CIGRE Russian National Committee

EXPLORE THE BEST PRACTICES OF THE RUSSIAN ENERGY SECTOR

ENERGY of UNIFIED GRID

SCIENTIFIC AND TECHNICAL JOURNAL

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ROSSETI

Special Issue to 47 CIGRE Session 2018

DEAR CIGRE FELLOWS!

I am pleased to welcome you to the 47th Paris Session!

Approaching its second centenary, CIGRE is changing externally and internally. The scale of the activities of its 16 Study Committees has grown. In addition to the traditional Electra journal, the Science & Engineering journal is gaining a larger readership. The New Generation Network and Women in Engineering communities are growing worldwide. For the first time, our Session agenda will feature a CEO Event where over 100 executives from different countries will learn about the benefits of CIGRE for their companies and will share their experience with other executives who have benefited from CIGRE.

In 2016, more than 3,000 Delegates and 8,000 Technical Exhibition visitors had a chance to update their vision of global trends of energy system development and enjoy informal interaction with the top professionals of the energy sector from across the globe. In 2018, we expect even more colleagues to attend.

The Russian (USSR) National Committee of CIGRE is one of the oldest committees and by the end of 2017 became the fifth largest in the world. It has representatives in all of 16 CIGRE Study Committees, numerous Working Groups, the Administrative Council, and Steering Committee. Russian experts twice were Chairs of the SCs — V.V. BOURGSDORF (SC 22 Overhead Lines) in 1976–1982, and I.A. GLEBOV (SC 11 Rotating Machines) in 1958–1968. The first woman to hold this position will be O.V. SINENKO, who will assume her responsibilities in 2018 (SC D2 Information Systems and Telecommunication).

For the past 20 years, 32 Russian members were recognized with the CIGRE Distinguished Member Award. In 2014, A.F. DYAKOV received a CIGRE Honorary Member Award. All of this demonstrates the level of contribution that Russian experts make to the CIGRE community.

Russia takes an active part in CIGRE Sessions. This year, 36 papers will be presented, including 11 from Young Members. For the second time, the Collective Exposition of the Russian CIGRE Community will take place within the scope of the CIGRE Technical Exhibition. The Russian Youth Section provides support to New Generation Network booth activities.

Russia is a very hospitable host of CIGRE events. In 2017 alone, it hosted Colloquium D2 and B5 International Conference. A meeting of the Joint Steering Committee & Technical Council is to be held in Moscow in 2019 on the initiative of Russian NC Chair Andrey MUROV.

I greatly appreciate the tradition of special issues of local industry magazines published for a CIGRE Session. This gives us an additional opportunity to gain an insight into other countries' energy sectors, their best practices and solutions, and to share local expertise with the CIGRE community, which is one of the main goals of the Association. I am confident that their valuable experience and visions presented in this Magazine can be implemented in many parts of the world.

I wish all of the readers a fruitful and enjoyable 47th Session. Let's make the world brighter together!

Rob STEPHEN,
President of CIGRE

DEAR CIGRE SESSION DELEGATES!

The Russian Federation has been cooperating productively with the International Council on Large Electric Systems for more than 95 years. During this time, the experts and manufacturers of power equipment took part in numerous joint projects aimed at improving the availability and quality of electricity for consumers worldwide.

The interest of foreign experts in the work of Russian specialists on the CIGRE platform is attributed to their vast experience in the development and management of large power systems in Russia. Additionally, Russian specialists have acquired extensive knowledge from their colleagues in this reputable academic and technical association. This longstanding partnership helps us create a reliable and efficient power industry of the future.

At the 47th CIGRE session held in Paris in 2018, the Russian delegation will take the most active part in the discussion of the issues of digital transformation of the industry and implementation of innovative technologies. The technical exhibition will feature a booth of Russian companies demonstrating their latest achievements in such areas as digitalization, cyber security, emergency control automation, energy efficiency, and high temperature superconductivity. These topics are gaining a greater momentum in the modern world.

I wish the journal's readers, delegates and guests of the 47th CIGRE session fruitful discussions, efficient experience sharing, and new valuable contacts for the development of a reliable and accessible power environment.

Sincerely,
Vyacheslav KRAVCHENKO
Deputy Minister of Energy
of the Russian Federation

MINISTRY OF ENERGY
OF THE RUSSIAN FEDERATION

DEAR COLLEAGUES!

On behalf of the Russian National Committee of CIGRE, I would like to welcome you to the 47th CIGRE Session!

Russian, and previously Soviet, energy specialists have been taking an active part in CIGRE activities for 95 years. According to the 2017 results, Russia ranks first in Europe and 5th in the world in terms of its membership.

CIGRE tools are there not only to help stay abreast of the world's leading developments and ideas, but also make a significant contribution to the international expert relations and fulfill the unique research potential conditioned by the specific features of development and operation of the power system of the world's largest country spanning 11 time zones and all climatic zones and ranking among the best in terms of power supply reliability and energy costs.

In 2018, Russia will present an unprecedented number of papers at the Session: 25 main papers and 11 papers from the Youth Section. For the third time a collective booth of Russian companies that are members of the Association will be presented at the Technical Exhibition of CIGRE. Unique Russian designs in the field of energy efficiency and high-temperature superconductivity will be unveiled there. The display will be dedicated to the country's latest solutions in emergency automation, cyber security and digitalization of energy facilities, which are gaining a greater focus in the modern world. Russia will for the first time showcase its own invention: a combined optical current and voltage transformer applied at HV digital substations and nonferrous smelters. These technologies are available only from two or three manufacturers in the world.

As part of the business program, there are plans to sign a number of agreements on developing international cooperation and promoting advanced domestic technologies to foreign markets. The existing tradition of bilateral meetings for experience sharing between Russian and foreign grid companies will continue.

A special issue of the sectoral science and technical journal Energy Unified Grid prepared for the participants of the 47th CIGRE Session features information about groundbreaking projects and solutions in the most prioritized areas of development of the Russian energy sector presented at the Session. Executives of companies — manufacturers of equipment - are sharing their success stories about promoting technologies to foreign markets through CIGRE tools.

I am confident that proposals from Russian colleagues will be of great interest to the international community of the sectoral experts and will find their way into the power systems of other countries.

I wish all participants of the 47th Session fruitful work and productive interaction with their colleagues in the field!

Andrey MUROV,
Chairman of Russian NC CIGRE,
Chairman of the Management Board of PJSC FGC UES

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RUSSIAN EXPERTS IN CIGRE — 95 YEARS OF COOPERATION

As of 2017, the Russian national committee of CIGRE is the 1st in Europe and the 5th in the world by the membership rating.

This is the result of a long way of developing partnership with the largest non-governmental international association in the industry lasting for as long as 95 years.

Keywords: Local Study Commettee; Russian National Commettee; Youth Section; Colloquium D2; RPA Conference.

The Russian NC of CIGRE is the 1st in Europe and the 5th in the world by the membership rating

Cooperation of Russia (USSR) and CIGRE has always been an industry-wide mission aimed at ensuring efficient channels of interaction for the Russian and international science in the sector. CIGRE tools are there not only to help keep up with all of the world's leading developments and ideas but also to make a tangible contribution into the international expert relations — to fulfill the unique research potential conditioned by the specifics of development and use of the power system of the world's largest country operating in 11 time zones and all climatic zones simultaneously and ranking among the best in terms of power supply reliability and energy cost.

Russia (the USSR) began cooperating with CIGRE in 1923, two years after the organization was established. In 1946, the Soviet representative, Mikhail SHATELEN, the country's first professor of electrical engineering, initiator of electrotechnical school in Russia, was elected a member of CIGRE Administrative Council for the first time. The first leader and mastermind of the USSR National Committee (NC) of CIGRE established in 1957 was Lev MAMIKONYANTS, and his deputy was Boris LEBEDEV, Chairman of the Soviet Committee for participation in international power industry associations (SovMEK). They laid the foundation and the basic approach for the future participation of Russia (USSR) in CIGRE.

From the 1960s on, Russia (the USSR) has been represented in all of CIGRE's Study Committees, bringing the country industry's greatest minds to the vanguard of international expert teamwork. In 1969, the USSR (Volgograd) hosted the session of Study Committee (SC) "Direct current transmissions" for the first time.

By 70's, already five sessions of CIGRE Study Committees had been held in the USSR. In 1971, the USSR (Moscow) hosted the meeting of CIGRE Ad-

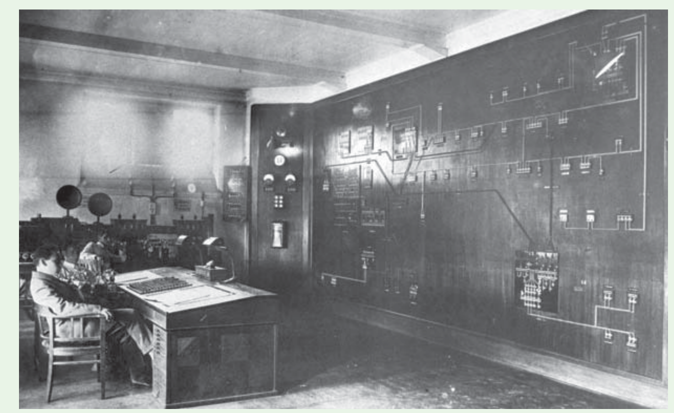


Fig. 1
The first dispatching center in Russia, 1920

Fig. 2
Report of Lev MAMIKONYANTS, the first Chairman of CIGRE USSR National Committee at the 21st CIGRE Session in 1966

ministrative Council for the first time. In 1989, in the USSR (Minsk and Vilnius), the Colloquium and the session of the SC "Communication and data transmission" as well as a session of the CIGRE Technical Committee were held for the first time.

> *Throughout these 95 years, Russian (Soviet) specialists were taking active part in CIGRE life*

Russia, also hosted Colloquium of SC "Rotating electrical machines" (Moscow, 1995), session of CIGRE Technical Committee (Moscow, 2002), session of the Steering Committee (Irkutsk, 2005), Colloquium of SC A2 "Transformers" (Moscow, 2005), and for the first time in contemporary Russia session of CIGRE Administrative Council (Kazan, 2013).

The creation of B5 Local Committee "Relay protection and automation" in Russia on the basis of JSC SO UPS aided by JSC VNIIR and the fruitful cooperation with CIGRE SC B5 allowed to organize in Russia regular international conferences "Actual trends in development of power system relay protection and automation" in different cities (Cheboksary, Moscow, Saint Petersburg, Yekaterinburg, Sochi) starting from 2007 to attract as many Russian specialists for discussion of modern trends in RPA technology development with international leading experts in this area as possible. The conferences are organized by JSC SO UPS, PJSC FGC UES, PJSC RusHydro, and JSC VNIIR, supported by the Russian Ministry of Energy and Russian NC of CIGRE.

Anatoly DYAKOV, professor, corresponding member of the Russian Academy of Sciences, greatly contributed to the development of relations between power industry professionals and their international colleagues in CIGRE. He dedicated over 30 years of his life to this work. Starting from 1988, he was continuously representing Russia in the Administrative Council and the Steering Committee of CIGRE. From 1989 to 2009, he headed the Soviet (from 1992, the Russian) national committee of CIGRE. In 2009, Anatoly DYAKOV was elected Honorary Chairman of the Russian NC of CIGRE and Chairman of the Technical Committee.

In his research work, Anatoly DYAKOV was focusing on the issues of development and implementation of a system to improve the reliability of the Unified Energy System of Russia. In recognition of his outstanding merits before the global power society, he was bestowed with the "CIGRE Distinguished Member" status in 2000, and awarded with the title of the "CIGRE Honorary Member" in 2014. He was the only person

Fig. 3

YURIY V. SHAROV, CHAIRMAN OF THE LOCAL TECHNICAL COMMITTEE

RESEARCH AND DEVELOPMENT

The R&D activity of the Russian NC of CIGRE is carried out under the supervision of the Local Technical Committee. The Technical Committee's Chairman is Prof. Yuriy SHAROV. The composition of the Technical Committee in terms of its individual members and their number is approved by the Presidium of Russian NC CIGRE as advised by the Technical Committee's Chairman for a period of four years.

MAIN FUNCTIONS OF THE TECHNICAL COMMITTEE

- Organization of activities of Russian representatives in CIGRE Study Committees;
- Organization of activities of the Russian NC of CIGRE Committees;
- Selection of Russian papers to be presented at a CIGRE Session;
- Selection and introduction of candidates from Russia to attend conferences, symposia, colloquia, and other CIGRE events and papers to be presented there;
- Organization and arrangement of meetings of the Local TC, drafting and approval of final documents.

AREA OF RESPONSIBILITY OF THE TECHNICAL COMMITTEE

- Drafting of a proposal regarding the main areas of the R&D activity of Russian NC of CIGRE;
- Development of plans, arrangement of research activities, formation of Local SCs;
- Oversight of activities of Russian NC of CIGRE representatives in CIGRE Study Committees.

WORKING GROUPS

Russian representatives take part in the activities of 30 % of international WGs. As of August of 2018, four international Working Groups were established under the leadership of the Russian NC.

In 2017–2018, ten national Working Groups began their activities. After collecting necessary data in Russia, some of them will continue their activity as international Working Groups.

PAPERS AT 47TH SESSION OF CIGRE SUBMITTED BY RUSSIA

In 2018, Russia presents an unprecedented number of papers at the Session: 25 main papers and 10 papers from the Youth Section.

Technical competence and informational awareness of Russian professional industrial community allows to determine common trends of development in the area of international development of scientific and technology exchange.

In 2018, Russia presents an unprecedented number of papers at the Session: 25 main ones and 10 from the Youth Section

in Russia (USSR) to receive this title over 95 years.

