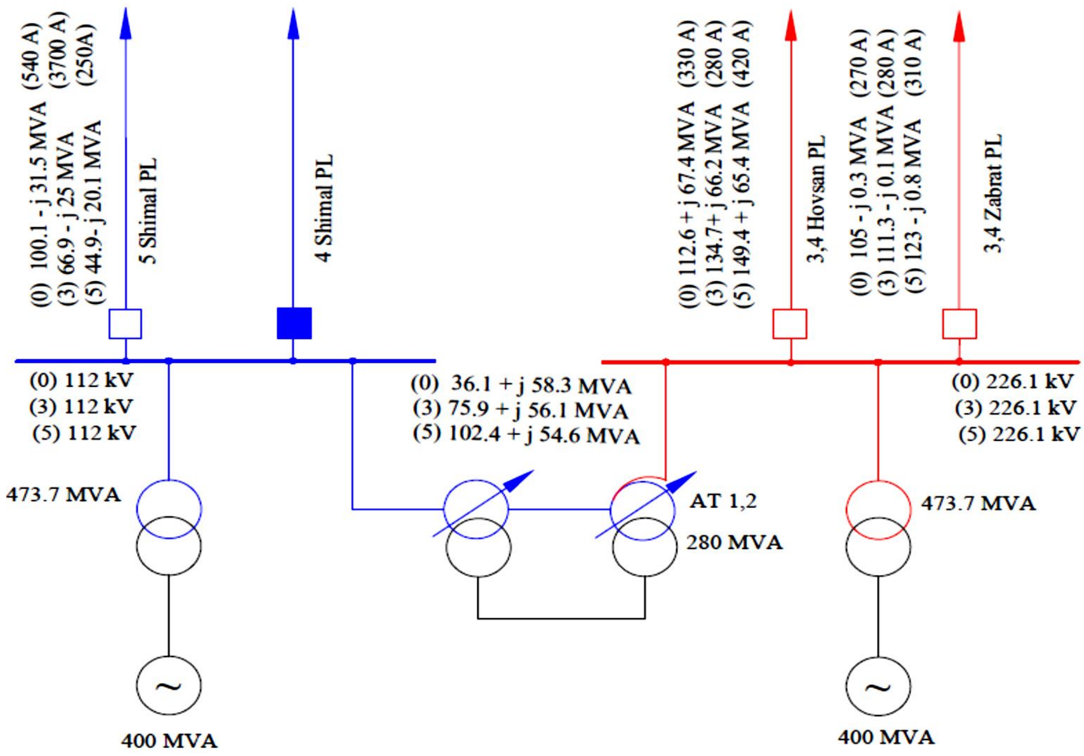


Figure 11. Structural scheme of power distribution in case of emergency opening of the Shimal-4 line

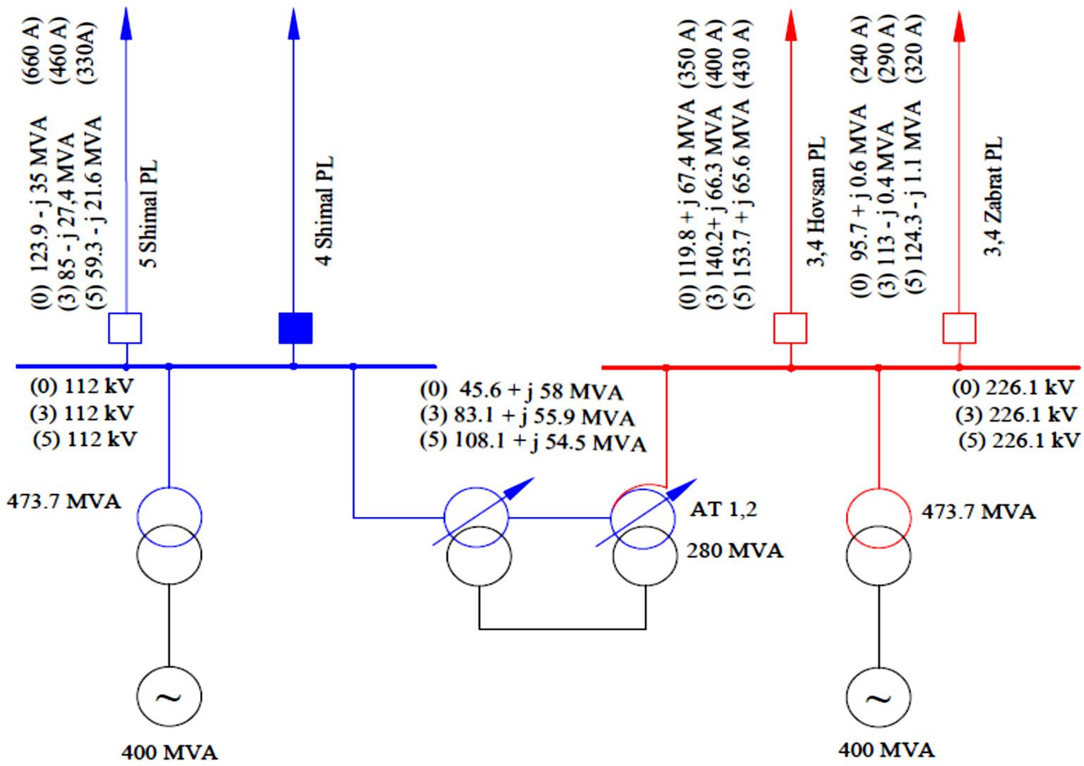


Fig. 12. Structural scheme of power distribution in case of emergency opening of the Shimal-1 line

Figure 11 and Figure 12 show power distribution schemes for 110 and 220 kV lines in cases of disconnection of the Shimal-1 and Shimal-2 transmission lines.

Cases of simultaneous shutdown of transmission lines Shimal-1 and Shimal-2 110 kV on N-2 are considered (i.e. the state of being in repair of one of the lines and emergency shutdown of the other line from protection). Figure 13 shows for the considered case of current loads of network elements. As you can see, there is an effective distribution of the loads of 110 and 220 kV transmission lines under the action of PST.

Figure14 shows a diagram of the power distribution along 110 and 220 kV lines when the SHimal-1 and Shimal-2 110 kV power lines are disconnected.

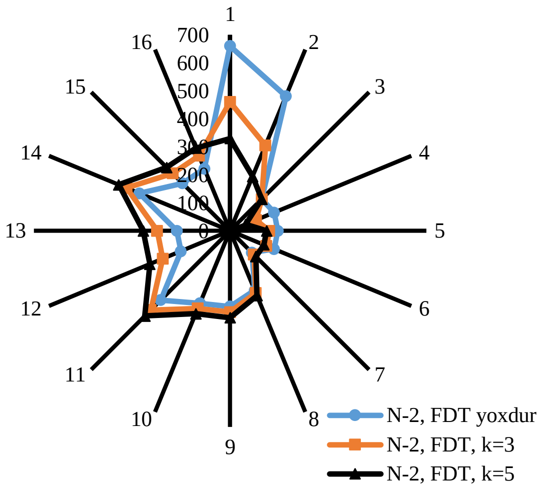


Figure 13. Profiles of currents flowing along lines with no and presence of PST on N-2 (disconnection of power lines Shimal-1 and Shimal-2)

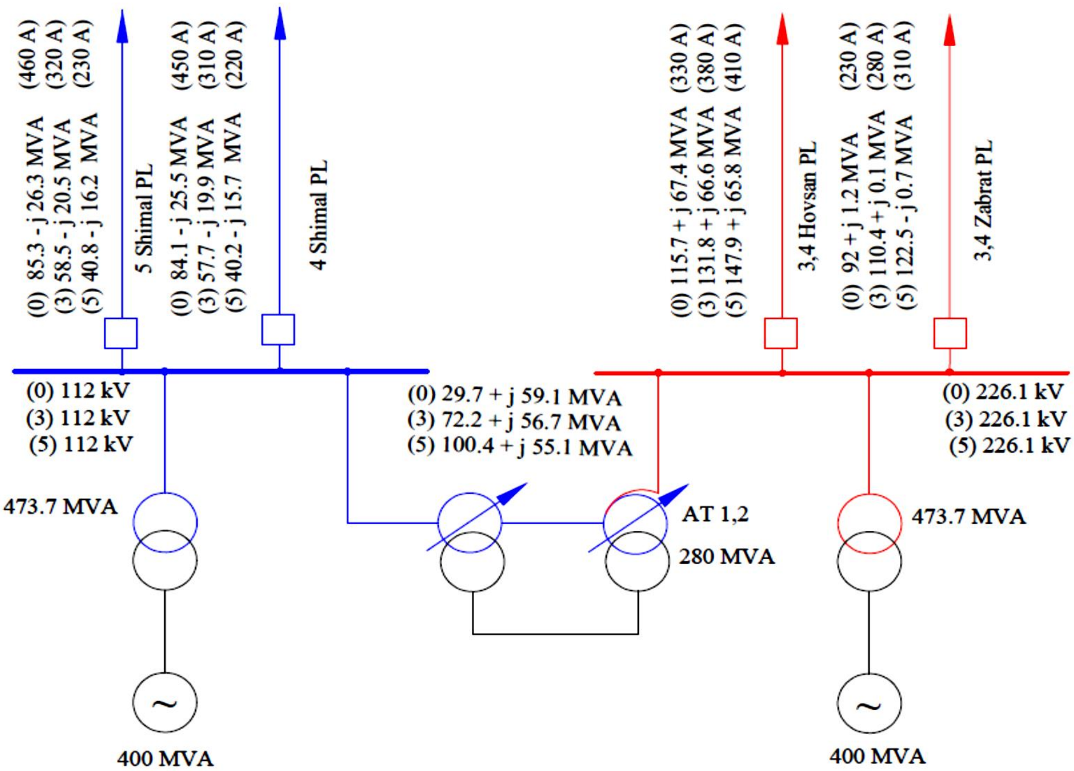
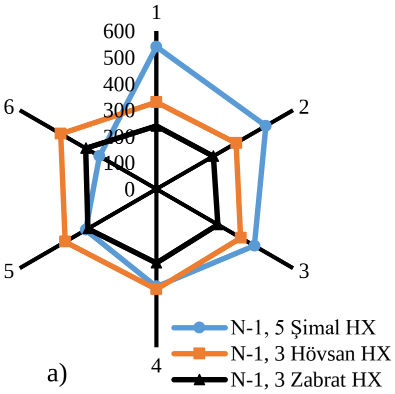


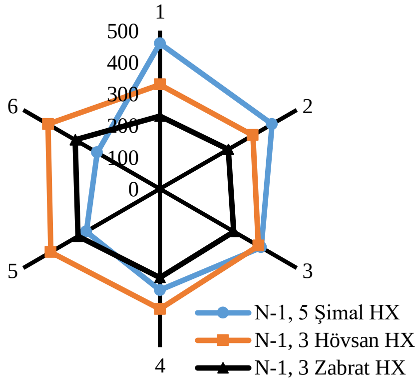
Figure 14. Power distribution schemes in cases shutdown

of transmission lines Shimal-1 and Shimal-2

Figures 15,a and 15,b show the impact of changes in the PST switch position on the loading of Shimal-5 110 kV power lines, Hovsan-3 and Zabrat-3 220 kV power lines when the Shimal-4 (a) and Shimal-4 (b) 110 kV lines are disconnected. In both cases, a decrease in the load of 110 kV lines and an increase in the load of 220 kV lines becomes obvious. A similar provision is confirmed for criterion N-2 (shutdown of Shimal-1 and Shimal-2 power lines) and for criterion N-3 (Shutdowns of Shimal-1, Shimal-2 and Hovsan-3 power lines) (see Figures 12a and b).



a)



b)

Figure 15. Profiles of power lines currents depending on
the position switch FPT in cases N-1
a - shutdown of the Shimal-4 transmission line;
b - shutdown of transmission lines Shimal-1.

In Figure 16 shows the pattern of power loss variation depending on the inverter number in the case of PST application. As it can be seen, with the effect of PST, significant power loss can be controlled and kept within the normative value.

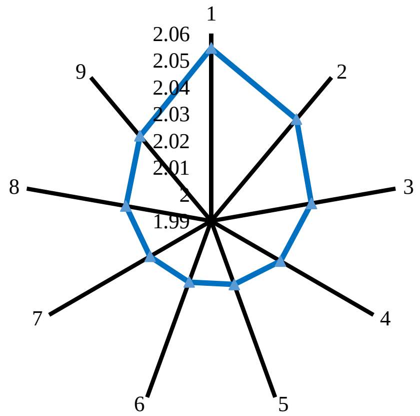


Figure 16. The effect of the application of PST
on the dynamics of power loss

As a result of the research, it can be noted that it is appropriate to install PST between 110 and 220 kV station busbars in the considered network region of the Azerenergy system. All report results confirm this.

CONCLUSIONS

1. Mode reports were conducted during simulation modeling for the equalization of active and reactive power distribution in the power district of the energy system on 110 and 220 kV power transmission lines. Based on the results of the report, it was determined that the application of phase-shifting transformers is more effective for equalizing the power distribution.

2. In order to confirm the efficiency of phase-shifting transformers, model reports on N-n criteria for normal and post-accident modes have been performed. The obtained results showed that in this case, the distribution of active and reactive power is equalized along the lines, power loss is reduced, and voltage regimes are improved. At the same time, the reactive power modes of power station generators remain unchanged in this case.

REFERENCES

[1] H.B.Guliyev, O.V.Ilyasov, “Application of cross-transformer for rational flow Distribution in electric networks of power systems”, “Machine-building and Energy: New Concepts and Technologies” International Scientific-practical Conference materials, AzTU, Baku, Azerbaijan, p.199-202, December 2-3, 2021. https://aztuconference.aztu.edu.az/conference_detail/11

[2] H.B.Guliyev, O.V.Ilyasov, “The problem of rational flow distribution in electric networks of power systems and ways its solution”, Electroenergetics, Electrotechnics, Electromechanics + Control (EEEC), Scientific–industrial journal, Vol.11, No.2, p.12-18, Baku, Azerbaijan, 2021, http://eeec.az/en/archive-2/

[3] Rakhmanov N.R., Ilyasov O.V., Guliev G.B. Application of voltage phase angle control in a power system with an unevenly loaded power supply network // Methodological issues of research on the reliability of large power systems: Vol. 71. Reliability of energy supply to consumers in the context of their rdigitalization. In 3 books. / Boreok 2 / Resp. ed. N.I. Shout. Irkutsk: ISEM SO RAN, 2020, p. 350-360. http://les.sei.irk.ru/pages/cborniki/

[4] Guliyev H.B., Ilyasov O.V. Substantiation of the efficiency of a phase-shifting transformer in repair modes (on the example of Azerenergy) // Methodological issues of studying the reliability of large energy systems: Issue. 72. Reliability of energy systems in the context of their digital transformation. In 3 books. / Book 1 / Rev. ed. N.I. Voropay. Volzhsky: ISEM SB RAS, 2021, pp. 270-280. http://les.sei.irk.ru/pages/cborniki/

[5] N.A.Yusifbayli, V.Nasibov, H.B.Guliyev, N.Aghaliyev, “Assessment of penetration level of variable renewable generations on the flexibility of power system”, Electroenergetics, Electrotechnics, Electromechanics + Control (EEEC), Scientific – industrial journal, Vol.11, No.1, c.31-44, 2021, Baku, Azerbaijan, http://eeec.az/en/archive-2/

[6] Kalinin L.P., Zaitsev D.A., Tirsu M.S., Qolub I.V. The Opportunities for Efficiency Increase of Phase-Shifting Transformers in Power Transmission Operational Modes // 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe). doi: 10.1109/ISGTEurope.-2019.890548029, Oct. 2019, Bucharest, Romania, pp.1–5. https://ieeexplore.ieee.org/document/8905480

[7] Verboomen J., Van Hertem D., Schavemaker P.H., Kling V.L., Belmans R. Phase shifting transformers: Principles and applications // International Conference on Future Power Systemsin (FPS), Amsterdam, the Netherlands, November 2005, p.6. https://ieeexplore.ieee.org/document/1600575

[8] Thomas J. Morrell, Jeff G. Eggebraaten. Applications for Phase-Shifting Transformers in Rural Power Systems // 2019 IEEE Rural Electric Power Conference (REPC). doi: 10.1109/REPC.2019.00020, 28 April-1 May 2019, Bloomington, MN,USA, p.70–74. https://ieeexplore.ieee.org/abstract/document/8783156

[9] Brilinsky A.S., Kritsky V.A., Smirnova L.S. Features of the use of phase-shifting complexes in electric power systems // News of the STC of the United Energy System. Moscow, 2018, No. 1 (78), p. 6-10.

[10] Dobrusin L.A. Trends in the use of phase-shifting transformers in the electric power industry // Energoexpert, 2012, No. 3, p.50 57.

[11] Youssef R.D. Phase-shifting transformers in load flow and short-circuit analysis: modelling and control // IEE Proceedings C – Generation, Transmission and Distribution, Vol. 140 , Iss. 4 , July 1993, pp.331–336. https://digital-library.theiet.org/content/journals/10.1049/ip-c.1993.0049

[12] José M. Cano, Md. Rejwanur R. Mojumdar, Joaquín G. Norniella, Gonzalo A. Orcajo. Phase shifting transformer model for direct approach power flow studies // Electrical Power and Energy Systems,2017,Vol.91,pp.71–79.
https://www.sciencedirect.com/science/article/pii/S0142061517300807

[13] Thatarad S., Kiatiyuth K. Load Alleviation in Transmission System by Using Phase Shifting Transformer // 2018 International Electrical Engineering Congress (iEECON). 7-9 March 2018, Krabi, Thailand. https://www.researchgate.net/publication/333062405

[14] Thompson M. Protection System for Phase-Shifting Transformers Improves Simplicity, Dependability, and Security // 39th Annual Western Protective Relay Conference, May 2015, 13 p. https://cms-cdn.selinc.com/assets/Literature/Publications/Technical%20Papers/6578_ProtectionSystem_MT_20150526_Web.pdf?v=20170324-134435

[15] Brilinsky A.S., Evdokunii G.A., Kritsky V.A., Matvienkov Yu.V., Sidelnikov A.P., Smirnova L.S. Phase-shifting transformer in the power distribution circuit of a large hydroelectric station // Izvestia STC of the United Energy System. Moscow, 2019, No. 1 (80), p.6-14. https://link.springer.com/article/10.1007/s10749-019-01045-5

[16] Manolis B., Keith R., BellW. Use of phase-shifting transformers on the Transmission Network in Great Britain // 45th International Universities Power Engineering Conference UPEC2010. 31 Aug.-3 Sept. 2010, Cardiff, Wales, UK. https://ieeexplore.ieee.org/document/5649431

ABOUT THE AUTHORS

Osman V. Ilyasov worked as a chief engineer in Sumgayit High Voltage Network District. In 2000, Deputy Chief Engineer of “Sumgayit YGES” LLC. In 2005, Chief Engineer of the Electricity Transmission Department of “Azerenergy” OJSC. In 2008, Head of the Electricity Transmission Department of “Azerenergy” OJSC, Since-2019 he has been working as the Chief Engineer of “Azerenergy” OJSC. Awards: October 19, 2007 Medal of Prosperity. October 19, 2012 Honored Engineer. June 30, 2021, Moscow, was awarded the honorary title of "Honored Power Engineer of the CIS" and awarded the Honorary Decree of the CIS Electric Power Council. He is married and has a son.

Huseyngulu B. Guliyev received his M.Sc. and Ph.D. degrees and is a Lead Scientific Researcher, He works as the dean of the Faculty of Energy and Automation of the Azerbaijan Technical University (Baku, Azerbaijan). Currently, he is an Associate Professor of Automation and Control Department in Azerbaijan Technical University. He is a member of the International Scientific Seminar. Yu. N. Rudenko “Methodological issues of researching the reliability of large energy systems” and the International Gnedenko e-Forum on Reliability of Energy Systems. He has more than 256 published articles, 3 patents and 1 monograph. His research interests are power systems operation and control, distributed generation systems, application of artificial intelligence to power systems control design, power system stability, renewable energy integration and power quality.

PERFORMANCE COEFFICIENT AND DETERMINATION OF THE OUTPUT PARAMETERS OF A THREE-PHASE TWO-STROKE ELECTROMAGNETIC VIBROMETER

Yusifov R.A.
"Azerishig" LLC
e-mail: ramil77.77@ mail.ru

Abstract. Determination of the optimal parameters of a three-phase two-stroke electromagnetic vibrometer of low-frequency mechanical vibrations based on a theoretical-chain model has been considered. Dependences of output power and performance coefficient are obtained to ensure effective vibration impact on heavy objects. The results obtained can be used in the optimal design of the vibrator design.

Keywords: three-phase two-stroke electromagnetic vibration exciter of low-frequency mechanical vibrations, performance coefficient, theoretical-circuit model, output power, vibrator.

ÜÇFAZALI İKİTAKTLI ELEKTROMAQNİT VİBROTƏSİRLƏNDİRİCİNİN FAYDALI İŞ ƏMSALI VƏ ÇIXIŞ PARAMETRLƏRININ TƏYINI

Yusifov R.A.
"Azərişıq" MMC
e-poçt: ramil77.77@ mail.ru

Annotasiya. Nəzəri dövrə modeli əsasında alçaq tezlikli mexaniki vibrasiyaların üçfazalı ikitaktlı elektromaqnit vibrotəsirləndiricinin optimal parametrlərinin təyini nəzərdən keçirilmişdir. Ağır obyektlərə təsirli vibrasiya təsirini təmin etmək üçün çıxış gücü və performans əmsalından asılılıqlar əldə edilir. Alınan nəticələr vibrotəsirləndiricilərin optimal layihələndirilməsində istifadə edilə bilər.

Açar sözlər: alçaq tezlikli mexaniki vibrasiyalar, üçfazalı ikitaktlı elektromaqnit vibrotəsirləndirici, faydalı iş əmsalı, nəzəri dövrə modeli, çıxış gücü, vibrator.

КОЭФФИЦИЕНТ ПОЛЕЗНОГО ДЕЙСВИЯ И ОПРЕДЕЛЕНИЕ ВЫХОДНЫХ ПАРАМЕТРОВ ТРЕХФАЗНОГО ДВУХТАКТНОГО ЭЛЕКТРОМАГНИТНОГО ВИБРОВОЗБУДИТЕЛЯ

Юсифов Р.А.
ООО «Азеришыг»
e-mail: ramil77.77@ mail.ru

Аннотация. Рассмотрено определение оптимальных параметров трехфазного двухтактного электромагнитного вибровозбудителя низкочастотных механических колебаний на основе теоретико-цепной модели. Получены зависимости выходной мощности и коэффициента полезного действия для обеспечения эффективного вибрационного

воздействия на тяжелые предметы. Полученные результаты могут быть использованы при оптимальном проектировании конструкции вибратора.