The Soviet national Committee's functions of streamlined policymaking and representation of the USSR's interests in CIGRE were guided by the relevant ministry. In 1992, those functions were ceded to JSC RAO UES of Russia. In 2008 (as the RAO ceased to the Russian NC function), the activities of the Russian NC were built on the basis of JSC System Operator of the United Power System, and since 2015, after Andrey MUROV was elected Chairman of Russian NC of CIGRE, the Committee is supported by PJSC FGC UES. The head of Local Technical Committee is Yuriy SHAROV, professor, member of the Board of PJSC Inter RAO, General Director of LLC Inter RAO Engineering.

Throughout these 95 years, Russian (Soviet) specialists were taking active part in CIGRE life. They not only worked proactively at the National Committee's level, in national and international working groups, but also captained the trends of research, i.e. defined the global R&D agenda. For instance, between 1958 and 1968 the SC "Rotating Electrical Machines" was headed by Igor GLEBOV, and from 1976 to 1982 the SC "Overhead Transmission Lines" was led by Vladimir BURGSDORF. In 1970, Lev MAMIKONYANTS, professor, was elected for the Technical Committee of CIGRE.

The first woman to head a Study Committee over the whole history of cooperation of Russia (USSR) with CIGRE is Olga SINENKO, who became the head of SC D2 "Information Systems and Telecommunication" in 2018.

Today holding CIGRE events in Russia remains one of the priorities of the Russian National Committee. In 2017 alone, with the support of the Russian NC of CIGRE's key partners: PJSC FGC UES (part of Rosseti Group), JSC SO UPS, and PJSC Inter RAO, a number events took place, including:

- ***International conference "RPA for Electric Power Systems 2017"*** (Saint Petersburg) organized by JSC SO-UPS, PJSC FGC UES, and PJSC RusHydro in cooperation with Local B5 SC "Relay protection and automation" of Russian NC of CIGRE and SC B5 of CIGRE and aided by the Russian Ministry of Energy and Russian NC of CIGRE.
The conference gathered over 350 RPA professionals from Russia and overseas, including 40 foreign participants from 24 countries. Its agenda included discussion of 160 papers (122 from Russia and 38 from abroad), beside speeches at the plenary meeting, CIGRE SC B5 seminar, and three panel discussions on topical RPA development areas. The hosts of the conference paid great attention to attracting young specialists to the event. The conference welcomed over 50 students and postgraduates from 14 field-specific educational institutions of the country.
- ***CIGRE SC D2 Colloquium "Information systems and telecommunications"*** (Moscow) organized by Local D2 SC (JSC RTSoft, Olga SINENKO) in cooperation with CIGRE SC D2 with support from PJSC FGC UES. This was a key event in IT for power industry, which took place in our country and brought over 150 experts from 26 countries, gathering great attention in Russia and abroad. The papers were presented by 55 speakers, including 13 papers prepared by the Russian NC of CIGRE Youth Section. The colloquium was visited by Philippe ADAM, Secretary General of CIGRE, who met with the National Committee management as well as with the Youth Section members.
- ***International conference "Digital Substation. Standard IEC 61850"*** organized jointly with the Dutch National Committee of CIGRE with support from PJSC FGC UES, Local A3 SC "High voltage equipment" (R&D Center at FGC UES, KOSOLAPOV I.A.) and Local B3 SC "Substations" (PJSC FGC UES, Dmitry VODENNIKOV). The event was attended by experts from 21 countries — it was decided to hold the Conference on a regular basis, every two years.
- ***"Jobs of the Future in Power Industry" panel discussion*** within the Moscow International Education Fair, brought together representatives of the Ministry of Education and the Ministry of Energy of Russia, chief officers of the key industry-related educational institutions, and representatives of the industry's largest companies in one venue for live discussion on the future of the field-specific education.
- ***Meeting of the WG D1.52 of SC D1 of CIGRE "Moisture measurement in insulating fluids and transformer insulation — An evaluation of solid state sensors and chemical methods".*** The organizers of the meeting were Local SC D1 "Materials and emerging test techniques" (Massa LLC — Plant Izolyator, Aleksandr SLAVINSKIY) and JSC Technical Inspection UES.

Fig. 4

Fig. 5
Russian NC CIGRE reporting conference on the results of the 46th CIGRE Session

For Russian industry experts there are traditional ***Reporting Conferences on the results of CIGRE Sessions*** where representatives of Russia in CIGRE SCs and heads of Local SCs provide a brief summary for those who is interested on the basic global trends of power system development, highlighting the most topical aspects for Russia.

An overview and analysis of results of Russia's participation in CIGRE Sessions are published in special editions of the "Energy abroad" appendix to the "Energetik" magazine.

In the coming years Russia is ready to welcome CIGRE events of no less importance:

2019:

- Joint meeting of the Steering Committee and the Technical Council of CIGRE (October, Moscow)
- International conference "Digital Substation. Standard IEC 61 850. Digitalization of power networks" (June, Moscow)

2020:

- International conference "Relay protection and automation of power systems" (June, Moscow)

2021:

- SC A1 Conference "Rotating Electrical MachinesФ (2021 — requested)

2023:

- Joint Colloquium of SC D1 "Materials and Emerging Test Techniques" and A3 "High Voltage Equipment" (2023 — requested. Other Local SCs are invited to join)

YOUTH SECTION

Today, the Youth Section of the Russian National Committee is one of the largest and the most successful youth associations in CIGRE's global practice.

The Youth Section concluded 20 cooperation agreements with leading Russian technical universities. Under the Youth Section program supported by leading power companies and partner universities, more than twenty all-Russia and international events are held on a regular annual basis, which include contests, quizzes and competitions, practice-oriented public lectures by representatives of Local SCs, forums, scientific and technical conferences. Participants of the section can learn from the industry's leading experts, share experience with colleagues, and present their research papers at the regional and international conferences, including the world's biggest power industry event, the CIGRE Session in Paris.

The wide geography of participants of the Youth Section events allows the students and postgraduates to assess their knowledge, compare the level of proficiency, show their expertise, and compete with the best young specialists. This interaction enriches all of its participants with new knowledge and experience, promoting the professional development of young researchers and formation of a succession pool for the industry.

Fig. 6
International conference "RPA for Electric Power Systems 2017"

LEADING SCIENCE AND ENGINEERING PARTNERS OF THE RUSSIAN NC OF CIGRE

To provide an organizational base for development of CIGRE research areas, Local SCs have been created since 2007 on the Russian level hosted by the basic entities — leading science and engineering partners in the relevant industrial areas. The main task of the leading science and engineering partner is to manage the international scientific and technical exchange in the respective line of knowledge research for the interests of the Russian industry society.

Agreements have been achieved by now to create 16 Local SCs:

1. A1 Rotating Electrical Machines — PJSC Inter RAO www.interrao.ru
2. A2 Power Transformers and Reactors — Togliatti Transformer LLC www.transformator.com.ru
3. A3 Transmission & Distribution Equipment — JSC R&D Center at FGC UES www.ntc-power.ru
4. B1 Insulated Cables — Tatcable LLC www.tatcable.ru
5. B2 Overhead Transmission Lines — PJSC FGC UES www.fsk-ees.ru
6. B3 Substations and Electrical Installations — PJSC FGC UES www.fsk-ees.ru
7. B4 DC Systems and Power Electronics — JSC NIIPT www.niipt.ru
8. B5 Relay Protection and Automation — JSC SO-UPS www.so-ups.ru
9. C1 Power System Development and Economics — Irkutsk National Research Technical University www.istu.edu
10. C2 Power System Operation and Control — JSC SO-UPS www.so-ups.ru
11. C3 Power System Environmental Performance — PJSC Inter RAO www.interrao.ru
12. C4 Power System Technical Performance — MPEI National Research University www.mpei.ru
13. C5 Electricity Markets and Regulation — NP Market Council Association www.np-sr.ru
14. C6 Active Distribution Systems & Distributed Energy Resources — Saint Petersburg Advanced Training Power Institute www.peipk.org

15. D1 Materials and Emerging Test Techniques — Massa LLC (Plant Izolyator) www.mosizolyator.ru
16. D2 Information Systems and Telecommunication — JSC RTSoft www.rtsoft.ru

RUSSIA AT THE 47TH CIGRE SESSION

The Russian National Committee of CIGRE traditionally organizes participation of the Russian delegates, including representatives of the management and experts of the leading companies, in the Session.

In 2018, Russia will present an unprecedented number of papers at the Session: 25 main ones and 10 from the Youth Section.

The works in the main agenda reflect the problematics on 14 lines of research:

- A1 Rotating Electrical Machines — 1 paper;
- A2 Transformers — 1 paper;
- A3 HV equipment — 2 papers;
- B1 Insulated Cables — 1 paper;
- B2 Overhead Lines — 1 paper;
- B3 Substations — 2 papers;
- B4 DC Systems & Power Electronics — 2 papers;
- B5 Relay Protection and Automation — 4 papers;
- C2 Power System operation and Control — 1 paper;
- C3 Power System Environmental Performance — 2 papers;
- C4 Power System Technical Performance — 2 papers;
- C6 Active Distribution Systems & Distributed Energy Resources — 1 paper;
- D1 Materials and Emerging Test Techniques — 3 papers;
- D2 Information Systems and Telecommunication — 2 papers.

The papers were prepared based on the preferential subjects approved by CIGRE central office, which were studied by the Russian professional community, during the traditional Reporting Conference of Russian NC CIGRE on the results of the 46th Session.

The Reporting Conference played an important part in studying the topics of papers during preparation for the 47th CIGRE Session by the voting results for the determination of Russia's prioritized subjects in the power grid development. The results of the Reporting Conference of the Russian NC on the outcome of the 46th Session and the preferential subjects for the 47th Session of CIGRE reflect that the opinions of Russian and foreign specialists really match in respect of the most topical subjects of research.

For the third time now a collective booth of Russian companies will be presented at the Technical Exhibition of CIGRE. This year, the members of the common display (booth 217) will be:

- JSC R&D Center at FGC UES;
- Prosoft-Systems Ltd.;
- JSC Positive Technologies;
- JSC SuperOx;
- JSC RTSoft;
- Togliatti Transformer LLC;
- MNPP Antraks LLC;

Fig. 7
International conference "Digital Substation, IEC standard 61850"

– Siberian Design and Assembly Company Ltd.

Unique Russian developments in the field of energy efficiency and high-temperature superconductivity will be presented.

The exposition will be dedicated to the Russian Companie's newest solutions in wide area of control automation, cybersecurity and digitalization of utilities, which are gaining more and more focus in the world.

It will be the first time that the Digital Display (Explore the Best Practices of the Russian Energy Sector) will be organized so that companies can take part in the exhibition remotely.

Profotech company will for the first time present its own development: a combined optical current and voltage transformer applied at HV digital substations and nonferrous smelters. These technologies are only available from two or three manufacturers in the world.

In total, 32 persons were granted with "CiGRE Distinguished Member Award" in the period between 1996 and 2016

As part of the business program, it is planned to sign a number of agreements on developing international cooperation and transferring advanced domestic technologies to foreign markets. It is planned to continue the positive practice of organizing bilateral meetings to share experience between Russian and foreign grid companies.

The following Russia representatives were awarded with the "CIGRE Distinguished Member" title in 2018:

- Valentin BARINOV;
- Alexander ILIENKO;
- Alexander KHRENNIKOV;
- Yury MORZHIN;
- Andrei PODSHIVALIN;
- Natalia VAGA;
- Nikolai VOROPAI.

In total, 32 persons were marked in the period between 1996 and 2016. The first awardees were: Lev MAMIKONYANTS, professor; Nikolai TIKHODEYEV, academician; and Igor GLEBOV, academician.

A letter of acknowledgment from the CIGRE Technical Committee (Technical Committee Award) in 2018 will be bestowed upon Goda NUDELMAN, Chairman of the Board of Directors of JSC VNIIR, who considerably contributed to the development of the integrated power grid in Russia and to the establishment of Local B5 SC of the Russian NC of CIGRE.

Fig. 8
International conference "Digital Substation, IEC standard 61850"

INTERVIEW WITH SC D2 CHAIRMAN OLGA V. SINENKO

Olga V. SINENKO, Chairman of study committee D2 CIGRE (Information systems and telecommunication), Chairman of Subcommittee D2, Russian National Committee of CIGRE

— Mrs. SINENKO, in May 2018, the Administrative Council of CIGRE unanimously approved your appointment as the new Study Committee D2 Chair. How did you manage to achieve such a great success, as the previous chairman of the SC from Russia, or to be more precise, from the USSR, was awarded this position more than thirty years ago. And what will this appointment bring in to the Russian energy community?

— Study Committee D2 (SC D2) is one of the youngest SCs of CIGRE (note: SC D2 was created in 2004), but we can hardly exaggerate its role, so rapidly growing nowadays, because information technology supports absolutely all spheres of human activity, including all the branches of the electric power industry. The main slogan of CIGRE — "for sustainable energy" — is based on the most progressive achievements in the field of automated control systems development, Big Data, Cloud Computing Architecture, Internet of things (IoT), blockchain and cybersecurity.

SC D2 provides the favorable professional platform for the work of international experts for IT in power sector. Such cooperation will definitely enrich both the international community and our country as one of the key CIGRE players (note: Russian NC of CIGRE is ranked first in Europe and fifth in the world for the number of its members), will further enhance the prestige of our professionals for IT in electric power industry.

— How will subcommittee D2 activities correlate with SC D2 work taking into account that both of the committees are headed by you?

— As the Chairman of SC D2 CIGRE I see my mission in reaching the key goals set by the Technical Committee of CIGRE within the overall strategy — initiation and launching of new SC D2 Working Groups (WG) as well as joint WG (JWG) in collaboration with other SCs. I`m going to pay the particular attention to "CIGRE Science & Engineering" journal, so that publications on "Information Systems and Telecommunication" will occupy an important position in this edition.

At the same time, as the Subcommittee D2 chairman, I will encourage the participation of Russian experts in the newly approved WGs and JWGs of SC D2, as well as initiate the Russian NC WGs launching.