Ключевые слова: трехфазный двухтактный электромагнитный вибровозбудитель низкочастотных механических колебаний, коэффициент полезного действия, теоретико-цепная модель, выходная мощность, вибратор.

I. INTRODUCTION

Energy efficiency is one of essential performance indicators for a three-phase two-stroke electromagnetic vibration exciter taking into account that its application is associated with bringing heavy objects into oscillatory motion and, therefore, the power consumption can be quite large. Generally speaking, this issue in relation to vibration exciters began to be discussed quite a long time ago. Most fully in relation to electromagnetic exciters of low-frequency mechanical vibrations, these issues are considered in [1-4]. However, there is also a number of features of the formation of energy estimates that remained undiscovered and a further consideration is required to clarify them.

II. THEORETICAL-CIRCUIT MODEL OF A THREE-PHASE TWO-STROKE ELECTRO-MAGNETIC VIBROMETER.

To fulfill the above, let’s carry out the following reasoning. Let’s note right away that it is the application of the theoretical-chain model that contributes to the refinement of the formation of energy estimates when transmitting power through energy channels in the exciter of the type under consideration.

At this point, it should be noted that the mentioned power transmission is associated with frequency conversion. Being an input, power in fig,1.b, is connected with the channel where $\omega_{(\text{к})}$ frequency is determined, and output power is determined in the channel where the frequency is associated with the frequency of mechanical vibrations (γ).

At the same time, a theoretical-circuit model makes it necessary to take into consideration that it is advisable to implement the mode of three-phase two-stroke electromagnetic vibrometer functioning, in which, grounds of consistency are taken into account among other factors (in particular, associated with filtration), as there are direct indications in the general theory of circuits [1-2]. In order to further detail all the mentioned considerations, let us turn to the consideration of the usually counted performance coefficient. In this case, we will focus on its form presented in [4], but rewritten in relation to the three-phase two-stroke electromagnetic vibrometer. Taking into account the tractive effort component $F_{\epsilon}(t)$ at frequency γ is defined as

$$F_{\epsilon_{(\nu)}}(t) = 3h\Phi_m^2\mu_{(k)}(\mu_{(k-1)} + \mu_{(k+1)})Cos(\gamma t + \theta) \qquad (1)$$

And, therefore, the instantaneous mechanical power at this frequency

$$P_{\epsilon_{(\gamma)}}(t) = F_{\epsilon_{(\nu)}}(t) \cdot \dot{X}_{(\gamma)}(t) \qquad (2)$$

where $\dot{X}_{(\gamma)}(t) = \gamma X_m \cdot Cos(\gamma t + \theta - \varphi_{\text{мех}})$ - instantaneous speed of mechanical vibrations at a frequencyγ. Then, the instantaneous power (t) , taking into account (1):

$$P(t) = 3h\gamma X_m \cdot \Phi_m^2 \cdot \gamma_{(k)}\big(\mu_{(k-1)} + \mu_{(k+1)}\big)Cos(\gamma t + +\theta)Cos(\gamma t + \theta - \varphi_{mec} \qquad (3)$$

In this case, the average output power over the channel γ power $P_{ave.mec}$ will be presented as:

$$P_{\text{ср.мех}} = \frac{1}{T_{(\gamma)}}\int^{T(\gamma)} F_{(\gamma)_m} \cdot \gamma \cdot X_m \text{x} \cdot Cos(\gamma t + \theta).Cos(\gamma t + \theta - \varphi_{\text{мех}})dt = \frac{1}{2}F_{(\gamma)_m} \cdot \gamma X_m \cdot Cos\varphi_{\text{мех}}$$
(4)

where $F_{(\gamma)_m} = 3h \cdot \Phi_m^2 \cdot \gamma_{(k)}(\gamma_{(k-1)} + \gamma_{(k+1)}$
otherwise:

$$P_{ave,mec\,\gamma} = \frac{3}{2}h\gamma X_m \Phi_m^2 \cdot \gamma_{(k)}(\gamma_{(k-1)} + \gamma_{(k=1)}) \cdot Cos\varphi_{mec} \qquad (5)$$

Considering, that $\beta = \frac{x}{\sigma_0}$ we get the following:

$$P_{\text{ср.мех}\,\gamma} = \frac{3}{2}\gamma\beta\sigma_0 h\Phi_m^2\gamma_{(k)}(\gamma_{(k-1)} + \gamma_{(k=1)})Cos\varphi_{\text{мех}} \qquad (6)$$

And taking into account explanations к $i_A(t)=i_{\sum}(t)=\dot{I}_0[\sum^{\infty}{}_1 A_{(k)m}* \sin(\gamma t_{(k)t} + \xi_{(k)})]$,
where $I_0=k*\Phi_m*\xi_0$, $A_{(k)m}$, $\xi_{(k)}$
we get:

$$P_{\text{ср.мех}\,\gamma} = \frac{3}{2}\gamma\beta L_0 I_0^2\gamma_{(k)}\big(\gamma_{(k-1)} + \gamma_{(k=1)}\big) \cdot Cos\varphi_{\text{мех}} \qquad (7)$$

It is known that performance coefficient is determined as:

$$\mu = \frac{P_{\text{ср.мех}}}{P_{\text{ср.эл}}}$$

and

$$\mu = \frac{1}{1 + \frac{\Delta P_{\text{ср}}}{P_{\text{ср}\gamma\text{мех}}}} \qquad (8)$$

where $\Delta P_{ср}=\Delta P_{меди}+\Delta P_{ст.}+\Delta P_{мех.}$ - power losses in copper, steel and mechanical movements from force components with frequencies other than frequency γ.

Then

$$\mu = \frac{1}{1 + \frac{2(\Delta P_{\text{меди}} + \Delta P_{\text{ст}} + \Delta P_{\text{мех)}}}{3\gamma\beta L_0 I_0^2\gamma_{(k)} \cdot \big(\gamma_{(k-1)} + \gamma_{(k=1)}\big) \cdot Cos\varphi_{\text{мех}}}} \qquad (9)$$

considering (6), (7) takes the form:

Let's note that conditionally nominal mode is resonant for mechanical part and, accordingly, $\varphi_{\text{мех}} = 0(Cos\varphi_{\text{мех}} = 1)$.

In consequence (9):

$$\mu = \frac{1}{1 + \frac{2(\Delta P_{\text{меди}} + \Delta P_{\text{ст}} + \Delta P_{\text{мех})}}{3\gamma\beta L_0 I_0^2 \cdot \gamma_{(k)}(\gamma_{(k-1)} + \gamma_{(k=1)})}} \qquad (10)$$

In this expression, power loss on mechanical motions from force components with frequents different from γ are minimal in relation to the sufficient quality factor of the mechanical subsystem [1-3]. Accordingly, the main power losses are determined with power losses in the copper and steel.

However, expression (10) should be matched with such a conception of performance coefficient of the exciter regarding which there are comments about its extreme properties.

This expression in general form is as follows:

$$\mu = \frac{P_{2H} \cdot \hat{\beta}}{P_{2H} \cdot \hat{\beta} + P_0 + \hat{\beta}^2 P_k} = \frac{1}{1 + \frac{1}{\hat{\beta}}\frac{P_0}{P_{2H}} + \hat{\beta}\frac{P_{1k}}{P_{2H}}} \qquad (11)$$

where $\hat{\beta} = \frac{\dot{X}}{\dot{x}_H}$ - the ratio of the current speed value to conditionally nominal value of this speed when considering performance coefficient in the mechanical subsystem such as fig.1a;

P_{2H} - conditionally nominal power on the load site fig.1,b;

P_0 - conditionally nominal load-independent power losses (speed $\dot{X}$);

P_k - conditionally nominal exciter load-dependent power losses.

It is known from the general theory of electrical machines [6] that extreme value μ in (11) takes place at

$$\hat{\beta}_{\text{опт}} = \sqrt{\frac{P_0}{P_{\text{к}}}} \qquad (12)$$

which is established when $\frac{d\mu}{d\hat{\beta}} = 0$

in this case taking into account (12):

$$\mu_{max} = \frac{P_{2H}}{P_{2H} + 2\sqrt{P_0 P_k}} \qquad (13)$$

The relevant curves are shown in fig.1a. The dotted line shows the course of curves for various combinations of P_0 and P_{κ} in (11) and (12).

Conditional power supply structure for the load Z_{mec} other than that shown in fig.1. This structure is a circuit fig.1b. Here, load-independent power losses (Z_{load}) are shown as transverse section of the parameter g_0 and load-dependent losses (Z_{load}) are shown as longitudinal section r_{Δ}. But expression (11) implies the presence of the

Comparing structures in fig.1a and 1b we note their formal nonconformity. However, in our case it is advisable to refer specifically to structure in fig.1. It is described with the following considerations.

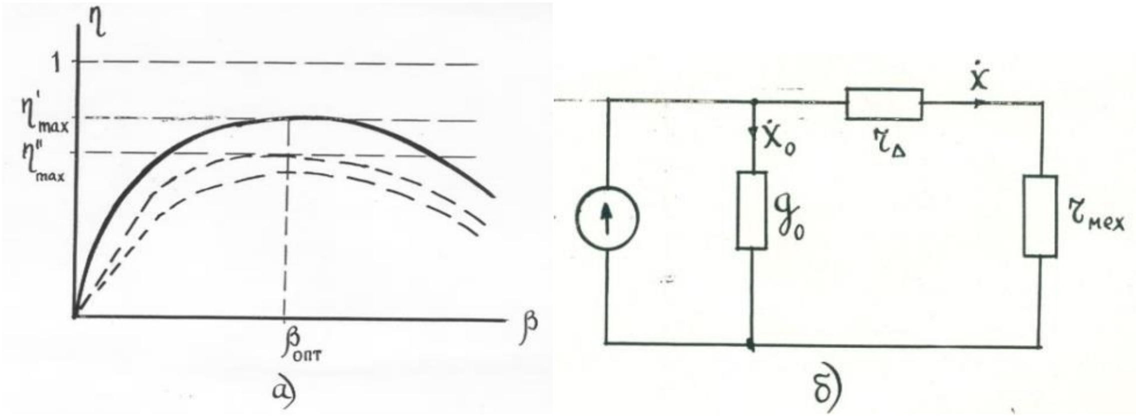


Fig.1. Curves $\eta = f(\beta)$ (a) and replacement circuit TEMV (b)

It is known [1-4] that power distribution over sections of the structure such as fig.1a and its change depending on the parameter change $r_{load_{ав}}$ fig. 2b (which corresponds to Z_{load} in fig.1) is determined by the regularities shown in fig.2a. At the same time, in the section $r_{load_{ав}}$ (Fig. 2b), the power $P_{2ав}$ reaches turning-point at $r_{\text{наг}_{ав}} = r_{\Delta_{ав_{da}}}$ under the conditions $F_{vdb} = const$. Thus, it is advisable to focus on the parameter combination$r_{\text{наг}_{ав}} = r_{\Delta_{ав_{da}}}$ in the circuit with the structure in Fig. 2b from the point of view of the implementation of the condition $P_{2ab} \to max$. But at the same time, this structure should be linked with the structure in Fig. 1b. To fulfill this, we should introduce sections r'_Δ и r''_Δ into the structure in Fig. 2b, and besides $r'_\Delta + r''_\Delta = r_{\Delta_{da}}$. Herein, r''_Δ is a load-independent power loss simulator, i.e.

$$P_2 = F_{ист}^2 \cdot g^0 = \dot{X}_0^2 r''_{\Delta da} \tag{14}$$

From the other side,

$$P_k = \dot{X}_k^2 r'_{\Delta da} \tag{15}$$

Based on (12) an optimal value considering (14) and (15).

$$\hat{\beta} = \sqrt{\frac{P_0}{P_k}} = \frac{\dot{X}_0}{\dot{X}_k} \sqrt{\frac{r''_{\Delta da}}{r'_{\Delta da}}} \tag{16}$$

But it is known [5] that in many cases optimization of electromechanical devices is carried out under the conditions $\dot{\beta}_{опт} = 1$ and, accordingly, $P_0 = P_к$. Then, (16) takes form

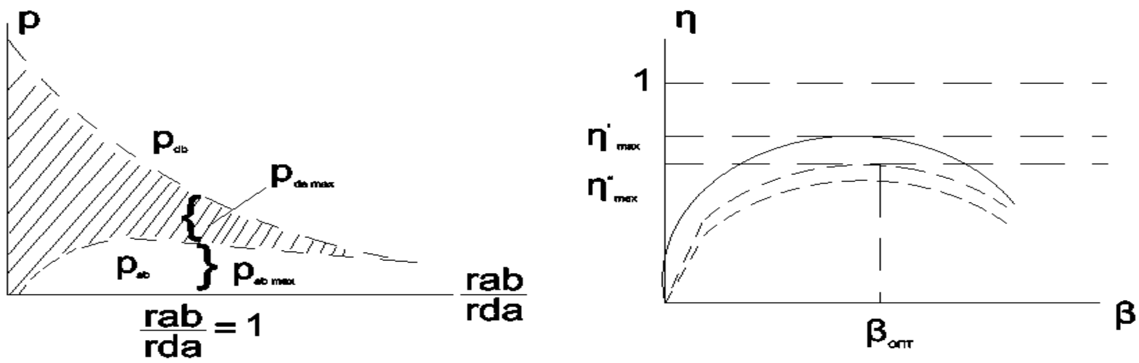
$$\dot{\beta}_{опт} = \frac{\dot{X}_0}{X_к} \qquad \frac{r''_{\Delta da}}{r'_{\Delta da}} = 1 \qquad (17)$$

and, accordingly $r''_{\Delta da} = r'_{\Delta da}$, and besides $r_{\Delta da} = 2r_{\Delta da}$

Thus, explanations mentioned above allow us to establish the equivalence of the circuits in fig.2b and 1b. But, in this case structure in fig.1 should be interpreted as an analogue of the circuit in fig.2b based on their energy considerations.

However, at the same time the source in the section of the input two-terminal of the circuit in fig.2b must be the source $F_v = F_{v_{xx}}$.

Based on fig.2,a circuit parameters fig.2,b $r_{\Delta_{da}} = r_{наг_{ав}}$.



a) b)

Fig. 2. Change regularities $\bar{\tilde{}}(r_{ab}/r_{da})$ (a) и $\eta = f(\beta)$ (б)

Let's take into consideration that in the structure in fig.1 $Z_{load} = r_{load}$ on the grounds of resonance in
the mechanical part and $Z_{вн} = r_{вн}$ from the transparency conditions of the input filters. Then, the optimal ratio for designing the considered type of exciter is the following ratio:

$$3\left[\frac{W}{2\delta_0 k_0 x_{L_0}}\left(\left|\Phi_{\frac{(к-1)}{m}}\right| + \left|\Phi_{\frac{(к+1)}{m}}\right|\right)\right]^2 \cdot r = r_{мех} \qquad (18)$$

The above expression allows us to establish the optimal values of the parameter of the designed three-phase two-stroke electromagnetic exciter of low-frequency mechanical vibrations.

CONCLUSIONS

The above simulation results allow us to state that a three-phase two-stroke electromagnetic vibrometer is a rational means for providing vibration impact on heavy objects during the mass passage of products in this section of in-line production. If necessary, a three-phase two-stroke electromagnetic vibrometer may also be applied to vibration impact on large masses of liquid or viscous components.

REFERENCES

[1] Chesnakov A.E. Vibrations of an electromagnetic vibrator in the presence of in-series-connected capacitor in its circuit // Scientific records of the Odessa Polytechnic Institute, 1999, pp. 134-155.
[2] Yusifov R.A. Mathematical model for experimental study of a vibration device with low-frequency mechanical vibration. Proceedings of the international conference: CAD and modeling in modern electronics. Bryansk, 2019, pp.136-139, DOI: 10.30987/conferencearticle_5e0282115c9ed3.43388650.
[3] Mammadov F.I., Huseynov R.A., Yusifov R.A. on the issue of obtaining a mathematical model of a vibration device with low-frequency mechanical vibration: - Sumgayit (SSU), Scientific news No. 4, 2012, volume 12.
[4] Nitusov Y.U., Babayev I.S. Tractive effort of electromagnetic exciters of low-frequency mechanical vibrations with their three-phase power supply, Moscow-1986, 11p. The manuscript was submitted to the Moscow State Technical University named after N..Bauman, Dep. in Informelectro March 19, 1986, N 320-ET.
[5] Babayev I.S., Gasimov R.A. Three-phase power supply of electromagnetic exciters of low-frequency mechanical vibrations//Improving the efficiency of electromechanical and semiconductor energy converters in control systems: Report at a scientific and technical conference. -Vladimir, 1986, p.89.
[6] Vibrating machines in construction and production of building materials // Ed. V.A. Bauman, M.: Mechanical engineering, 1980, p.548.
[7] Nitusov Y.Y., Babayev I.S. Tractive effort in electromagnetic exciters of low-frequency mechanical vibrations with their three-phase power supply, M., 1991, p.11. The manuscript was submitted to the Moscow State Technical University named after N.E. Bauman, Dep., in Informelectro on March 19, 1991, N 320-ET.

Yusifov Ramil Ali oglu, was born on December 16, 1977 in the village of Ashagi Mollu, Gubadli region of the Republic of Azerbaijan. In 1999 he graduated from the Azerbaijan State Oil Academy with a degree in electronics and microelectronics. In 2007, he graduated from the master's program of Sumgayit State University with a degree in Power Supply, and then entered the doctoral program of this university. Scientific direction: power distribution management, modeling of power supply systems, study of operating modes of power electrical equipment.

ENERGY EFFICIENCY IS THE MAIN FACTOR OF EFFECTIVE MANAGEMENT OF ENERGY SYSTEMS

Chingiz Shafi Oglu Ibadov
Doctor of Philosophy in Economics
"Azerishiq" Open Joint Stock Company
E-mail: chingiz.ibadov@mail.ru

One of the main tasks of the state in the field of using energy resources is the optimization of the operation mode of energy systems, the production, storage, transmission, distribution of energy, as well as the elimination of excess energy consumption and losses in its sale and consumption, and the stabilization of the tariff policy in this area. The adoption of the law of the Republic of Azerbaijan "On efficient use of energy resources and energy efficiency" dated August 20, 2021 has made these issues even more urgent. With the Decree of the President of the Republic of Azerbaijan Mr. Ilham Aliyev "On Accelerating Reforms in the Energy Sector of the Republic of Azerbaijan" dated May 29, 2019, the Ministry of Energy, taking into account the advanced international experience, established the main priorities and goals of the development of this sector, "Long-term Development Strategy of the Energy Sector of the Republic of Azerbaijan" was assigned to prepare the project. Jointly between the Ministry of Energy and the European Union in order to ensure the implementation of tasks arising from this Order to cooperation the process of preparing the National Action Plan on energy efficiency has been started within the framework of the relevant project.

Thus, increasing the efficiency of the country's energy systems, including the economically efficient transmission, distribution and consumption of energy, as well as the organization of management, is one of the most urgent problems of the modern era. The total economic effect obtained from the efficient management of electricity networks and reduction of losses of "Azerishiq" Open Joint Stock Company (hereinafter - OJSC) can be estimated at the level of 100 million manats per year.

Key words:energy efficiency, technical losses, energy balance, commercial losses, economic efficiency.

ENERJİ EFFEKTİVLİYİ – ENERJİ SİSTEMLƏRİNİN SƏMƏRƏLİ İDARƏ EDİLMƏSİNİN BAŞLICA AMİLİDİR

ÇİNGİZ ŞƏFİ OĞLU İBADOV
iqtisad üzrə fəlsəfə doktoru
“Azərişıq”Açıq Səhmdar Cəmiyyəti

Enerji resurslarından istifadə sahəsində dövlətin əsas vəzifələrindən biri enerji sistemlərinin iş rejiminin optimallaşdırılması, enerjinin istehsalı, saxlanması, ötürülməsi, paylanması, habelə satışında və istehlakında normadan artıq enerji sərfinin və itkilərin aradan qaldırılması, bu sahədə tarif siyasətinin stabilləşdirilməsidir. Azərbaycan Respublikasının “Enerji resurslarından səmərəli istifadə və enerji effektliyi haqqında” 20 avqust 2021-ci il tarixli qanununun qəbul edilməsi bu məsələləri daha da aktuallaşdırmışdır. Azərbaycan Respublikasının Prezidenti cənab İlham Əliyevin “Azərbaycan

Respublikasının energetika sektorunda islahatların sürətləndirilməsi haqqında" 29 may 2019-cu il tarixli Sərəncamı ilə Energetika Nazirliyinə qabaqcıl beynəlxalq təcrübəni nəzərə almaqla bu sektorunun inkişafının əsas prioritetləri və hədəfləri müəyyən edilərək, "Azərbaycan Respublikasının energetika sektorunun uzunmüddətli inkişaf Strategiyası"nın layihəsini hazırlamaq tapşırılmışdır. Bu Sərəncamdan irəli gələn tapşırıqların icrasını təmin etmək məqsədi ilə Energetika Nazirliyi ilə Avropa ittifaqı arasında birgə əməkdaşlığa başlanılmış, müvafiq layihə çərçivəsində enerji səmərəliliyi üzrə Milli Fəaliyyət Planının hazırlanması prosesinə start verilmişdir.

Beləliklə, ölkənin enerji sistemlərinin səmərəliliyinin artırılması, o cümlədən enerjinin iqtisadi cəhətdən səmərəli ötürülməsi, paylanması və istehlak edilməsi, həmçinin idarə edilməsinin təşkili müasir dövrün ən aktual problemlərindən biridir. "Azərişıq" Açıq Səhmdar Cəmiyyətinin *(bundan sonra – ASC)* elektrik şəbəkələrinin səmərəli idarə edilməsindən və itkilərin azaldılmasından alınan ümumi iqtisadi effekt ildə 100 milyon manat səviyyəsində qiymətləndirilə bilər.

Açar sözlər: enerji effektliyi, texniki itkilər, enerji balansı, kommersiya itkiləri, iqtisadi səmərəlilik.

The organizational framework for energy efficiency includes various stakeholders. Activities related to energy efficiency should be coordinated in individual energy systems of the republic, in the industrial, construction, and transport sectors, and energy efficiency rules for renewable energy sources and environmental protection should be developed.

One of the tasks of the state in this field is to conduct scientific researches in the field of efficient use of energy resources and energy efficiency and to promote the application of innovations. Conventional statistical analysis in the field of energy efficiency show that in the real economy it is characterized by waste, while energy transmission and distribution are directly related to losses.