— What do you personally plan to introduce in SC D2?

— I`m planning to launch more JWGs in cooperation with other committees, which, in its turn, means the following publications of useful technical brochures.

I`m going to take part in the process of extension of the CIGRE developments (technical brochures, green books, reference papers) into the world's energy companies activities, to reinforce the feedback on the SC D2 activities efficiency based on the final results from power utilities. As well as, the educational programs in universities and adjustment training centres should rely much more on the results of CIGRE.

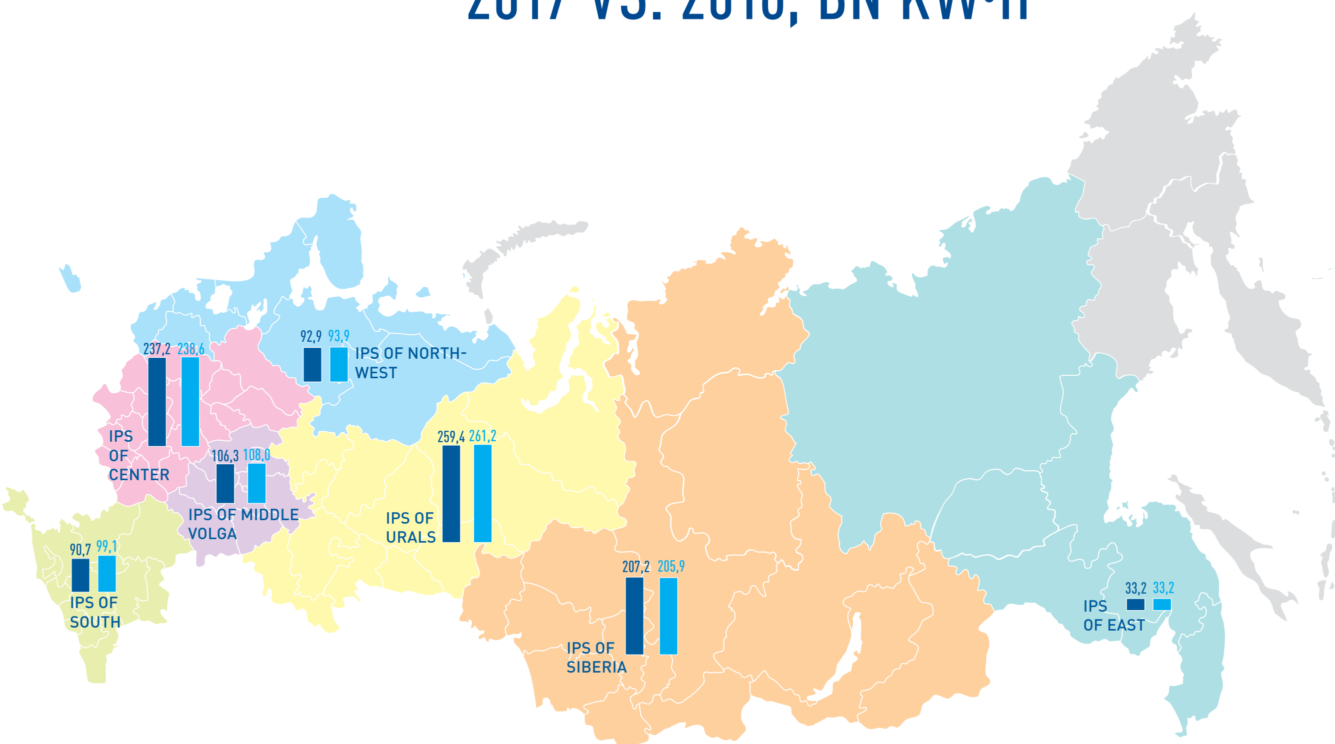
In addition, within SC D2 activities I want to develop further cooperation with international associations and standardization organizations, such as IEC, IEEE, etc.

— What message do you want to convey to the readers in conclusion?

— In conclusion, I would like to wish all the participants of the 47th session of CIGRE productive days, gaining new knowledge and useful information with its obligatory subsequent revision and consolidation. Moreover, I want to invite those companies and experts who have not become CIGRE members yet, to join our activities. This decision will allow you to get an essential experience and will provide you with a unique opportunity for professional communication in the most elite environment of the global electric power industry — CIGRE!

PERFORMANCE INDICATORS OF UNIFIED ENERGY SYSTEM OF RUSSIA

POWER CONSUMPTION BY IPS 2017 VS. 2016, BN KW·H



Legend
- 2016 consumption
- 2017 consumption

Consumption in UES of Russia in 2017 reached 1,039.9 bn kWh, which is 1.3 % higher than in 2016.

Generation amounted to 1,053.9 bn kWh, which is 0.5 % higher than in 2016.

FGC UES

ROSSETI

PJSC ROSSETI — the operator of energy networks in Russia — is one of the largest power companies in the world. The company manages 2,34 million kilometers of power lines and 502 thousand substations with the total transformer capacity of more than 781 thousand MVA.

PJSC FGC UES (part of ROSSETI Group of Companies) was established in accordance with the electrical power industry reformation program of the Russian Federation as a company responsible for the management of the Unified National (Russian) Electric Grid (UNEG) for the purpose of its preservation and development.

«SO UPS», JSC

"SO UPS", JSC is the sole specialized organization performing centralized operational dispatch management in the Russian United Power System.

748 POWER STATIONS WITH INSTALLED CAPACITY OVER 5 MW

239 GW WITH TOTAL INSTALLED CAPACITY

12 000 110-750 KV SUBSTATIONS

480 THOUS. KM LENGTH OF OHTL

133 INTERCONNECTOR TRANSMISSION LINES

155 GW HISTORICAL PEAK OF POWER CONSUMPTION IN UES OF RUSSIA

GENERATION BREAKDOWN IN UES OF RUSSIA IN 2017, BN KW·H

THERMAL	611.3	(58.0 %)
NUCLEAR	202.6	(19.2 %)
HYDRO	178.9	(17.0 %)
WIND	0.1	(0.01 %)
SOLAR	0.5	(0.05 %)
DISTRIBUTED ENERGY SOURCES	60.3	(5.7 %)

ON THE WAY TO A NEW POWER INDUSTRY

AUTHOR:

A.N. BUSLOV,
COLUMNIST
OF THE ENERGY
OF THE UNIFIED GRID
JOURNAL

Digitalization and introduction of innovative solutions enhancing energy efficiency and reducing losses are the key trends of development of the major grid companies worldwide. One of the leaders in these areas in Russia is FGC UES, a Unified National Power operator that manages 142,400 km of transmission lines and 944 substations with a total power of 347,300 MVA.

Keywords: FGC UES; digitalization; digital substation; optical current and voltage transformers; automated metering systems; telemetry; remote control; digital communication channels; energy efficient substation; superconductive materials.

Poselkovaya 220kV substation in Krasnodar Territory is one of seven FGC UES facilities where telecontrol is already implemented

Fig. 1
Tobol 500kV substation is the first extra-high voltage facility in Russia where a package of digital technologies has been implemented

After taking office, Vladimir PUTIN, President of Russia, signed a decree determining the strategic fields of social and economic development of the country for six upcoming years. More efficient implementation of innovative technologies is one of the priorities. The document explicitly stresses the need to establish smart control systems for electrical grids.

142,400 km of transmission lines and 944 substations with a total power of 347,300 MVA

Presently, the Russian Ministry of Energy is executing "road maps" for implementing innovations in the fuel and energy sector (FES) and developing the National Technology Initiative, EnergyNet. As Alexey TEXLER, First Deputy Minister of Energy, said at a session of the working group for the development of the concept and program of the FES digital transformation held in April, at the current stage "it is important to identify promising technological projects and create a suite of successful solutions for their scaling and replication." — Alexey Texler, First Deputy Minister of Energy.

The ministry has selected 20 projects for the whole FES that are of nationwide importance and can yield a tangible economic effect. FGC UES is engaged in three of them: the company is the designer of solutions for utilizing superconductive materials and increasing the efficiency of substations, as well as one of the key parties to the Digital Substation project.

FGC UES is one of the leaders in digitalization and introduction of innovative solutions

DIGITAL CONVERSIONS

"The global economy is undergoing a profound transformation. The changing technological paradigm of our consumers has impact on the required quality of service of grid companies. Realizing this, we have chosen digitalization as one of the key trajectories of our company's development," says Andrey MUROV, Chairman of the Management Board of FGC UES. Transformations are underway in several fields: implementation of digital substation technologies, introduction of automated metering systems, telemetry and remote control, and development of an operational communication network.

"We have chosen digitalization as one of the key trajectories of our company's development," — says Andrey MUROV, Chairman of the Management Board of FGC UES

The company has been applying solutions under international standard IEC 61850 for more than 10 years, with 196 substations partially digitized. A practical effect has been achieved: the scope of routine preventive maintenance of relay protection and automation (RPA) systems has been reduced from 40 to 8 hours.

In April of 2018, FGC UES commissioned the 500 kV Tobol substation in order to supply electrical power to the West Siberian Petrochemical Plant. This is Russia's first ultrahigh voltage facility with integrated digital technologies (including automation and control systems with the use of optical current and voltage transformers). The next step will be digitalization of the 220 kV Luch substation — one of the main power centers in Moscow Region. Over 30 similar projects are slated for implementation by 2025.

In 2018, FGC UES began phased introduction of the digital design service into its engineering sphere based on the electronic catalog of standardized documentation on RPA complexes, automated process control systems, and emergency signal and command transmission devices. This software is a digital toolkit where the user may simulate a substation using standard segments consisting of commercially available equipment and control systems. The elements may be combined into a single system whose consistency is verified by the software. Implementation of the digital design will help accelerate the pace of construction and upgrade of power grid facilities, minimize the risk of error, and scale up new technologies more efficiently. Manufacturers will be able to streamline the production of equipment with a focus on the standard solutions included in the e-catalog.

The company is putting a lot of effort into developing a technological communication network, which serves as the basis for implementation of a wide range of digital solutions, including digital substation technologies, telemetry, and remote control. At present, 84 % of FGC UES facilities are connected with electrical power control centers by digital communication channels. The key technology is fiber optic communication lines (FOCL) spanning 74,000 km. By 2025, 105,000 km are to be built and 100 % of the company's substations are to be equipped with digital communication channels.

By 2017, automated power metering systems were implemented at all of FGC UES facilities. State-of-the-art digital data collection and control systems have been implemented at 55 % of FGC UES substations; by

Fig. 2
Skolkovo 220kV underground substation involved in electrical power supply

Fig. 3
Ochakovo 500kV substation is the Moscow Power Ring facility participating in the Energy Efficient Substation project

2025, such systems will be implemented at 100 % of the facilities.

By that time, all Network Management Centers (NMC) of FGC UES will be equipped with automated systems for remote surveillance, performance monitoring, and control of equipment of substations and the electrical grid. The NMC remote control technology has already been implemented at seven substations in Northwestern, Southern and Central Russia. FGC UES is planning jointly with the System Operator to convert 93 backbone grid facilities to the new operation mode by 2021.

Currently, FGC UES is developing the Digital Transformation Strategy, which will be a policy document incorporating the best practices of the Innovative Development Program and Automation Program. In addition to basic technological challenges, digitalization includes pilot implementation of end-to-end improvement technologies (unmanned hardware, tablet computers, data mining, Internet of Things, video analytics, positioning technologies, geographic information systems, etc.), which can be scaled up as the technologies become more affordable.

"In the end, digitalization will be a win-win solution for all of its parties," said Alexey TEXLER in his speech at the Krasnoyarsk Economic Forum earlier this year. With implementation of digital projects, power facilities will be able to optimize their costs, improve performance, expand the range of services, and reduce the costs of downtimes and emergencies. Engineering companies and industrial enterprises will get a "market impetus" for manufacturing innovative products. The country as a whole will improve the reliability and quality of power supply to consumers, enhance the performance stability of key power systems, and find competitive new digital markets functioning for the benefit of all players.

"Digitalization is not merely a trend anymore; it is a blueprint for action. FGC UES is going to spend 50 bn rubles on digitalization of networks and processes in the next five years, that is, 10 bn rubles annually," says Andrey MUROV. A noticeable effect is expected from these investments. In particular, remote control will bring the performance of utilities to a totally new level. The completed pilot projects have shown that the time of scheduled switching operations is reduced drastically (by dozens of times), the risk of human error is minimized, and the reliability of performance is enhanced.

Application of digital substation technologies is expected to allow FGC UES to reduce its operational expenditures by up to 40 % by means of timely troubleshooting of equipment and remote control, transitioning from preventive maintenance to condition-based maintenance, decreasing the number of operators, ensuring the interchangeability of equipment from different manufacturers, and reducing the stock reserves. Capital expenditures will be decreased by 20 % thanks to the lower cost of construction of substation control centers, cabling infrastructure, and application of standard engineering solutions.

ENERGY EFFICIENT SUBSTATION

A pressing issue of the grid system is the considerable number of substations commissioned in the second half of the 20th century. They fail to meet today's energy efficiency requirements — in particular, the annual expenditures of FGC UES for auxiliary needs of power facilities amount to 1 bn rubles.

The "Energy Efficient Substation" project carried out by the company is aimed at solving this problem. It is focused on reducing the auxiliary power needs by up to 50 % at existing facilities and up to 80 % at new facilities. This will result not only in higher efficiency but in better sustainability of the electrical grid.

For example, today up to 30 % of the total auxiliary power consumption is used for the cooling of transformers. Introduction of a liquid cooling system will improve the energy efficiency considerably. Additionally, every power facility has up to 200 units of equipment that require heating. Transformer heat recovery and automated heating control systems will also contribute to improved energy efficiency.