In the chain of production, storage, transmission, distribution and sale of energy, the weakest link in these links is energy distribution. So, in each of these processes, losses and technological waste are inevitable. However, significant losses during distribution and sales lead to corruption-related offences and looting of energy resources. At present, energy is lost in networks in a large amount from production to delivery to the consumer, and part of it is masked by the phrase "technological waste is inevitable". Since these networks are legal entities whose shares (shares) are controlled by the state, they operate directly or indirectly with subsidies from the state budget and operate at a loss. These cases are typical for all former CIS countries.

It is more appropriate to ensure energy efficiency in the distribution and sale networks of energy resources, that is, to investigate the reduction of losses on the example of the field of electric power, conduct research and prepare proposals. Thus, in terms of management, accountability and organizational measures of electric networks, it is typical for other utility sectors.

In all studies conducted on the investigation of losses of electrical networks, the actual losses of electricity are expressed as the sum of technical and commercial components. In other words, the amount of actual (total) losses of electric energy in electric networks is defined as the difference between the volume of electric energy supplied to the electric network from other networks or electricity producers and the volume of electric energy consumed by consumers connected to this network. Of course, flows from other network companies (peretok) should be taken into account in this process. For networks, actual (total) losses during transmission and distribution of electricity are the most important indicator of efficiency, the state of the electricity metering system,

The fact that the actual (total) losses are significantly higher than the technical losses remains an important and unsolved problem of state importance in our country and in almost all former Soviet republics. All this requires a systematic approach to solving the problem, conducting additional research, concrete recommendations to state organizations and power networks, and applying purposeful methods in management. High losses in electric networks lead to large financial costs, loss-making networks, and as a result, direct increase in utility tariffs. Additional power flows in power grids, production of additional electricity in power plants and fuel consumption to compensate for this.

Reducing the losses of electric energy in electric networks can be a very complex and complex problem, requiring a large capital investment, a high degree of qualification of working personnel, their financial interest in solving this problem, and their constant attention. One of the most important of these measures is the proper organization of management and requirements for working personnel. The following can be attributed to these measures:

- regular training and improvement of the qualification of working personnel taking into account the innovations in this field;
- realization by the working personnel that this work is a very important problem of state importance;
- financial and moral motivation of working personnel;
- wide coverage of the fight against commercial losses in the press, as well as contact with non-governmental organizations;
- further strengthening of measures that increase financial, administrative and criminal responsibility for commercial losses;
- making decisions based on the results of balance sheets in management and controlling their implementation.

Members of the board of directors of electric networks and mid-level managers should know what work and measures should be taken to reduce losses, and should carry out specific tasks and operations to solve the problems encountered.

In order to reduce losses in the energy sector, it is necessary to carry out the following operations in the management of networks:

- Creating a precise energy purchase system from production to consumption and applying a state control mechanism to it;
- Calculation and normalization of technical losses;
- Programming, creating an innovative balance system and calculating total losses at all levels;
- Creation and analysis of report tables, localization of losses;
- Specifying commercial losses and likely locations by conducting analytical analyses;
- Perfection of the sales system.

In the field of calculation, normalization and application of technical losses (technological consumption), considerable researches have been conducted, works have been published, books have been written and are still being continued. However, calculation of actual losses, commercial losses, energy balance model, design, application, analysis, forecasting, complete, comprehensive and objective research have not been done.

The energy balance in energy systems is calculated by the following formula:

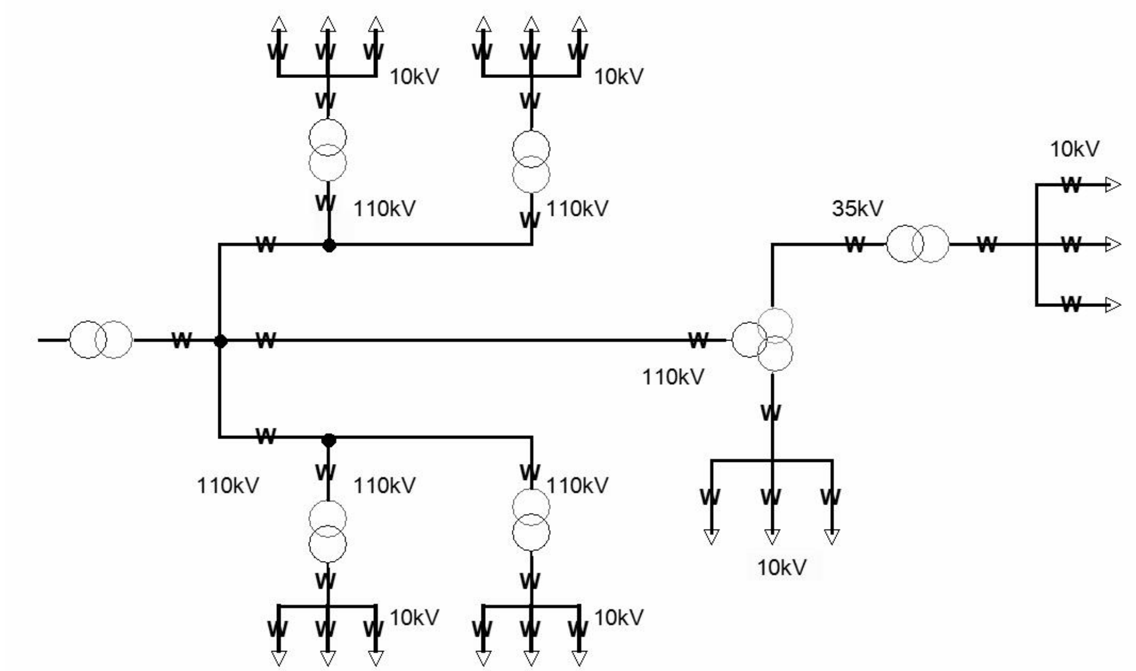
$$W_b = W_{Fay} + \sum W_T + \sum W_i \pm \sum W_{com}$$

Wb- energy released to the network; ΣWi – sum of personal consumption;
WFay– useful energy; ΣWком – commercial losses;
ΣWT– the sum of technical losses.

Measures to reduce actual losses are the total application of organizational, legal, scientific, technical, technological and economic measures. All measures should be based on mathematical calculations - balance sheets.

Balance statements should be made in the following parts, starting from the accounting points of electricity purchase from energy producers to the accounting points installed at the latest 0.4kV voltage level:

- Balance of electricity on the 110/35/20 kV level (high voltage network);
- Balance of electricity on the 10/6/0.4 kV level (low voltage network);
- Balance of electricity received by 10/6/0.4 kV transformers and electricity delivered to the consumer.



W- electricity meter.

Figure 1. Installation of balance meters in 110/35/10kV distribution networks

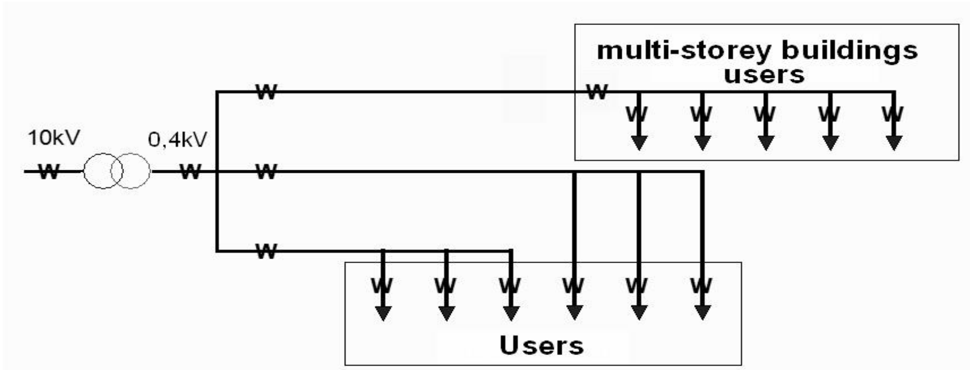


Figure 2. Installation of balance meters in 10/0.4 kV networks

Compilation of energy balance, preparation of reports and analysis based on meter readings on these levels should be considered as part of network management.

The main task of network management is to accurately report the actual losses of electric networks through the innovative energy balance, subtract the technological consumption from it, localize the remaining losses and calculate them from the 110 kV network to the 0.4 kV networks, that is, to the consumer, investigate its causes and determine the commercial losses. it consists of determining its character, and finally achieving a gradual complete elimination of losses through special measures.

In this area, let's get acquainted with the measures taken by "Azerishiq" OJSC in the distribution networks.

Comparison of electricity purchased and consumed by "Azerishiq" OJSC in 2016 and 2020

Table 1

Years	Received	Technical Loss		Useful	Total Sold	Out of Balance	
	kWh	%	kWh	kWh	kWh	kWh	%
2020	18 535 040 465	8.94%	1 656 695 227	16 878 345 238	16 452 399 185	425 946 053	2.52%
2019	19 035 384 814	9.66%	1 839 275 261	17 196 109 553	16 838 361 205	357 748 347	2.08%
2018	18 785 609 856	9.75%	1 831 573 930	16 954 035 926	16 317 726 464	636 309 462	3.75%
2017	18 587 666 539	9.85%	1 831 359 914	16 756 306 625	15 763 825 399	992 481 225	5.92%
2016	19 256 463 592	10.04%	1 934 009 443	17 322 454 149	16 045 800 366	1 276 653 782	7.37%

From 2015, when "Azerishiq" OJSC was established, to the present period, approximately 40-45% of distribution networks have been restored and reconstructed, thereby confirming the profitability of investing in networks with high losses. As a result, according to the results of 2020, technical losses across the country were reduced to 8.9%, and the level of payment for the sold electricity increased to 96.2%. In addition, with the application of the Energy Balance system, the losses in the network regions, including the regional networks with more energy losses, were determined and relevant analyzes were carried out.

Due to economic development, the natural growth of loads due to the increase in the number of consumers, and the change in their distribution over the territory, the energy system must be constantly reconstructed in order to ensure the transmission of energy to consumers with the least loss. The reconstruction measures can be divided into two groups: First, should include activities that do not require additional investment in network development.

The second group includes activities that require additional investment. It is a technical and economic task to reveal the economic efficiency of loss reduction measures through capital investments.

The efficiency indicator of measures to reduce electricity losses is calculated as the ratio of the volume of losses to the amount of capital investment spent for their reduction.

In 55-60% of the distribution networks of "Azerishiq" OJSC, there are devices and equipment that have passed their service life several times and do not allow to achieve energy efficiency and customer satisfaction, which cause energy losses and thereby the loss of state funds.

Through the balance sheets, it was determined that the amount of electricity lost in Distribution Networks for 2020 was 426 million kWh or 36.2 million manats, of which most of the losses were in 7 Network districts: Sabirabad, Shamkir, Aghjabadi, Salyan, Masalli , Jalilabad, Neftchala districts. While the amount of lost electricity in all other Network Regions is 196 million kWh or 16.6 million manats, the amount of lost electricity in these regions whose network equipment is old and past its service life is 230 million kWh or 19.5 million manats .

The demand for natural gas consumption has increased due to the 319 million kilowatts of electricity undelivered to consumers annually due to losses.

As a result, during the year, the amount of lost energy on distribution networks was 36.2 million manats, the amount of energy not delivered was 27.11 million manats, and the total amount was 63.31 million manats.

In 2016 **in 2020**

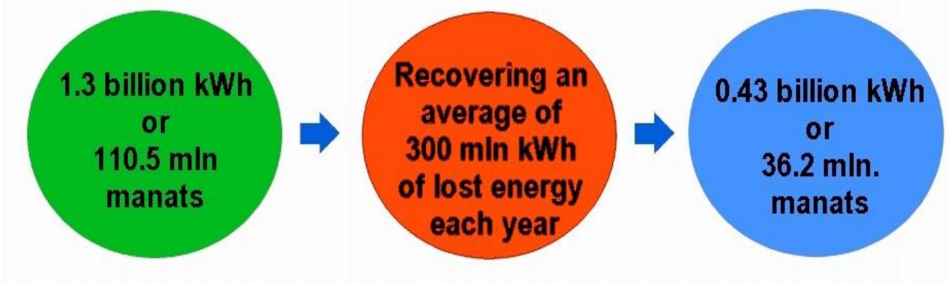


Figure 3. Energy imbalance indicators for 2016-2020 distribution networks of "Azerishiq" OJSC

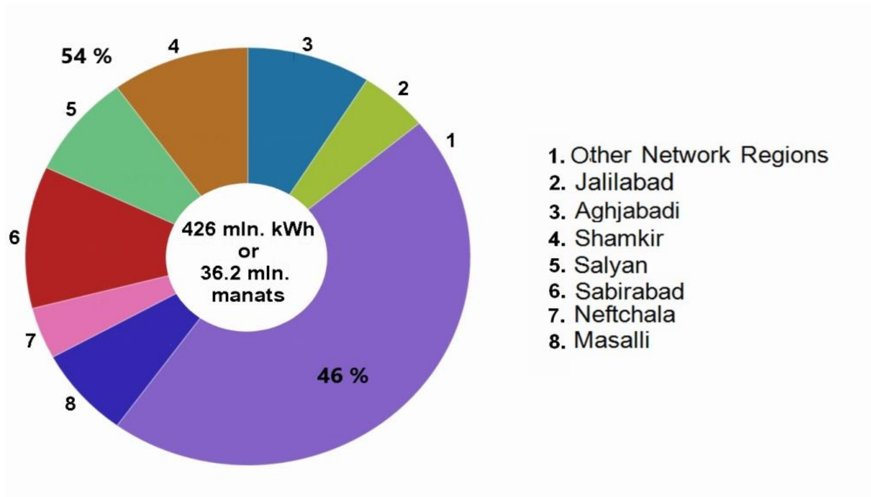


Figure 4. "Azerishiq" OJSC regional distribution network losses of electrical energy networks

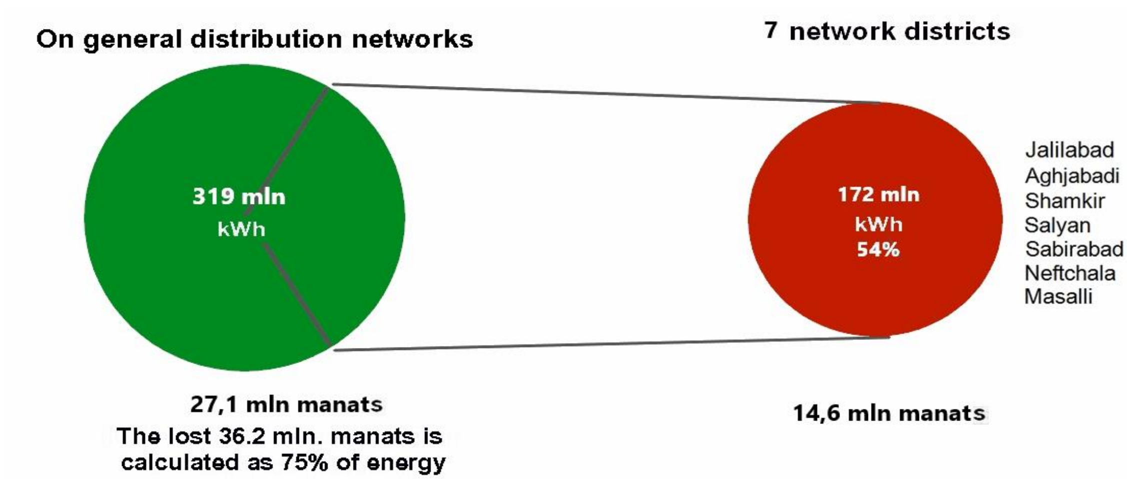


Figure 5. Network regions with the highest annual undelivered electricity across distribution

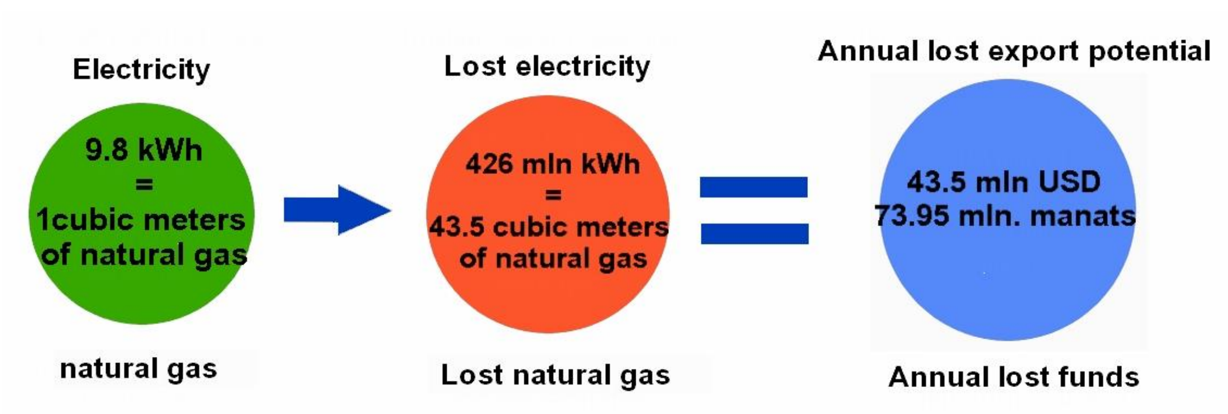


Figure 6. Negative impact of electricity losses on natural gas export potential

Thus, this analysis proves that the development and strengthening of distribution networks, taking into account the results of the balance sheets, is extremely appropriate. As a result:

- annual lost electricity can be recovered;
- natural gas resources of the country can be saved;
- the export potential of natural gas increases;
- foreign exchange revenues to the state budget increase;
- gas consumption in electricity production decreases;
- With the restoration of lost electricity (36.2 million manats) and the increase of natural gas export potential (73.95 million manats), it is possible to return more than 110 million manats annually.

As we can see, it is not enough to draw up balance sheets only for the country, in order to achieve the results. The electricity balance of the country should consist of the sum of the balance sheets of regions, districts, substations, cable and overhead transmission lines, and finally with consumers. More precisely, from consumer to production, every building (apartment), village, city, district, etc. the electricity received should be compared with the total electricity used by consumers in that area. As a result of this, it is possible to find the amount and specific location of the actual (total) lost energy, investigate the causes and, depending on the nature of the loss, take measures to prevent or restore it.

Now let's analyze the network losses of "Azerishiq" OJSC in Baku city:

Comparison of received and consumed energy of "Azerishiq" OJSC Baku RETSIs in 2016 and 2020

Table 2

Years	Received	Technical Loss		Useful Energy	Total Sold	Out of Balance	
	kWh	%	kWh	kWh	kWh	kWh	%
2020	8 430 181 864	7.49%	631 658 089	7 798 523 776	8 024 691 120	-226 167 344	-2.90%
2019	8 978 613 450	7.89%	708 007 231	8 270 606 220	8 496 744 331	-226 138 112	-2.73%
2018	8 953 873 311	7.98%	714 485 575	8 239 387 736	8 338 920 597	-99 532 860	-1.21%
2017	8 739 055 170	8.05%	703 059 507	8 035 995 664	8 163 777 311	-127 781647	-1.59%
2016	8 963 210 418	8.22%	737 086 374	8 226 124 044	8 221 704 720	4 419 324	0.05%

"Azerishiq" OJSC conducted balance sheets for all regions and cities of the republic (except for Nakhchivan MR) and determined that 7 regions have the most losses, as well as 63 of the total 611 low-voltage transmission lines in these regions have the most losses. It is possible to save 74 million manats as a result of carrying out technical improvement and strengthening works on these lines, as well as accounting clarification.

Observations show that there are a total of 193 villages, settlements and other residential and non-residential settlements - users - on those lost air lines. However, since the current technical condition of the network does not allow measuring the electricity received by these villages and settlements separately, it is not possible to carry out the balance statements with full accuracy, that is, to TM and KTMs, and to apply the balance statements. These 10/0.6 kV overhead lines, covering 5-6 and sometimes 10-15 villages of the regions, with a length of 50-80 km, require millions of funds.

Localization of existing electricity losses in individual residential areas on these overhead lines by means of balance sheets should first of all be used to invest in the lines with the most losses, and in the lines with no losses to be content with current repairs, to plan annual investments, reducing losses, at the expense of the resulting profit, in sequence, it will make it possible to improve the health of the networks and save the state funds to the maximum.

It should be noted that more than 6 billion manats have been invested in the power grids of Baku city in the last 10 years at the expense of various sources, including the state budget, and the circular system for the transmission of electric energy created in Absheron substations, mainly to reduce losses by 3-4% in the last 5 years, Baku allowed to reduce it to 5% in 2020 for the city. This is a very admirable event. However,traditional reporting balance sheets in "Azerishiq" OJSC do not allow to analyze this. In other words, the current balance sheet procedure is a slightly modified version of the tables from the 80s of the last century, calculated on useful energy. As a result, the reduction of the technical loss norm from 9% in 2015 to 7.5% in 2020 ultimately led to an "imbalance" of -2.9%.

It is appropriate to draw up comparative tables of electricity purchased and sold by year for all networks (district, city) in the following order:

Comparison of purchased and sold electricity and actual losses of "Azerishiq" OJSC
Baku RETSIs in 2016 and 2020

Table 3

Years	Received	Sold	Actual loss		Technical Loss (normative)	Commercial loss
	kWh	kWh	kWh	%	%	%
2020	8 430 181 864	8 024 691 120	405 490 744	4.81%	7.49%	-
2019	8 978 613 450	8 496 744 331	481 869 119	5.37%	7.89%	-
2018	8 953 873 311	8 338 920 597	614 952 715	6.87%	7.98%	-
2017	8 739 055 170	8 163 777 311	575 277 860	6.58%	8.05%	-
2016	8 963 210 418	8 221 704 720	741 505 698	8.27%	8.22%	0.05%

Comparison of purchased and sold electricity and actual losses of "Azerishiq" OJSC by regions in 2016 and 2020

Table 4

Years	Received	Sold	Actual loss		Technical Loss	Commercial loss
	kWh	kWh	kWh	%	%	%
2020	10 104 858 601	8 427 708 065	1 677 150 535	16.60%	10.14%	6.46%
2019	10 056 771 364	8 341 616 874	1 715 154 489	17.05%	11.25%	5.8%
2018	9 831 736 544	7 978 805 867	1 852 930 677	18.85%	11.36%	7.49%
2017	9 848 611 369	7 600 048 088	2 248 563 280	22.83%	11.46%	11.37%
2016	10 293 253 174	7 824 095 646	2 469 157 528	23.99%	11.63%	12.63%

As can be seen from the tables, the term useful energy was not used in the balance sheets. Using the concept of actual (total) loss, it is more appropriate to make full reports on total losses and move towards economic efficiency in networks. In this case, the energy balance for distribution networks can be calculated by the following formula:

$$W_{ac} = \sum W_{rec} - \sum W_{Sold}$$

also

$$W_{ac} = \sum W_T - \sum W_{com}$$

Wrec- received electricity; Wcom- are commercial losses;
Wsold- sold electricity; WT- technical losses;
Wac– actual losses.