Today up to 30 % of the total auxiliary power consumption is used for the cooling of transformers

Such technologies have been successfully introduced at four mainline substations of Central Russia and Volga Region: 750 kV Vladimirskaya, 500 kV Ochakovo and Nizhegorodskaya, and 220 kV Kudma. In total, 12 pilot projects have been selected; another 160 brownfield and 20 greenfield projects will be covered later. Implementation of an innovative cooling system in 2018 began at three 750 kV ultrahigh voltage facilities in Central Russia: Opytnaya, Bely Rast, and Metallurgicheskaya.

The total budget of the Energy Efficient Substation project is 2.4 bn rubles. The economic effect for FGC UES alone is estimated at 2.7 bn rubles by 2026, and replication of the experience across the whole electrical grid of Russia will yield a multifold effect.

UTILIZATION OF NEW MATERIALS AND SUPERCONDUCTIVITY

Since 2010, FGC UES has been working on designing equipment with utilization of high-temperature superconductive materials. In 2018, the company completed life-cycle tests of a high-temperature superconducting DC cable line (HTSC CL) spanning 2.5 km, which is the first in Russia and the largest in the world. The prototype tested with full operation cycle simulation will be put into operation in 2020 in the power system of St. Petersburg, which will improve the reliability of the city's power supply.

Application of high-temperature superconductors is a global trend in a wide range of industries, not only the electrical power sector. Implementation of HTSC in the grid will enable transmission of higher power at low voltage, minimize losses, and save up to 20 % of line construction costs.

This technology is especially effective for the construction of ring circuits and power bridges and power generation at large power stations, including NPPs. Using HTSC in megalopolises would enable more flexible planning of development and arrangement of power consumption centers by adding capacity in the course of regional development without the need to lay additional cable lines and would significantly reduce the voltage class for high power transmission.

There are dozens of experimental cable lines in the world built to explore the possibility of power transmission using the superconductivity effect with the maximum length of 1 km. Besides Russia, research in this field is conducted in Japan, the Republic of Korea, European Union, and USA.

The FGC UES project is inter-sectoral. Apart from electrical grids, its results can be implemented in all energy-intensive industries, including power facilities of transport enterprises, petrochemical works, refineries, and mining and metallurgical plants. Scaling of the technologies based on high-temperature superconductivity will boost the energy efficiency of national economy.

Fig. 4
HTSC unit of the 2.5 km cable line tested at FGC UES testing site in 2017

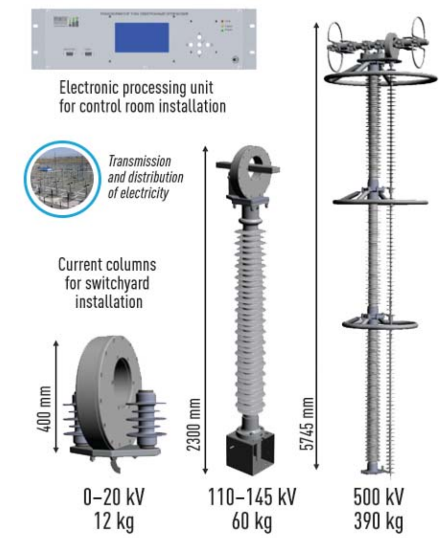
DIGITAL AND INFORMATION BASIS FOR CREATION OF THE INTELLECTUAL GRIDS

PROFOTECH JSC is a unique Russian company, a manufacturer of digital electronic optical measuring transformers, with its own know-how for manufacturing products and the technology for production of magnetically sensitive optical fiber that is a key element for all of the company products.

PROFOTECH provides a completely digital and informational basis for the creation of intelligent networks. The company products are utilized as a single source of data for automation devices, monitoring, metering and relay protection on digital substations, fully conforming to the IEC 61850 automation standard.

PROFOTECH technologies allow to significantly increase the accuracy of measurements and move to a new orbit of measurements using only digital signal processing. The use of optical technologies for relay protection and emergency automation will ensure the most accurate and fast operation of these systems.

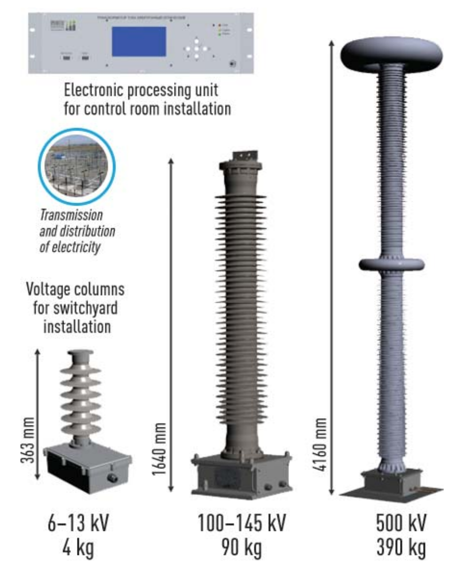
Profotech actively develops its international production cooperation, participating in the projects of digital substations construction. The production of unique combined electron-optical current and voltage transformers has been mastered in partnership with the Swiss company Maxwell



ELECTRONIC FIBER-OPTICAL CURRENT TRANSFORMER (EFOCT)

Parameter	Value
Working principle	Faraday effect in special optical fiber
Insulation	silicon ribbons, dry air (indoor), gel (outdoor)
Rated Voltage	0-750 kV
Rated Primary Current	200 – 40 000 A
Digital interface	IEC 61850-9-2LE (with PRP, PTP support)
Accuracy class	0.2s (metering) 5TPE (protection)

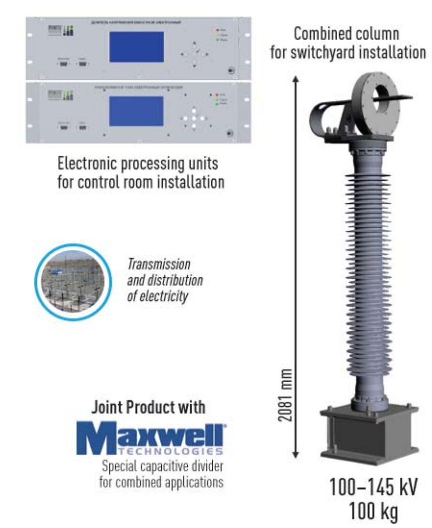
Table 1



ELECTRONIC VOLTAGE TRANSFORMERS (EVT)

Parameter	Value
Working principle	resistive (up to 13kV) or capacitive (higher than 110 kV) divider with ADC module
Insulation	silicon ribbons, mineral oil
Rated Voltage	0-750 kV
Digital interface	IEC 61850-9-2LE (with PRP, PTP support)
Accuracy class	0.2 (metering) 3P (protection)

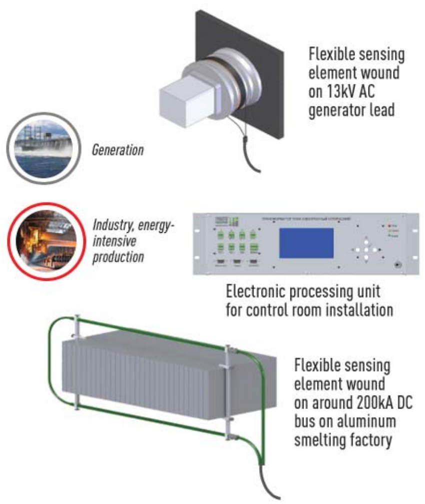
Table 2



COMBINED NON-CONVENTIONAL INSTRUMENT TRANSFORMER (CNCIT)

Parameter	Value
Working principle	resistive (up to 13kV) or capacitive (higher than 110kV) divider with ADC module
Insulation	silicon ribbons, mineral oil
Rated Voltage	0-750 kV
Digital interface	IEC 61850-9-2LE (with PRP, PTP support)
Accuracy class	0.2 (metering) 3P (protection)

Table 3



FLEXIBLE ELECTRONIC FIBER-OPTICAL CURRENT TRANSFORMER (FEFOCT)

Parameter	Value
Working principle	resistive (up to 13kV) or capacitive (higher than 110kV) divider with ADC module
Insulation	silicon ribbons, mineral oil
Rated Voltage	0-750 kV
Digital interface	IEC 61850-9-2LE (with PRP, PTP support)
Accuracy class	0.2 (metering) 3P (protection)

Table 4

Technologies SA. The result of this work is successfully operated at the Villarepos substation by the Swiss electric grid company GROUP-E (Figures 2 and 3).

At the same time, Profotech develops cooperation with the Portuguese Corporation EFACEC with the airm for the development of integrated solutions based on the Digital Substation technology. At the meeting in mid-June of 2018 the intentions to promote the integrated digital solutions in joint cooperation were confirmed.

According to the successful test results, the compatibility of Profotech products and the relay protection terminals made by SIEMENS was also successfully confirmed.

The Profotech company is a permanent member of CIGRE, and actively participates in the current 47th Session of the CIGRE.

Taking this opportunity, we invite all readers of the "Energy of Unified Grid" scientific and technical journal to visit our joint stand with Maxwell Technologies SA (Condis brand) at the exposition of the CIGRE Technical Exhibition (stand No. 144).

With best regards,
Profotech team

Fig. 1
The 3-phase combined NCIT is installed at the Villarepos Substation in Switzerland

Fig. 2
Engineers Demid POPOV and Thomas Heid completed the installation of an electronic measuring transformer at the GROUP-E substation in Switzerland

Fig. 3
Profotech and Maxwell international team (Russia, Switzerland)

"RTSOFT" — REAL TIME AND PERSPECTIVE IT FOR POWER ENERGY OF THE FUTURE

For publicity purposes

CONTRIBUTION OF CIGRE STATE-OF-THE-ART ACHIEVEMENTS IN THE DEVELOPMENT OF AN INNOVATIVE ENGINEERING COMPANY

JSC "RTSoft", founded in 1992, is an innovative engineering company which provides a wide range of hardware and software products for industry and power engineering both for Russian and foreign markets.

RTSoft offers solutions for different kinds of businesses such as: electric power industries, nuclear power industries, oil and gas industries, metallurgy, transportation, instrument engineering, IT, telecommunications, railway industries, utilities and building automation, specialized solutions.

RTSoft software, hardware and systems

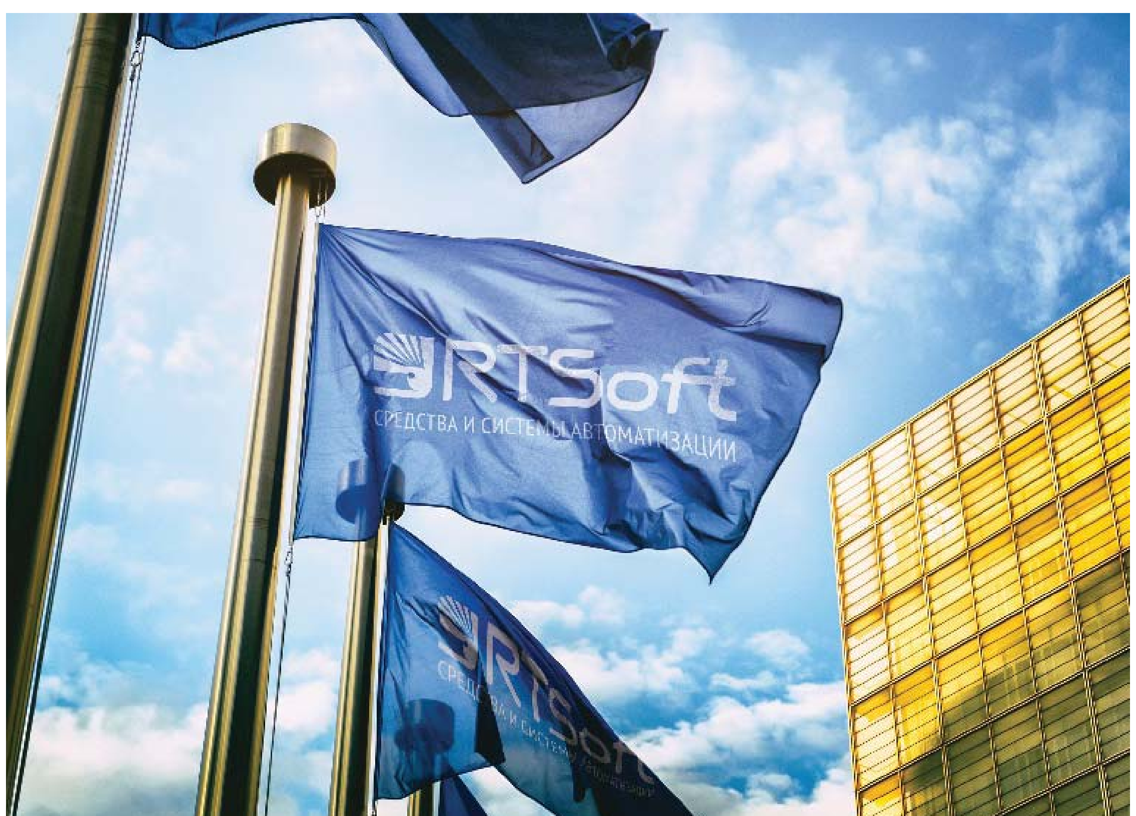


Fig. 1

In 2014 RTSoft became a basic institution for Subcommittee D2 "Information systems and telecommunications" of the Russian National Committee CIGRE, the company assigned the status of "Russian NC CIGRE leading scientific and technical partner".

RTSoft activities as a basic institution have led to the partnership with "National Technology Initiative" EnergyNet with the granted status of EnergyNet competence centre. This cooperation is extremely fruitful for the further expansion of innovative, breakthrough, export-oriented topics in the electric power industry.

Throughout its history, RTSoft team relies on international cooperation, advanced international technologies and standards, with their unconditional adaptation according to Russian features. Due to effectively built collaboration with Russian and foreign technology and production partners, international associations and standardization organizations, the company offers its customers advanced equipment and innovative solutions that meet international quality standards.