Either in this case, we can obviously see the commercial losses appear as a component of the energy balance technical losses should be compared with actual losses. If the actual losses are ≤ less than the technical losses, this can be an indication of profitable operation of the networks.

The comparison of the purchased, sold and actual losses in "Azerishiq" OJSC by years shows that the level of energy losses should be determined in advance at the stage of investment development, taking into account the development of the field. As a result of this decision, a technical-economic justification of losses and a possible design level should be prepared. If there are no errors in the technical-economic justification of the investment, then it can be expected that the actual losses will be close to the normative of technical losses and no additional technical measures are needed. If the actual energy losses in the power system are lower than the normative level of technical losses, as can be seen from Table No. 4, such a situation has arisen in the networks of Baku city. But even in this case, in addition to optimization of work modes and network mode, balance reports aimed at reducing energy losses should be carried out and other organizational measures should be implemented. As a rule, these measures should be implemented without additional investments.

There is a lot of potential for energy efficiency in electricity, gas and heating networks. One of the main conditions for the development and liberalization of these networks is structural change. The separation of transmission from production and distribution from sale is the main condition for liberalization, as a result transparency, and the creation of new economic relations between them based on market laws. The unbundling process should begin with establishing an independent financial accounting structure for generation, transmission, distribution and sales entities and gradually converting them into separate legal entities. The fact that distribution and sales structures are separated from production and operate as separate legal entities will adapt them to the requirements of the liberal market and force them to take necessary operational and commercial measures.

Electricity balance reports are also the basis for planning and optimizing power plant operating modes, fuel reserves, equipment repair schedules, calculating tariffs for electricity transmission, distribution and sale services, and planning losses in the state energy balance. In the states where the liberal market economy is formed, the balance sheets are the basis for the purchase of losses. Unfortunately, until today there are no regulatory documents regulating the procedure for determining the electrical energy balance, as well as the procedure for calculating its structural components. However, the demand for accurate balance sheet preparation and its reliability is constantly increasing.

The fact is that after structural changes, the chains are obliged to compensate their actual losses in the wholesale market by purchasing. In most networks, mainly in regions, the actual losses of electricity exceed the technological consumption, that is, the technical loss norms. Thus, during structural changes, distribution networks will suffer financial losses. In networks, not accurately measuring losses in time and not accurately drawing up balance sheets can lead to huge problems. Currently, distribution and sales in one organization obscures these tasks.

The lack of scientific research in this field, their main direction is the methods of determining the actual (total) losses of electricity, the methods of accounting for the consumed electricity, the low ability of consumers to pay, insufficient motivation of personnel to reduce the losses of electricity in networks, the actual (total) losses it is still one of the factors that "serve" it.

Distribution networks will be forced to calculate the actual (total) losses of electricity in a more detailed and reasonable manner, to determine the structure of excess losses, to develop more efficient software for calculating losses and reducing them after structural separation from sales. Otherwise, the networks will have to pay for the losses.

The purpose of the scientific research to be conducted is to ensure the validity and reliability of the calculation of the balance of electricity in networks of different voltage levels, its components, including the actual (total) losses in the conditions of incomplete information about the consumed electricity.

For this purpose, the analysis of the dynamics of electricity losses in the networks of "Azerishiq" OJSC, the development of methods for calculating the actual losses of electricity and the amount of consumed electricity under liberal market conditions, the balance of 110-0.4kV networks, taking into account the internal flows of electricity including drawing up, as well as developing methods for calculating typical load schedules and consumption volumes based on available primary data, estimating reserves for reducing losses and developing a methodology of factors affecting their level. As these studies are carried out, their results can be published in the materials of local and international conferences with the approval of "Azerishiq" OJSC.

CONCLUSION.

1. In order to gradually achieve energy efficiency in the republic, it is appropriate to start with the reduction of total losses in electricity, gas and heating networks to normative technical losses. For this purpose, measuring total losses from production to consumption through balance sheets, drawing up balance sheets for the country and establishing state control over it, conducting analytical analyses, drawing up precise investment plans, and implementing organizational measures.

2. In energy systems, electricity, gas and heat networks, production - transmission should be separated from distribution and sales, should receive the status of an independent legal entity, and economic relations based on liberal market laws should be established with other system operators. Networks should move to vertical and horizontal corporate management based on balance sheets. They should achieve the reduction of the total losses of all management networks to the level of technical losses, the elimination of commercial losses and, as a result, economic efficiency.

3. In the last 10 years, the total losses of electric network systems of "Azerishiq" OJSC have been significantly reduced as a result of the investment of 6 billion manats from various sources, organizational and technical measures, including the improvement of balance sheets and sales of electricity. This indicator has been reduced to 3-5% in the electric grids of Baku city by region. In addition to confirming the effectiveness of the investment, it is a clear evidence that the investment is formed on the basis of balance sheets, not retail or end-to-end.

4. Balance reports should be improved, conducted on total losses, fully programmed and balance counters should be smart type at the same time as sales report counters.must be read online. The balance sheet software should be integrated with the software of the sales and technical databases to create innovative balance sheets.

5. It is great demend of time to conduct scientific research on the organization of management on the basis of energy balance reports, commercial losses, its organizers, and regularly prepare and submit recommendations to networks and state organizations about the results. It is possible to continue these studies, periodically publish scientific articles, participate in international conferences held in this field, and train young scientific personnel on the example of "Azerishiq" OJSC. Research on commercial losses will help the country's networks to operate profitably and consumer satisfaction, and ultimately to solve many social issues.

REFERENCE

1. Law of the Republic of Azerbaijan "On efficient use of energy resources and energy efficiency", July 9, 2021.
2. *Stephen Stoft*. Energy system economy. Introduction to the design of electricity markets, 2006.
3. *Vorotnitsky V. E., Kalinkina M. A., Komkova E. V., Pyatigor V. И*. Reduction of electric power losses in electric networks. Energy conservation, 2005. No. 2.
4. *Vorotnitskiy V.E., Zhelezko Yu.S., Kazantsev V.N. и др*. Losses of electric power in electric power systems, 1983.
5. *Balametov*A.B., Khalilov ED The results of energy saving measures in the power grids of the electric power system of Azerbaijan. Problems of energy No. 3, 2018.
6. *Balametov*A.B., Khalilov ED Calculation, analysis and normalization of electric power losses in the power grids of the energy system. "ELM", Baku - 2015. -234 pages.
7. *Balametov A*.B. Reserves for reducing electricity losses in electric networks. Problems of energy 2014, №4, стр. 17-25.
8. *Ramazanov K.N., Balametov A.V*., To the question of improving the efficiency of the Azerbaijan energy system. Problems of energy, 2000, No. 1
9. *Vazirov O*.Y. Accounting of electric energy, Baku, 2003
10. Energy of Azerbaijan. State Statistics Committee of the Republic of Azerbaijan. Baku - 2020.
11. "Azerishiq" OJSC, Annual reports of sales, control and balance departments, Baku - 2020.

Ibadov Chingiz Shafi was born in 1957. Alumnus of the Azerbaijan Technical University in 1979 with a specialty of engineer mechanic, later in 2000 graduated from the Azerbaijan University of Economics. In 2002, received a Doctor of Philosophy degree in the sphere of economic efficiency in the economical industry. Author of one monograph and 16 published scientific works. Since 2003, he has worked in various positions in the field of electricity distribution and sale in the energy sector of Azerbaijan. Currently, he is working on textbook " Electricity balance of electric networks - investigation of losses".

THERMAL STORAGE SYSTEMS USED IN SOLAR THERMAL POWER PLANTS

MAMMADOVA E.A.
[1]Azerbaijan Technical University, Baku, Azerbaijan
mammadova84@mail.ru

Abstract: Due to global population growth and industrialization, the demand for energy is increasing dramatically. Renewable energy sources that can be derived from natural resources such as wind, solar, biomass and geothermal energy have been encouraged by many countries due to the benefits of being sustainable and have not contributed to global CO_2 greenhouse gas emissions. However, there is a mismatch between most renewable energy supplies and consumer demand. The simple integration of thermal energy storage makes concentrating solar power dispatchable and unique among all other renewable energy generating alternatives. Concentrating solar energy technology generates electricity by concentrating a beam of solar radiation into a small area where the heat transfer fluid is heated, and this energy is ultimately transferred to steam.

Key words: renewable energy, network integration, power quality, solar energy system.

GÜNƏŞ İSTİLİK-ELEKTRİK STANSİYALARINDA İSTİFADƏ EDİLƏN İSTİLİK SAXLAMA SİSTEMLƏRİ

MƏMMƏDOVA E.A.
[1]Azərbaycan Texniki Universteti, Bakı, Azərbaycan
mammadova84@mail.ru

Xülasə: Qlobal əhali artımı və sənayeləşmə ilə əlaqədar olaraq enerjiyə tələbat kəskin şəkildə artır. Külək, günəş, biokütlə və geotermal enerji kimi təbii ehtiyatlardan əldə edilə bilən bərpa olunan enerji mənbələri davamlı olmanın faydalarına görə bir çox ölkə tərəfindən təşviq edilmişdir və qlobal CO_2 istixana qazı emissiyalarına heç bir töhfə verməmişdir. Bununla belə, əksər bərpa olunan enerji təchizatı ilə istehlakçı tələbi arasında uyğunsuzluq var. İstilik enerjisi anbarının sadə inteqrasiyası günəş enerjisinin konsentrasiyasını göndərilə bilən və bütün digər bərpa olunan enerji yaradan alternativlər arasında unikal edir. Günəş enerjisinin cəmlənməsi texnologiyası günəş radiasiyasının şüasını istilik ötürücü mayenin qızdırıldığı kiçik bir sahəyə cəmləyərək elektrik enerjisi istehsal edir və bu enerji sonda buxara ötürülür.

Açar sözlər: bərpa olunan enerji, şəbəkə inteqrasiyası, enerji keyfiyyəti, günəş enerjisi sistemi

СИСТЕМЫ НАКОПЛЕНИЯ ТЕПЛА, ИСПОЛЬЗУЕМЫЕ В СОЛНЕЧНЫХ ТЕПЛОВЫХ ЭЛЕКТРОСТАНЦИЯХ

МАММАДОВА Э.А.
Азербайджанский Технический Университет, Баку, Азербайджан
mammadova84@mail.ru

Аннотация: Из-за глобального роста населения и индустриализации спрос на энергию резко возрастает. Возобновляемые источники энергии, которые могут быть получены из природных ресурсов, таких как энергия ветра, солнца, биомассы и геотермальной энергии, поощряются многими странами из-за преимуществ устойчивости и не способствуют глобальным выбросам парниковых газов CO_2. Однако существует несоответствие между поставками большинства возобновляемых источников энергии и потребительским спросом. Простая интеграция аккумулирования тепловой энергии делает концентрацию солнечной энергии управляемой и уникальной среди всех других альтернатив производства возобновляемой энергии. Технология концентрирующую солнечную энергию вырабатывает электроэнергию, концентрируя луч солнечного излучения на небольшой площади, где нагревается теплоноситель, и эта энергия в конечном итоге передается пару.