"Without the international experience, the cooperation of professionals worldwide, the participation in specialized professional engineering and standardization associations, we could have hardly moved forward today," — believes RTSoft General director Olga SINENKO, Chairman of SC D2 CIGRE, Chairman of Subcommittee D2 Russian NC of CIGRE, D.Sc.

> *Without international experience, cooperation of professionals worldwide, participation in specialized professional engineering and standardization associations, we could have hardly moved forward today*

In partnership with the substation automation leader, Sprecher Automation GmbH, RTSoft in its R&D Department in the city of Chernogolovka has invented Distributed Control System Smart-SPRECON. This collaboration allowed to integrate in the solution the recent Russian and foreign achievements, as well as to cover the direction of digital substations. Distributed Control System Smart-SPRECON meets international standards and requirements for power utilities, which makes possible implementing the platform not only in Russia, but also at foreign markets.

The possibility to keep abreast of the world's development trends in the power energy sector, which CIGRE events: colloquiums, symposia and Paris sessions provide its participants with, enabled RTSoft to open a new department in 2015 — the Smart Grid Technologies Center. Consequently, in 2016 RTSoft presented its innovative solutions in Smart Grid and Distributed Generation at the technical exhibition within the 46th session of CIGRE.

COMPANY PROFILE

25+
years of experience

9000+
projects

600+
SW engineers

350+
Products, I&C complexes and solutions

We are in Russia, Germany and Eastern Europe

Moreover, cooperation with CIGRE may be regarded as a catalyst for a number of other innovative processes of the company. For example, in 2018 RTSoft has successfylly opened its R&D branch in the Skolkovo Center for Development and Commercialization of New Technologies.

Interactive Energy Lab as RTSoft's R&D departament develops innovative solutions in the energy-efficient technologies cluster in two main areas: algorithms and software for optimal management of distributed energy resources as a part of Microgrid, distribution networks and power supply systems for electricity consumers and methodology, algorithms and software for monitoring of relay protection systems and for automation of other Protection Departments tasks.

The next essential milestone RTSoft has reached is the creation the subsidiary RTSoft GmbH in Germany (www.rtsoft.de) in order to promote the software products of RTSoft abroad. In 2018, RTSoft GmbH became a member of The Alliance for Rural Electrification (ARE, www.ruralelec.org), an international business association that promotes a sustainable decentralised renewable energy industry for the 21st century, activating markets for affordable energy services, and creating local jobs and inclusive economies. Partnership with ARE and its members will make electrification projects more efficient and decrease power energy price for end users in rural areas. In addition to that, RTSoft is an active participant of joint research programs with the German Fraunhofer Institutes, Leipzig University and projects for development of IIoT applications for power industry.

At the technical exhibition within the 47th CIGRE session RTSoft will demonstrate its innovative solutions at its booth № 274 and at the joint Russion National Committee booth № 217.

The exposition at RTSoft booth will draw your attention to its unique development — Protection Suite software package for automating Relay Protection Department activities — from Calculations to Risk-based maintenance — for Power Utilities of all types (www.rtsoft-energy.com). The Integrated software suite is aimed at specialists of protection departments and dispatch centers of national system operators and companies operating the main power infrastructure.

RTSoft Protection Software Suite automates major processes in the Protection Lifecycle in any Power Utility, starting from settings calculation, followed by protection system wide coordination.

Based on disturbance monitoring functions the Suite automates identification and localization of fault events in power system, and then performs simulation of fault conditions in the precise power system model with digital twins of relay protection devices inside to obtain reference behaviour during fault events — expected list of tripping, starting for each protection functional block.

This is a part of protection operation evaluation algorithm with protection health diagnostics and condition (risk-based) index calculation.

RTSoft Protection Suite set of functions is universal for industry professionals worldwide and includes 10 groups of features:

- Disturbance monitoring
- Outage data collection and Event notification
- Fault location
- Protection settings calculation
- Advanced Relay modelling
- Lifecycle Documentation Hub and Management system
- Fault root cause analysis
- Protection operation evaluation — local and wide-area
- Protection health diagnostics

- Personnel Training and Development

Protection calculation functions fulfil set of IEC standards requirements. In the Russian Federation, the development was supported by the Ministry of Energy, System Operator of the Unified Power System, RusHydro, Rosseti, the implementation of the pilot project is planned for Federal Grid Company of Unified Energy System. As for foreign markets, Protection Suite has been implemented in Armenia, Tajikistan and is planned to start projects in Croatia, Romania, as well as in Vietnam. Protection Suite was among top twenty IT solutions in the competition held by Moscow Agency of Innovations within the program Road Show IT 2018 among the high-tech sector companies.

At the Russian NC joint booth, RTSoft will present the AMIGO software package (Advanced Modeling and Intelligent Grid Optimization, www.amigo-energy.com). Micro-grid control software AMIGO is an integrated energy management system for autonomous hybrid power plants, energy efficient buildings, production facilities.

As an integrated system, AMIGO performs the functions of secondary regulation of active power and energy, managing various types of distributed energy resources, and operates either fully automatically or in the mode of the dispatcher's advisor.

Unlike the similar EMS systems, advanced system AMIGO is based on the two key advantages that significantly reduce the cost of operation and maintenance of the generating equipment for the end user:

- algorithms for forecasting the load, generating RES and prices at the electricity market and
- functions for optimizing the equipment composition and electrical regimes according to specified criteria (reducing consumers' costs for electricity, reducing electricity losses in networks, the level of wear of electrical equipment, etc.).

Simultaneously, AMIGO is a vendor-agnostic software, which allows companies-system integrators to create optimal, from the viewpoint of hardware architecture, projects.

Together with the The Alliance for Rural Electrification, the complex is planned to be implemented in several minigrid projects in South-East Asia and Africa. The development was awarded a gold medal at the exhibition "Electrical networks of Russia", moreover it was supported by the Agency for Strategic Initiatives and included in the top 100 Russian innovative products.

The professionalism of RTsoft team, adherence to the best traditions of russian engineering school and a course on advanced international technologies through close interaction with CIGRE — all these factors turn out to be the basis for preserving the core values of the company, as well as for sustainable development of RTSoft in smart energy, energy efficiency and cybersecurity under the motto "From big power systems to microgrids".

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Fig. 2
Olga Sinenko, Oleg Dubnov and Mikhail Tykuchinsky open RTSoft partner center in Skolkovo

IZOLYATOR'S STRATEGY OF INTERNATIONAL COOPERATION

For publicity purposes

120 years
IZOLYATOR
Centuries-old traditions – state-of-the-art technologies

International cooperation has always been an important part of our work and Izolyator development. We greatly value every opportunity to prove reliability and efficiency of our technologies by one of the most challenging tests — the test of time. We are searching for exactly such long-term and efficient partnerships, opening new regions of our presence.

Alexander SLAVINSKY

Chairman of the Board of Directors of Izolyator, SC D1 CIGRE Regular Member, Head of Local SC D1, Russian expert at IEC (TC 36 / SC 36A / JMT 5), Doctor of Engineering Science

Expansion of international cooperation and promotion of the integrative development of the power complex between national and regional electric power systems are strategic objectives of state importance today. Russian companies have actively engaged in the processes of building integrative ties with power engineers and electrical engineering companies from all over the world.

Strengthening of partner relations with power grid and generating companies as well as transformer plants in Europe and Asia is a key objective for Izolyator.

Presently, Izolyator exports its products to more than 30 countries of the world, and the company staff members are always open to dialogue, so that a friendly discourse could be continued with partners.

All high-voltage bushings that we make are certified according to Russian and international standards. Using own patented technologies, only the best available equipment and materials, work of highly qualified personnel and stage by stage production process control, guaranty a high technical level and product quality of Izolyator plant products.

Izolyator has carefully analyzed the key trends of the international power market as part of strategic partners research and long-term cooperation planning. Our research has shown that India is one of the most promising partners in that respect.

The power complex of India is rapidly developing by, for instance, improving backbone power lines. Friendly ties since the Soviet Union times, a positive dialogue between the Federal Grid Company of the Unified Energy System of Russia (FGC UES) and the India Power Grid Corporation of India Limited Ltd., as well as Izolyator's operations on the Indian power market, allowed us to continue exchanges between the power grid companies and industrial enterprises of the two countries.

Another important factor of cooperation development is Russia's active role in the International Council on Large Electric Systems CIGRE. India is an active contributor to the Council, too: PowerGrid management heads the Indian National Committee of

Izolyator is a global leader in development and manufacture of 12–1200 kV HV bushings. The manufacturing facility of the company allows for production of 12 thousand high-voltage bushings annually. In its over a 122-year history, the plant has made over 620 thousand high-voltage bushings, operating on the overwhelming majority of power facilities in Russia and the CIS countries as well as 30 other countries in the world.

Fig. 1
High-production insulation winding machine 252–1200 kV

Fig. 2
Meeting of FGC UES and Izolyator representatives with I. S. JHA, Chairman & Managing Director of PowerGrid (in the center) and board members of PowerGrid

CIGRE. Izolyator, in its turn, received a status of the Leading science and technology partner to Russian National Committee of CIGRE (Russian NC CIGRE) and became a base enterprise of study committee D1 Russian NC CIGRE "Materials and Emerging Test Techniques".

Importantly, all our communications with partners are always very open. Thus, Izolyator, as the first in the world supplier of high-voltage RIP bushings to the state Indian power grid company PowerGrid, ran a series of public workshop for the technical specialists of PowerGrid, regional power grid companies APTRANSCO, TSTRANSCO and transformer plants T&R, CG, TELK, TBEA, Toshiba, where it familiarized the Indian colleagues with the technical features and construction design of Izolyator plant products.

Having expanded its presence, Izolyator began to work with the companies that control distribution of electric power across the states of India. In 2017, Izolyator plant received an inspection of representatives of PowerGrid and the regional power grid company TSTRANSCO. A series of successful tests of 145 kV 1250 A HV RIP bushings at Izolyator plant and the All-Russian Electrical Engineering Institute named after V. I. LENIN and 30 pieces of 52, 252 and 420 kV high-voltage bushings has proved to the Indian partners that Izolyator products can be and should be trusted!

We should mention that all the tests and the inspection went in full compliance with IEC 60137-2017 standard, proving the high quality of our products. Besides, we received several orders for bushings of various voltages from Indian power grid companies and transformer equipment OEMs, which we timely delivered under the contract terms.

As a cooperation initiative, in December 2017, we organized several business meetings in India: between FGC UES and PowerGrid and between industrial enterprises and power equipment OEMs of India and Russia.

Power Grid Corporation of India Limited (PowerGrid) is an India-based state company, engaged in construction, operation and maintenance of inter-state transmission system. The company owns and operates transmission network of about 106.804 thousand km of Extra High Voltage (EHV) transmission lines, 184 EHVAC & High Voltage Direct Current (HVDC) Substations with 205 923 MVA transformer capacity.

Fig. 3
The transformer with Izolyator bushings at PowerGrid 400 kV substation

We also ran a "Public Conference in power industry between Russia and India". Representatives of all key divisions of PowerGrid and technical specialists from the largest Indian electrical engineering companies took part in the conference.

Among the most important results of the meetings and conference, is consideration of Russia's leading power products manufacturers' experience for modernization of electrical complex of India. It is based on the long-standing successful interactions with the Federal Grid Company of Russia that has the longest outstretch of power lines in the world and, consequently, the biggest park of high-voltage equipment, operating in various climate conditions.

Izolyator presented key principles of assessment of operating risks of obsolete equipment, types of scheduled measurements, requirements for additional diagnostics and principles of decision-making on OIP bushings replacement.

Actively contacting regional power grid and generating companies, strengthening mutually beneficial and long-term relations with key consumers of high-voltage bushings in the Indian market, Izolyator was able to increase its order portfolio.

As result of that extensive work in the region, we signed supply contracts for large batches of high-voltage RIP bushings with rated voltages 52, 252, 420 and 800 kV to different regions of India — more than 520 pcs totally!

Izolyator is developing a productive dialogue with Indian partners, sends shipments and shares experience in operation and maintenance of high-voltage bushings.

In the first quarter of 2018, Izolyator won a tender of the state Indian power grid company Power Grid Corporation of India Limited for delivery of 420 and 800 kV high-voltage RIP bushings.

As Izolyator expands its presence in Asian markets, we expect to sign a Memorandum of Understanding with the Indian Mehru at CIGRE session in Paris. The document will entail creation of a joint venture to manufacture HV bushings with modern RIP insulation on the territory of India. Mehru Electrical & Mechanical Engineers (P) Ltd. makes measuring transformers for up to 420 kV voltages. The company is one of the leading suppliers of measuring transformers not only in India, but in the whole world.

Operation on the highest level and in conformity with world standards is what gives Izolyator advantage over other manufacturers of electrical equipment. The constructive dialogue of Russian and Indian colleagues is a remarkable fact, speaking for consideration, openness and interest to development of long-term and mutually beneficial partner relations.

Fig. 4
Assembly shop of Izolyator plant

PROSPECTS OF USING HTSC CABLE LINES FOR LONG DISTANCES ENERGY TRANSFER

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The location of powerful electric power sources at great distances from large cities and electric power consumers, leads to the need to transport large energy flows over considerable distances. The use of superconducting cable lines will significantly improve the efficiency, reliability and environmental friendliness of long-distance transmissions.

Keywords: superconducting cable line; power bridge; transmitted power; cryogenic station; critical current; gigawatt.