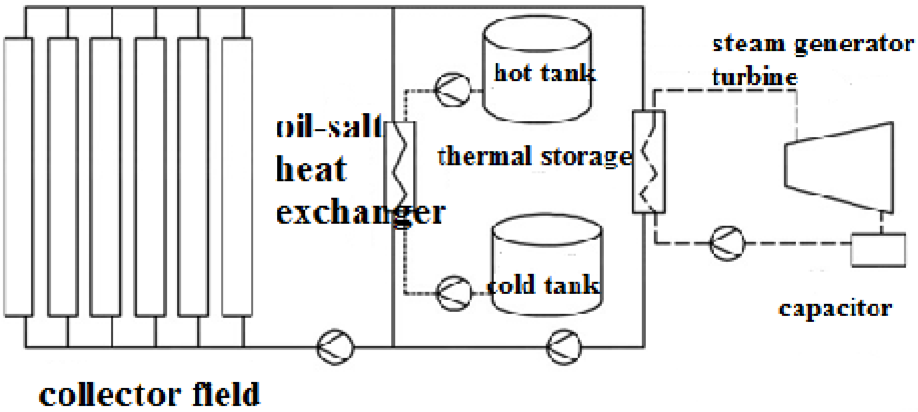
Ключевые слова: возобновляемая энергетика, сетевая интеграция, качество электроэнергии, солнечная энергетическая система.

Due to global population growth and industrialization, the demand for energy is increasing dramatically. Renewable energy sources that can be derived from natural resources such as wind, solar, biomass and geothermal energy have been encouraged by many countries due to the benefits of being sustainable and have not contributed to global CO_2 greenhouse gas emissions. However, there is a mismatch between most renewable energy supplies and consumer demand. The simple integration of thermal energy storage makes concentrating solar power dispatchable and unique among all other renewable energy generating alternatives. This technology generates electricity by concentrating a beam of solar radiation into a small area where the heat transfer fluid is heated, and this energy is ultimately transferred to steam.

To date, solar fuel power plants with parabolic trough concentrating installations are the most promising in the conditions of fossil fuel deficit in the global energy balance. In this paper, the technical and economic parameters of thermal energy storage based on 4 different materials are considered and the most optimal material for the accumulation of thermal energy in Solar Fuel Power Plants.

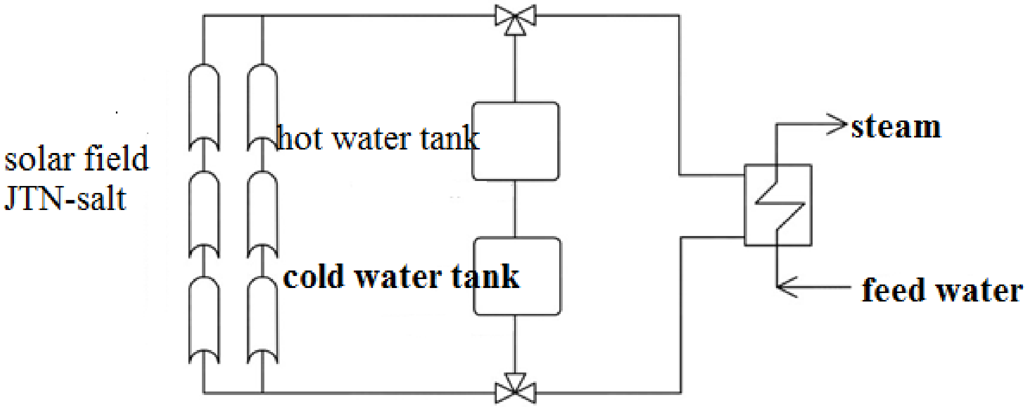
Thermal Energy Storage technology solves the temporary mismatch between solar energy consumption and electricity demand, which provides a clear advantage for Solar Fuel Power Plants plants based on parabolic-cylindrical concentrating compared to other renewable energy sources. In addition, the accumulation of electrical energy using batteries has not proven to be cost-effective. Depending on the daily and annual change in solar radiation and the profile of electricity demand, Solar Fuel Power Plants plants integrated with heat storage systems may have different operating strategies, and the storage system may offer the following functions [2,3]: (1) mitigation of short fluctuations during transient weather conditions, such as cloudy periods; (2) shifting the generation period from peak hours of solar insolation to peak hours of power demand; (3) extending the generation period when solar energy is not available, which improves the annual power factor and requires a larger solar field than a system without storage.

Research and designed applications have identified a number of potential viable thermal energy storage system approaches for solar power plants. All of the different approaches have technologies, performance, and cost ratios that need to be considered in systems engineering and optimization studies. On fig. 1 shows a schematic diagram of an indirect (indirect) two-tank thermal energy storage system. In the case of indirect classification, the system requires two heat transfer fluids, the first one absorbs energy from sunlight in a solar field, and the second liquid transfers the absorbed and stored energy to traditional steam-generating heat exchangers on the power block. To transfer energy from the solar field to the heat carrier to the power unit and the thermal energy storage coolant, another heat exchanger or a set of heat exchangers is required. These additional heat exchangers add cost and reduce overall plant efficiency, but are relatively easy to control. The short-term thermal storage option for parabolic-cylindrical concentrating technologies distributes a "hot oil" heat transfer medium, such as Therminol VP-1, in a solar field and transfers the collected heat through heat exchangers to another heat transfer medium (eg, molten salt) used in a two-tank thermal storage system. The "cold" tank stores and buffers the lower temperature fluid downstream of the power pack and feeds the supply side of the solar field. After absorbing solar energy, it is either fed directly to the heat exchangers of the power unit, or / and stored (through an intermediate oil-salt heat exchanger) in a “hot” tank for later use when required. This type of indirect, two-tank system was used in the SolarTwo solar power plant, built and operated in the mid-1990s. [4]



Picture 1. Indirect (indirect) thermal energy storage scheme with two reservoirs.

The current basic design of Solar Power Generation System (SPGS) stations uses Therminol VP-1 coolant in the collector field. Therminol VP-1 has a low freezing point (12°C) and is stable up to about 400°C, allowing plants to use higher pressure, higher temperature and more efficient Rankine turbines. However, it is difficult to use this heat transfer fluid as a heat storage medium because its vapor pressure is too high to practically store it in any significant amount at higher temperatures. Therminol VP-1 is relatively expensive, and presents an environmental problem if leaked.

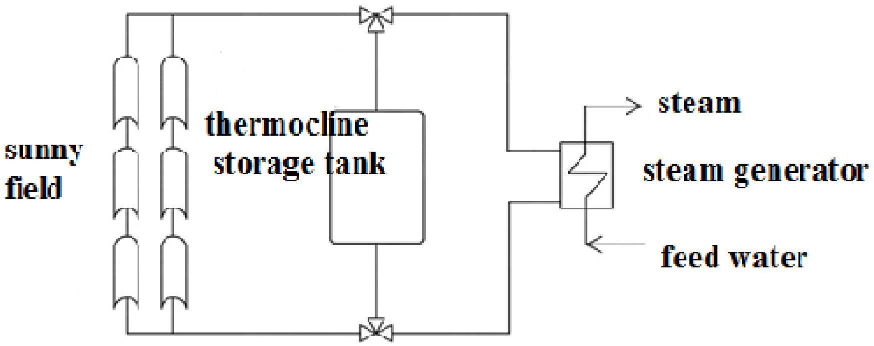


Picture 2. Direct two-tank thermal energy storage scheme.

Instead of using an indirect configuration of the thermal energy storage system, another option is to create a "direct" two-tank thermal energy storage system (Fig. 2). This allows the same fluid to be used in both the solar field and the heat storage system, eliminating the need for expensive heat exchangers. As part of the Trough USA Initiative, an industry-laboratory team led by Kearney and

Associates [5,6] evaluated the feasibility of using inorganic molten salts in both the solar field coolants and the thermal energy storage environment in parabolic-cylindrical concentrating plants. This approach eliminates the use of expensive oil-salt heat exchangers. In addition, the solar field can be operated at higher outlet temperatures (450 to 500°C) than is currently possible with Therminol VP-1, which increases the efficiency of the energy cycle and further reduces the cost of heat storage. The main disadvantage of most molten salt formulations is relatively high freezing points. Because of this, great care must be taken to ensure that the heat transfer salt does not freeze in the solar field. The higher outlet temperature also has some negative consequences, including higher heat loss in the solar field, concerns about the durability of the selective coating on parabolic-cylindrical concentrating receivers, and the need for more expensive piping and materials to withstand elevated operating temperatures. Overall, the initial results for this direct molten salt coolant and heat storage concept look promising, the main issue being the relatively high freezing point of the molten salts.

Another option for a potentially significant reduction in thermal energy costs is the use of a direct, single-vessel thermocline storage system with molten salt nitrates as a direct heat carrier (Fig. 3). A thermocline storage system uses a single tank that is only marginally larger than one of the tanks in a two-tank storage system (eg, used in SolarTwo [4]). By using hot and cold fluid in the same reservoir, the thermocline storage system relies on thermal buoyancy to maintain thermal stratification. The main medium for the accumulation of the medium is an inexpensive filler material, which is used to seal this reservoir. The filler displaces most of the molten salt that can be used in a comparable two-tank system. Research has shown that single-tank thermocline storage systems can offer the lowest energy cost option, which results in potentially reduced tank construction capital costs (and associated pump, valve, and piping costs). [5,6,7].



Picture 3. Scheme of direct thermocline thermal energy storage.

Currently, in the Republic it is planned to build both photovoltaic stations and solar-fuel power plants based on parabolic trough concentrating with and without thermal energy storage. Based on the above analysis, it can be argued that for the Republic of Azerbaijan, the construction of solar-fuel power plants based on parabolic-cylindrical concentrating thermal energy storage with a single-tank thermocline storage system is economically more attractive, since the costs associated with the construction of this system are estimated to be 35% lower storage systems with two tanks.

References

[1] Н.Р. Авезова, А.Э. Хаитмухамедов, А.Ю. Усманов, Б.Б. Болиев Солнечно-тепловые электростанции в мире: опыт разработки и эксплуатации//Гелиотехника, 2016, №4, стр. 63-69.

[2] U.S. Department of Energy. 2014 SunShot initiative portfolio book: concentrating solar power. Washington, DC: Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy; 2014.

[3] Kuravi S, Trahan J, Goswami DY, Rahman MM, Stefanakos EK. Thermal energy storage technologies and systems for concentrating solar power plants. Prog Energy Combust Sci 2013; 39:285–319.

[4] Kelly, B., "Lessons Learned, Project History, and Operating Experience of the Solar Two Project," SAND2000-2598, Sandia National Laboratories, Albuquerque, New Mexico, November 2000.

[5] USA Trough Initiative, "Task 2 Report: Thermal Storage for Rankine Cycle Power Plants," Nexant LLC under Task Order Authorization Number KAF-9-29765-09, San Francisco, California, February 8, 2000.

[6] Kearney & Associates, "Engineering Evaluation of a Molten Salt HTF in a Parabolic Trough Solar Field, Task 6 Report: Final System Performance and Cost Comparisons," NREL Contract No. NAA- 1-3044104, August 20, 2001.

[7] Price, H., "A Parabolic Trough Solar Power Plant Simulation Model," Proceedings of ISES 2003: International Solar Energy Conference, March 2003.

Mammadova Esmira Adil - Lecturer at the Department of "Energy Efficiency and Green Energy Technologies" AzTU. Engages in research on renewable energy sources and their use.
In 2016, she defended his dissertation and received the degree of Doctor of Philosophy in Technology

Contents