General view of the cryogenic station with current inputs of the cable line

INTRODUCTION

More recently, the scientific community celebrated the 100th anniversary of the discovery of phenomenon of superconductivity and the 30th anniversary of the discovery of high-temperature superconductivity (HTSC), which has shown the world the possibility of transition from a costly cooling of low-temperature superconductors with liquid helium to a fundamentally new nitrogen temperature level [1]. Currently, there are several dozen experimental cable lines in the world designed to study the possibility of electricity transmission using the superconductivity effect, but their lengths do not exceed one kilometer. The use of superconducting cable lines will significantly reduce the voltage class and increase the unit transmission power due to the increase in operating currents. This opens up the possibility of transmission at reduced voltage, which significantly affects the cost of entire infrastructure of the cable line. In addition, there is no voltage drop along the line length in a superconducting line, which is important for long lines.

ELECTRICAL SCHEME OF SUPERCONDUCTING LINE (A) AND POSSIBLE SCHEMES OF COOLING WITH THE PLACEMENT OF CRYOGENIC STATION FROM ONE END OF THE LINE (B), AND ALONG THE CABLE ROUTE (C)

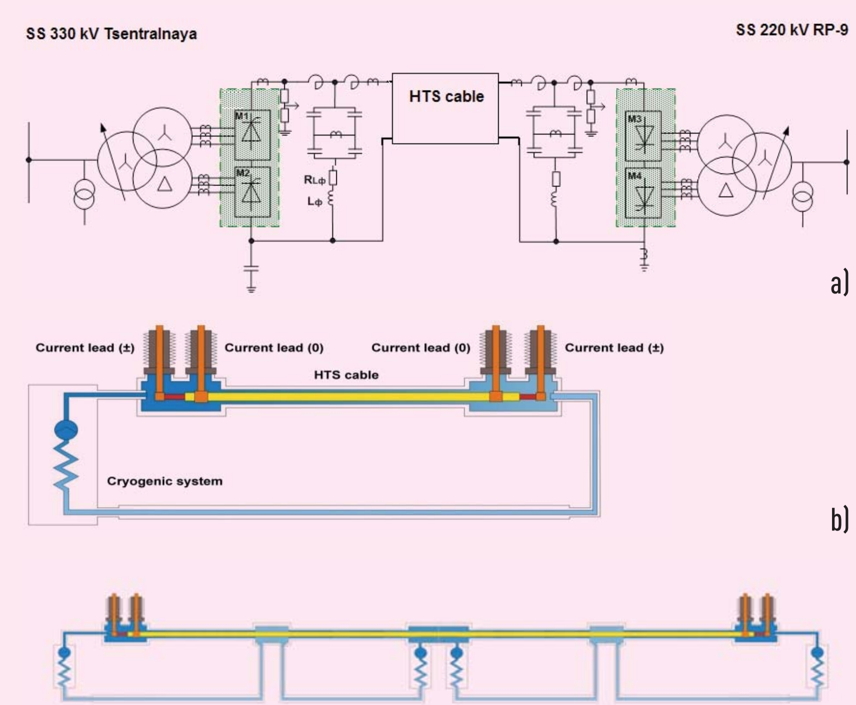

Fig. 1

SUPERCONDUCTING CABLE LINES IN A POWER SYSTEM

High-temperature superconducting cable lines (HTSC CL) are an innovative development that allows solving a significant part of the problem of energy supply to consumers. In electrical networks, it is possible to create a circuit with the use of AC and DC superconducting cables. However, long-distance cable transmissions are possible only with the use of DC lines, since any, including superconducting, AC cable lines have a length limitation, due to the occurrence of charging currents, which lead to a decrease in power at the far end of the line.

$$Ic=U\omega C_0 L, \quad (1)$$

where U is phase voltage, ω is circular frequency, C_0 is capacitance, and L is line length.

As a result, the length of AC cable lines does not exceed several tens of kilometers.

ST. PETERSBURG PROJECT, RUSSIA

The Russian HTSC DC CL project, intended for connecting "Tsentralnaya" 330 kV Substation and "RP-9" 220 kV Substation in St. Petersburg power grid. The length of the cable is 2.5 km, and the loop of pumping with liquid nitrogen is 5.0 km. The introduction of HTSC DC CL into the power grid in this case allows implementing a reversible power mode and providing an increase of reliability of power supply to consumers without the occurrence of unacceptable (emergency) electric regimes and without increasing the short-circuit currents [9]. Design parameters of the line are presented in Table 1.

CONSTRUCTION OF SUPERCONDUCTING CABLE LINE

Fig. 2 shows the superconducting cable layout and its appearance. As a basic design, monopolar design with forward and reverse conductor in one cable was chosen. The cable consists of the following concentric layers. Stabilizing forming element is designed so as to provide the necessary mechanical strength and protection of direct conductor from overheating in emergency situations. Superconducting straight conductor consists of twenty-two tapes with a critical current of 160 A superimposed in two layers on the forming element. Diameters and layer twist pitches are designed for equality of their impedances, which ensures an equal distribution of current between the layers. High-voltage insulation is designed for rated voltage. Superconducting return conductor consists of nineteen tapes with a critical current of 180 A placed in one layer. Next are external stabilizer, external (screen) insulation, electrical (non-superconducting) screen. The cable is placed in a cryostat consisting of two corrugated pipes with vacuum thermal insulation between them and an external protective coating of cross-linked polyethylene.

High value of critical current density in superconductor allowed the placement of forward and reverse conductors in one cable, which leads to localization of magnetic field inside the section of return conductor of the cable. The absence of electromagnetic and thermal scattering fields and the use of liquid nitrogen for impregnation make such cables environmentally friendly and significantly reduce the requirements for cable routing.

Cable line is completed with the necessary fittings [10]. Current leads are used to connect superconducting cable wires to the network and

CHARACTERISTICS OF THE HIGH-TEMPERATURE SUPERCONDUCTING LINE

Transmitted power	50 MW	Type of converters	12-pulse
Rated voltage	20 kV	Possibility of reverse	Provided
Rated current	2500 A	Cooling capacity of cryogenic plant	12kW @ 70k
Working temperature	66-80K	Pressure of liquid nitrogen	up to 1.4MPa
Length of cable	2500 m	Flow rate of liquid nitrogen	0.1 ÷ 0.6 kg/s

Table 1

SUPERCONDUCTING CABLE DESIGN

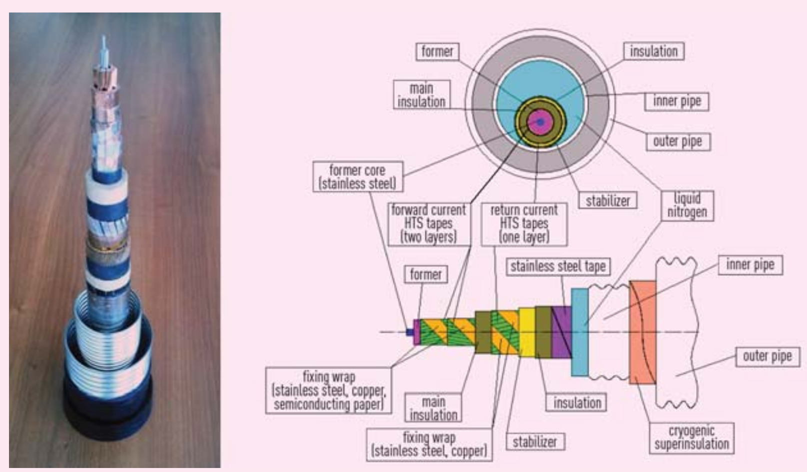

Fig. 2

for the entry/exit of liquid nitrogen into the cable. Temperature difference along the length of the current lead reaches 200 °C. The coupling is intended for joining sections of the cryostat and for connecting segments of the HTSC cable.

The general scheme of cryogenic-flowing part of the cable line is similar to that shown in Figure 1b. The cryogenic station is located on one side of the cable line. Liquid nitrogen is pumped through the cryostat with a high-temperature superconducting cable and returns through the cryostat of a smaller diameter. The total length of the loop is 5 km. Cryogenic station of a closed type is made according to a two-circuit scheme. The cooling circuit includes HTSC cable in a cryostat, circulation pump, heat exchanger and tank with supercooled nitrogen. The gas (helium) supercooling circuit consists of primary coil of heat exchanger, compressor and expander. This circuit provides lowering of temperature of nitrogen after heating it while passing the cooling circuit.

GENERAL VIEW OF 860 M HIGH-VOLTAGE SUPERCONDUCTING CABLE AT THE TEST SITE

Fig. 3

CURRENT-VOLTAGE CHARACTERISTIC OF THE 860-METER LINE AND TEMPERATURE DEPENDENCE OF CRITICAL CURRENT ON TEMPERATURE FOR THE 60-METER LINE

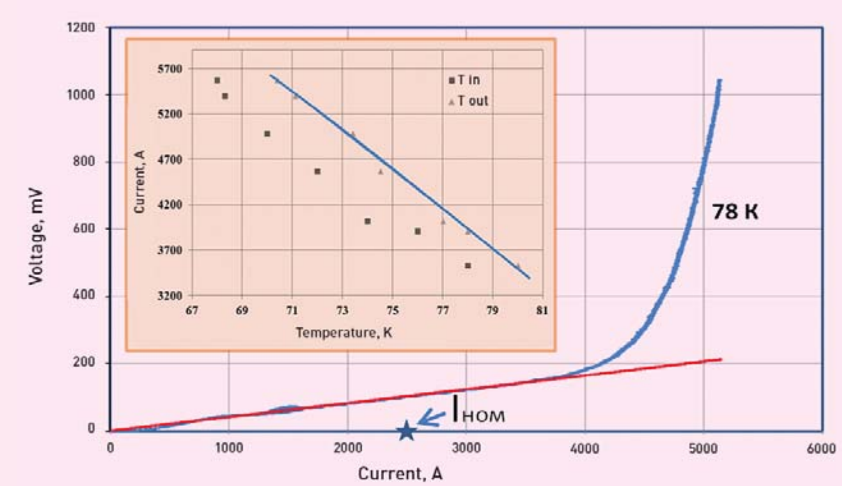

Fig. 4

RESULTS OF TESTING OF HIGH-TEMPERATURE SUPERCONDUCTOR CABLE LINES

HTSC CL and its elements were tested in accordance with the developed program. When compiling the test program, the requirements of Russian GOST for testing of similar traditional-type cables [11] and CIGRE recommendation for testing superconducting cables [12] were taken into account. Two 30-meter cable samples, two full-scale lengths (430 + 430 m), three pairs of current leads, and three couplers were tested.

Full-scale tests were carried out on two cable lengths assembled with two current leads and one coupler [13]. The total length of the line was 860 meters. Its general view is shown in Fig. 3. Current-voltage characteristic of the line and the critical current are shown in Fig. 4. The inset to the figure also shows the dependence of critical current on the temperature at inlet and outlet of the cable line.

The electrical resistance of the coupler was less than one microohm. The resistance of current inputs (including the "warm" part) was 20–21 μΩ at 80 K, which corresponds to heat generation of not more than 140 W at a nominal current. The resistance of current inputs remained stable up to a current of 5000 A. Measurements were made of critical current in temperature range 68–78 K and high-voltage tests. The critical current of two HTSC conductors was in the range of 3420 to 3550 A at 78 K. When the temperature was lowered to 68 K, the critical current increased to more than 5000 A (Fig. 4) [13]. Critical current of the cable was almost equal to the sum of critical currents of original superconducting tapes, which indicates the development of reliable design and manufacturing technology for HTSC cables.

VIEW AND LAYOUT OF 1000-METER EXPERIMENTAL CABLE LINE OF THE ISHIKARI PROJECT

Fig. 5

Hydraulic tests were carried out with a steady flow of refrigerant equal to 30 liters per minute. In this case, pressure drop along the length was 0.43 atm, which corresponds to 1.25 atm for linear approximation to a length of 2.5 km. The coefficient of hydraulic resistance was 0.0672.

All cables and fittings successfully withstood vacuum, cryogenic and electrical tests.

ISHIKARI PROJECT, JAPAN

HTSC cable was mounted in a U-shaped line (Fig. 5) with a length of 1000 meters with two couplings [14, 15]. The direct and reverse flow of liquid nitrogen is organized inside a common cryostat, as shown in Figure 6. The main goal of the project is to carry out researches and obtain basic knowledge for the development of longer lines.

The goal for design of the high-temperature superconducting line was to obtain best performance in the main parameters critical for design of long length HTSC power transmission lines. Smooth cryostats are used instead of traditional corrugated ones to reduce the hydraulic resistance of the flow channel and, therefore, to reduce the energy loss for circulation of liquid nitrogen. The greatest attention is paid to reducing the heat input into cryogenic volume.

Two cryostat designs, shown in Fig. 6, were used to study the possibility of reducing external heat input in the project. The best results were obtained at the 482-meter section of cryogenic pipe with the cable protected by a radiation shield, which are in thermal contact with the liquid nitrogen return pipe (Fig. 6a). This allowed to reduce heat input to the pipe with the cable to an extremely low value of 0.034 W/m [15]. This construction is considered as base for the next generation of HTSC lines. The structure of screen-vacuum thermal insulation has also been optimized by the criteria of cost and efficiency. To improve conditions for evacuation, external large diameter pipes were used. To prevent the occurrence of large mechanical stresses due to changes in the HTSC cable length upon cooling, a new technique has been developed for preliminary spiral laying of the cable in a cryostat pipe.

As a result, at the temperature of liquid nitrogen, the cable is straight, and at room temperature, it is arranges spirally along the walls of the pipe. In addition, to compensate for residual stresses, the terminal cryostats are mobile. All these solutions are extremely important in design of the cryogenic part of long HTSC lines.

ON THE POSSIBILITY OF CREATING LONG-LENGTH HTSC CABLE LINES

Based on results obtained by research groups in implementation of these two projects, we will make a preliminary assessment of the possibility of creating long HTSC cable lines. We will evaluate the following parameters:

- possible levels of transmitted power;
- amount of energy loss in the line;
- organization of a cooling system.

CONSTRUCTION OF TWO ISHIKARI CRYOSTATS

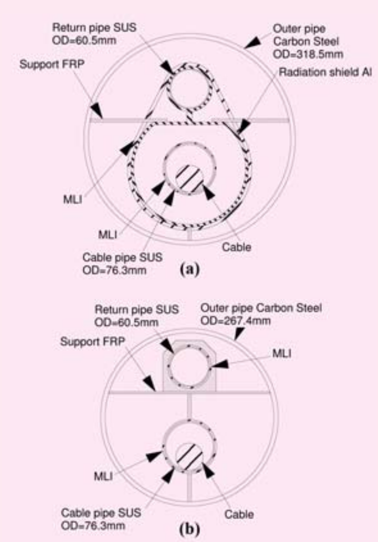

Fig. 6

High-temperature superconducting cable lines are an innovative development that allows solving a significant part of the problem of energy supply to consumers

POSSIBLE LEVELS OF TRANSMITTED POWER OVER HTSC DC CABLE LINE

We estimate a possible level of transmitted power at various voltages based on achieved characteristics of superconducting materials. With design critical current density of 200 A/mm^2 [16], it is realistic to create direct current cables with a rated current of 10.0-20.0 kA. Cables with a working current of 10.0 kA have already been created [2, 17]. For the estimates given in Table 2 below, we used the rated current equal to 15.0 kA.

TRANSMITTED POWER IN HTSC DC LINE (IN MW)

Transmission voltage, kV	Monopolar transmission		Bipolar transmission	
	One line	Two lines	One line	Two lines
50	750	1500	1500	3000
100	1500	3000	3000	6000
200	3000	6000	6000	12000

Table 2

To increase the reliability of transmission, it is advisable to consider transmission along two parallel lines, i.e. in a two-circuit design. As it can be seen from the table, the power of the order of 6000 MW can be transferred to the network already at a voltage of 100 kV with bipolar transmission or 200 kV with monopolar transmission. In this case, only 2–4 cables are required for transmission.

LOSS OF ENERGY IN SUPERCONDUCTING LINE

The energy losses in a high-temperature DC superconducting line are composed of:

1. Converters energy loss of about 2 % of the line power.
2. Heat input through current leads (unities of kW).
3. Losses associated with heat input into cold zone through the cryostat, multiplied by the refrigeration ratio.

The first two quantities do not depend on the length. For long lines, heat inflow through the current leads can be neglected. Let's take into account the length-independent component of the energy loss equal to 2 % of transmitted power. There are no electrical losses in superconducting DC cable.

Heat transfer through the pipes of modern flexible corrugated cryostats is (1.0–1.5) W/m. The refrigeration ratio is 12–18, then the power loss per meter of line length will be 12–27 W/m. We take an average value of 20 W/m. Let's limit total loss in 3 % of transmission power. In this case the losses in superconducting line, taking into account energy consumption for cooling, should not exceed 1 %. The results of calculating maximum length of a high-temperature superconducting line, whose total losses are no more than 3 % of its nominal power, are presented in Table 3.

LENGTH OF THE HTSC DC LINE THE TOTAL ENERGY LOSS IN WHICH IS EQUAL TO 3 % OF TRANSMITTED POWER

Capacity in MW	100	300	500	1000	3000	6000
Length in km	50	150	250	500	1500	3000

Table 3

From the above table it follows that the use of high temperature DC superconducting line will significantly reduce energy losses during long distance transmission. For long lines, it is most expedient to use smooth cryostats by analogy with those developed in Ishikari project, which will lead to decrease in energy losses from external heat input and friction losses. Then total losses in the line will be less than 2 % of transmitted power.

COOLING THE LINE WITH DETERMINATION OF THE MAXIMUM DISTANCE BETWEEN THE CRYOGENIC STATIONS

When calculating cooling of the line, we proceed from the following initial data:

- Maximum temperature of superconducting cable cooled by liquid nitrogen should not exceed 78–80 K, which leads to an allowable temperature difference along the length of the order of 10 K.
- Permissible pressure drop along the length is determined by characteristics of cryostat and for flexible cryostats based on corrugated pipes is 10–15 atmospheres. For smooth pipes, the allowable pressure can reach several tens of atmospheres.
- Minimum nitrogen pressure and maximum nitrogen temperature in high-voltage application area should ensure that gas bubbles cannot form which substantially reduce the electrical strength. This corresponds to the following conditions: the pressure is not less than 1.0 atm, and the temperature is not higher than 78 K.

The first condition is a consequence of the fact that the range of existence of liquid phase of nitrogen is limited from below by freezing point and from above by boiling point,

OPERATING TEMPERATURE RANGE OF LIQUID NITROGEN DEPENDING ON THE PRESSURE (RED LINE IS BOILING POINT, BLUE LINE IS FREEZING TEMPERATURE)

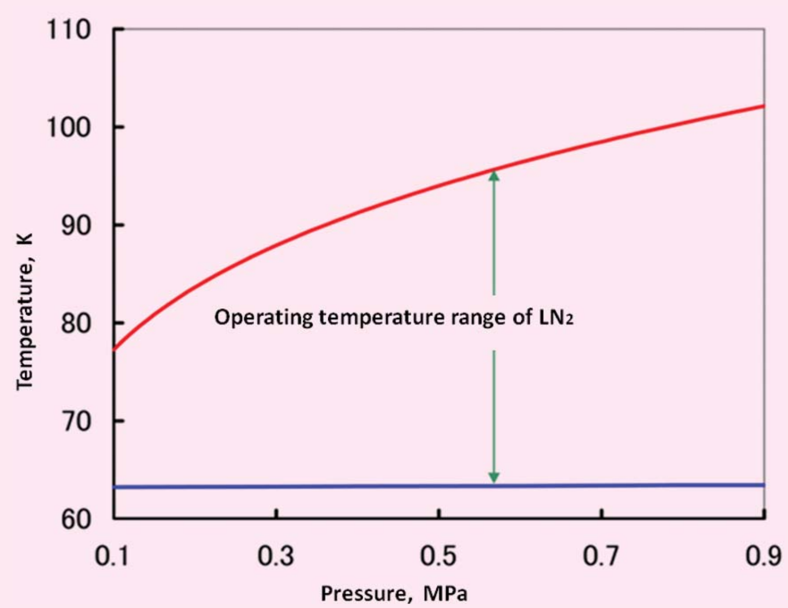

Fig. 7

and is only 77.4 K – 63.2 K = 14.2 K at 1 atm (Figure 7). Although it can be expanded by increasing the pressure in the system (making, for example, 20.6 K at 2 atm.), but the lower temperature limit (freezing point) remains practically unchanged.

Consequently, expansion of the range leads to an increase in temperature at the exit from the cryostat and, therefore, to a decrease of superconducting material critical current.

In order to ensure the predetermined temperature drop ΔT along the length of cable line, it is necessary to pump a certain amount of coolant to remove the heat supplied to the cryostat [18]. If the concentrated thermal load at the line ends is neglected, the mass flow of liquid nitrogen necessary to remove incoming heat and heat generated by friction will be determined as

$$\dot{m} = \frac{L(q+q_f)}{C_p \Delta T} \qquad (2)$$

where: $\dot{m}$ is consumption of liquid nitrogen, kg/s; L is length of the cryostat, m; q is specific heat load through thermal insulation, W/m; q_f is specific heat release from friction, W/m; C_p is specific heat of liquid nitrogen, J/kg·K.

Mass flow is related to the flow rate by expression

$$\dot{m}=\rho v A \qquad (3)$$

where ρ is density of liquid nitrogen, kg/m^3; v is flow velocity, m/s; A is cross-sectional area of the channel, m^2.

Typical values of external heat input for modern corrugated cryostats are 1.0 to 1.5 W/m. Using the foregoing relationships, we estimate the heat and mass transfer characteristics for HTSC cable with external diameter of 39–40 mm placed in cryostats with internal diameter of 60, 66, and 84 mm. The results of calculations are summarized in Table 4. From Table 4 it follows that pressure drop can be easily regulated by increasing the diameter of the cryostat. However, as the diameter of the cryostat increases, external heat input into the cold zone increases.

Another way to reduce the pressure drop (not less than 2 times) is the use of smooth tubes with bellows interconnections as the inner tube of a cryostat, as shown in Fig. 6.

The main limiting factor for increasing the distance between cooling stations is the temperature drop along the length of the cable. However, as it can be seen from Table 4, for a cryostat with internal diameter of 84 mm this distance may be 10 km. Unfortunately, the flow rate cannot be increased indefinitely, since at high flow rates, in accordance with formula 2, additional heat generation occurs due to dissipation of energy as a result of friction of the coolant in the cooling channel and the pressure drop along the length increases dramatically.

The main way to reduce the temperature drop is to reduce heat input to the cold zone. This can be done both by improving thermal insulation of a cryostat and by lowering temperature difference between the outer and inner shells of the channel in which HTSC cable is located.

A radiation shield can be a promising solution. This design was worked out in Ishikari. Cryostat has a relatively large diameter, and a pipe with cable and a return pipe are placed into it. The cryostat circuit shown in Figure 6a allows to significantly reduce the heat input to the cable channel by placing the screen cooled by reverse flow of liquid nitrogen between the outer shell of the cryostat and the cable pipe. The results of measuring heat inflows [14,15] allow us to estimate the length of the cable line at which the temperature difference along the length does not exceed a given value. Table 5 presents the results of the estimated calculation for the cryostat with Ishikari-2 radiation screen.

As it follows from the comparison of Tables 4 and 5, with an increase in length of the cable line to 10 km or more, it is necessary to use rigid cryostats with a smooth tube. The distance between cryogenic stations can reach 10 km for lines based on flexible cryostats, and when switching to smooth pipes, the distance between cooling stations can be increased to 30–80 km.

With design critical current density of 200 A/mm^2, it is realistic to create direct current cables with a rated current of 10.0-20.0 kA

Long lines can be created by replicating pumping areas, as shown in Fig. 1c.

Of course, the calculations presented above are of an evaluation nature and require experimental confirmation. However, the results obtained during the implementation of the two above-mentioned projects inspire confidence in possibility of implementing a line with length of about 10 km as the next stage in development of high-temperature superconducting technologies for transmission of energy over long distances.

CONCLUSION

With the current level of development of superconducting and cryogenic technology, it is possible to create long superconducting cable lines for transmission of energy over distances of tens of kilometers. Then, the power of a single line can reach several gigawatts, and the energy losses in it will be significantly lower than in traditional lines. The electrical voltage on the line and the converter station can be reduced to 200 kV or less. Cryogenic stations for line cooling can be located at its ends with a line length up to 20 to 40 km (in perspective up to 80 km). When creating longer lines, cryogenic stations should be located along the route in distances of 20–60 km. The maximum length of a line with this approach has no technical limitations.

There is every reason to hope that in foreseeable future, powerful DC superconducting cable lines will allow to optimize electric networks of megacities and form a global energy network with transfer of electric power to long distances, to make interconnecting links, to connect unsynchronized power systems, to build long underwater lines, etc. All this will significantly increase efficiency and reliability of electrical networks.

TEMPERATURE AND PRESSURE DROP ALONG THE LENGTH OF HIGH-TEMPERATURE SUPERCONDUCTING LINE

Internal diameter of the cryostat, mm	Cable length, km	Flow rate of l. nitrogen, l / min.	Temperature difference, K.	Difference of pressure, atm
60	2.5	40	4.0	4.8
	5.0	40	7.5	14.0
66	2.5	40	4.0	3.0
84	2.5	40	4.0	0.4
	5.0	40	8.0	1.1
	10.0	60	11.0	4.5
		80	8.4	8.0

Table 4

ESTIMATED LENGTH OF THE HIGH-TEMPERATURE SUPERCONDUCTING LINE

Temperature difference, K	Consumption of liquid nitrogen, l / min	Temperature difference of 1 km, K	Length of the line, km
8	10	0.122	66
	5	0.244	33
10	10	0.122	82
	5	0.244	41

Table 5

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DIGITAL SUBSTATION TEST SITE

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With the test site developed at a live experimental substation, it is possible to simulate in real time the disturbances occurring in an adjacent electrical network and at the power facility itself. This, in turn, makes it possible to considerably shorten the time of implementation of new technologies when testing the functional performance of equipment and to analyze different options of a local area network for substations of any voltage class.

Keywords: digital substation; IEC 61850; DSS test site (DSS TS); process bus; station bus; testing and simulation facility; real-time digital simulator (RTDS).

The optical transformers of the Digital Substation Test Site in R&D Center at FGC UES

INTRODUCTION

On October 3-5, 2017, JSC R&D Center at FGC UES hosted an important international event in the field of development of digital technologies in the power industry held in Moscow and entitled International Conference "Digital Substation. Standard IEC 61850." The conference was organized jointly with DNV GL (formerly KEMA). The general partner of the conference was PJSC FGC UES, part of PJSC ROSSETI Group of Companies; a great contribution to the event was made by Russian NC of CIGRE. The conference was attended by more than 230 Russian and foreign specialists from 16 countries.

The event was followed by a discussion emphasizing that the main objective of the conference was to establish a Center of Competence serving as a joint platform for discussing issues pertaining to the implementation of the Digital Substation technologies, and the objective was achieved. Participants of the conference noted the high level of organization, relevance and completeness of the topics covered.

It is no coincidence that JSC R&D Center at FGC UES was selected to host such an event, given the following developments:

– On assignment from PJSC FGC UES, jointly with other organizations, the FGC Digital Substation Simulator Concept was developed in 2011–2012.
– In 2010, on the basis of the 110 kV substation, JSC R&D Center at FGC UES built Russia's first digital substation, where IEC standard 61850 (8-1 and 9-2 LE) was implemented for the transfer of measured cycle parameters (currents and voltages) at the 110 kV side from optical combined CTs and VTs in a digital form to the SS control system and for sharing data between secondary switching devices: the Digital Substation Test Site (DSS TS).

As part of the DSS TS, an array of R&D efforts was dedicated to the

STRUCTURAL SCHEMA OF DSS TS BY JSC R&D CENTER AT FGC UES

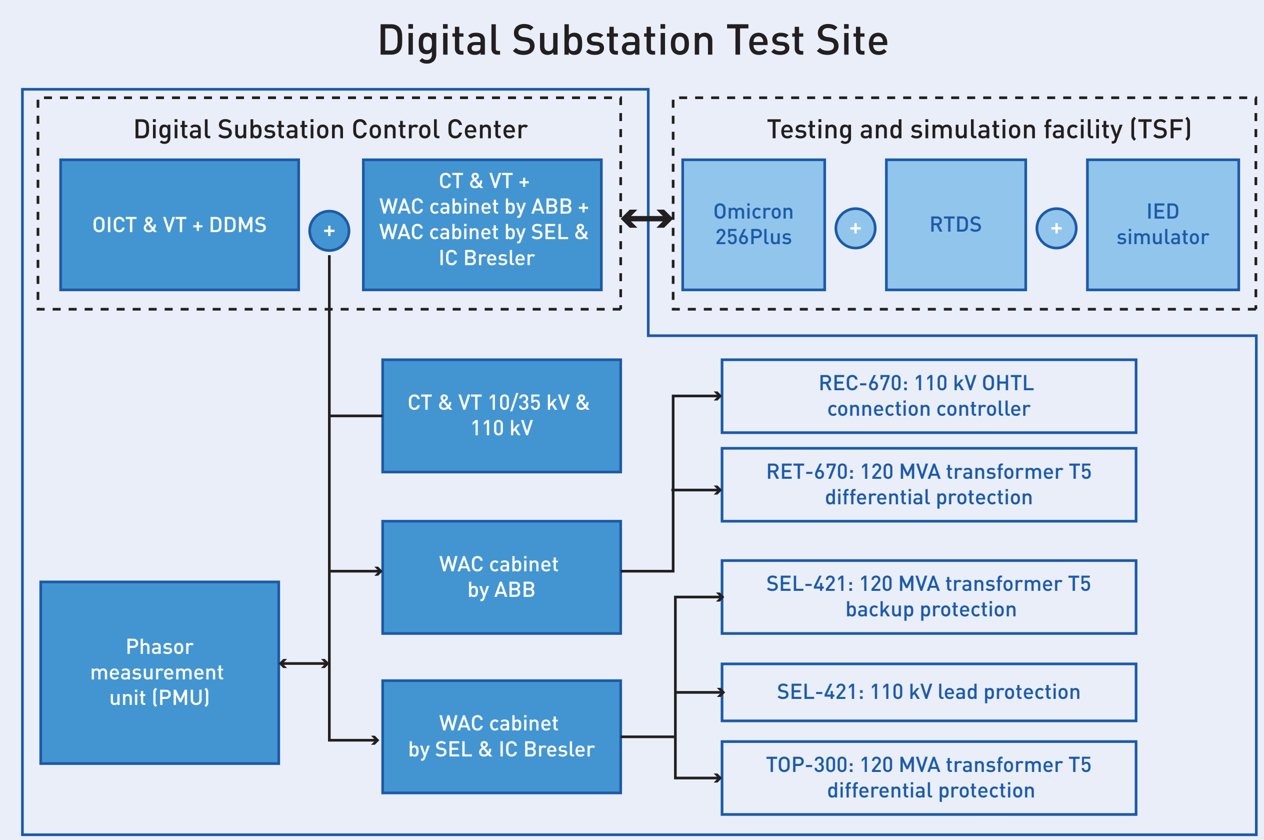

Fig. 1

development of the Digital Substation (DSS) components:

1. Merging units that convert analog signals from instrument CTs and VTs into digital streams as per IEC 61850-9-2(LE),
2. High voltage circuit breaker field converter (HVCBFC), which converts digital streams (IEC 61850-8-1) into discrete signals to control the HV circuit breaker drive,
3. Pilot models for the analysis of DSS LAN digital streams to be used for commissioning and day-to-day operation:
- suite for the analysis of communicative interactions of DSS components,
- suite for the evaluation of dynamic characteristics of communication equipment (digital switches) and network characteristics of DSS secondary switching digital terminals.
4. The DSS TS is the ground for:
- various types of tests of equipment carried out with utilization of the Digital Substation technology;
- guided technical tours, with a curriculum devised for personnel training of related companies and works performed at different levels by representatives from educational institutions;
- international collaboration on the certification of equipment to the IEC 61850 standard.

HISTORICAL BACKGROUND: WHO NEEDS THE DIGITAL SUBSTATION TEST SITE (DSS TS)?

In 2010–2011, by order of Federal grid company, by three organizations – JSC "NTC of electric power industry" (currently JSC "NTC" Federal grid

TEST SITE — 110 KV SWITCHYARD, RTDS, SSCC, TRAINING CENTER (SPECIAL CLASSROOM)

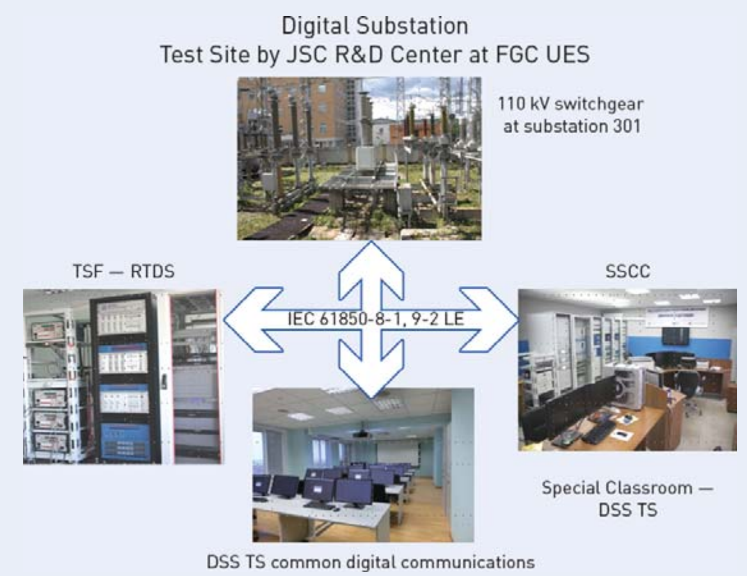

Fig. 2

company"), JSC" Institute "Energosetproekt "and JSC" Continuum "developed the Concept of software and hardware complex (PAC)" digital substation ENES". At the same time, work was started on a pilot project called "Creation of a pilot test site for testing and complex testing of the main elements and subsystems of the digital substation, as well as complex technical solutions for process control". It was proposed to create a test site on the basis of the existing 110 kV experimental substation of JSC "STC FGC UES".

The introduction of new technology into operational practice, as a rule, is carried out through the mechanism of pilot development of equipment. This leads to the fact that an additional, essentially experimental backup circuit is created at the facility, the equipment of which operates on the signal, which makes any project more expensive and creates additional problems for operating personnel.

The equipment, developed with using the new technology, can to work for a long time in the mode of monitoring disturbances in the external electrical network and at the substation, without triggering even the signal, in the absence of disturbances in the functioning of equipment in the electrical network and in the substation, therefore to obtain a full operational experience with such the method of mastering technology in a relatively short period (quarter, semester, year) is extremely difficult.

DSS TS MISSIONS

The DSS technology is based on the utilization of equipment developed in accordance with IEC 61850, which describes the information models of primary and secondary equipment, classifies the levels of the substation automation system, and sets the rules for data interchange between the devices (process bus, station bus,

so-called "digital circuits") included in the substation automation system.

When developing the DSS technology, it is necessary to address a number of interrelated challenges on a holistic basis. First of all, a method for applying the provisions of IEC 61850 should be devised and tested in practice. In other words, it is necessary to create a DSS prototype, verify technical solutions on test specimens, and work out recommendations for industry-related organizations on how to apply the innovative technology.

In addition, the DSS TS should play the role of an academic educational center to promote the DSS technology into operational practice. The experience accumulated with the DSS prototype operation should contribute to the development of normative documents pertaining to the design, commissioning, and operation of similar facilities.

The most significant tasks for which the DSS TS is intended include testing of the equipment designed in conformity with IEC 61850 for interoperability: optical current and voltage transformers, analog and discrete signal converters, and intellectual electronic devices (IED), which are analogs relay protection and emergency control automation terminals.

This technology is based on the transfer of data streams in an Ethernet-based communication environment. In this case, the most critical issues are to comply with the standard's requirements to delivering messages of various categories within specified timeframes and organize synchronous operation of devices.

The main technical solutions for the components of the DSS technology, tested at the test site DSS on the prototype of software and hardware complex DSS, form the basis for the development of typical solutions for substations of various voltage classes.

To accelerate the introduction of equipment created using the new technology, it was necessary to create an active test site that simulates perturbations on the equipment under test to verify the claimed technical characteristics. In addition, in the case of equipment installation at an operating power facility (to check immunity of the equipment's from electromagnetic interference of various types, switching overvoltages, etc.), it becomes possible to conduct tests in conditions in which this equipment will subsequently work.

An active test site must have a testing and simulation facility (TSF) to simulate disturbances (different types of short circuits, sudden shutdowns of primary equipment at the facility and in the adjacent power network), which should be applied to the secondary equipment under test, i.e., this means that the TSF should produce distur-

In 2010-2011, commissioned by JSC FGC UES, JSC R&D Center at FGC UES, JSC Institut Energosetproekt and JSC Kontinuum developed the FGC Digital Substation Simulator Concept

SUITE FOR CHECKING THE DYNAMIC BEHAVIOR OF A COMMUNICATION NETWORK

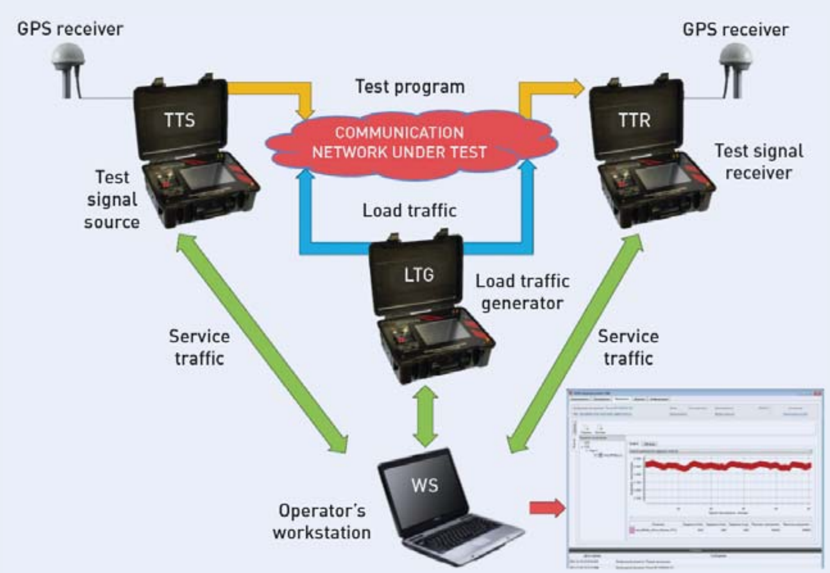

Fig. 3

bances in three phases in real time. In addition, the TSF should be able to produce disturbances both in analog form, such as instantaneous values of currents and voltages, and in digital form in accordance with IEC 61850 9-2LE (to implement the process bus).

The DSS TS development includes creation of a digital circuit for primary instrument equipment (current transformer (CT) and voltage transformer (VT)) and secondary equipment in combination with the testing and simulation facility. This approach allows verifying the technical solutions for the layout of secondary equipment, its information links with primary equipment and with upper and medium levels of the power facility's process control automation system (verifying the communication environment architecture for the process bus and the station bus) as well as the functional characteristics of the equipment itself in the event of different types of disturbances in the external network within a reasonably short time, and, finally, formulating requirements to the engineering solutions. When considering the possibility of implementing this technology at real power facilities, it was assumed that it would be necessary to add to the existing main microprocessor-based and backup security terminals that use analog inputs from conventional electromagnetic CTs and VTs a third experimental digital circuit with protections receiving inputs in digital form (in accordance with IEC 61850-9-2LE) and working on that signal, which would increase the project cost considerably. When conducting experimental activities using the active test site for different model options of primary and secondary equipment, it is possible to obtain a set of typical circuits for station buses and process buses and later on perform the implementation at power facilities without additional experimental 'digital' standby circuits. Additionally, compatibility will be verified with the existing certified equipment compliant with IEC 61850.

DSS TS STRUCTURE AND EQUIPMENT CONFIGURATION

JSC R&D Center at FGC UES began constructing the test site in September of 2010. The DSS TS consists of:

- 110/10 kV substation No. 301 — live electrical installation with a specialized double-wound transformer consisting of a three-phase group of 40 MVA, with a switchable second winding allowing to obtain 10, 20, 35, and 90 kV. Two groups of optical measuring current and voltage transformers (CT and VT) are installed at 110 kV substation switchgear);
- the DSS control center (SSCC), with a digital data measuring system (DDMS) including four intellectual electronic devices (IED, in terms of IEC 61850), data computations complex (DCC) based on KOTMI-2010 SCADA, with transformer digital protection and 110 kV circuit breaker controller installed (using equipment from reputable foreign and domestic manufacturers of wide area control and emergency control automation devices: ABB, SEL, IC Bresler, Alstom-Grid, Ekra);
- DSS TS laboratory equipped with a testing and simulation facility (TSF) comprised of: real-time digital simulator (RTDS); OMICRON and PETOM 61850 test units; software digital terminal simulator (IED) with simulators of digital data streams for loading the process buses and station bus during 'storm' tests and other types of tests. Communication environments of the SSCC of substation No. 301 and the laboratory are linked by a high-speed fiber optic communication channel.

To create a state-of-the-art TSF allowing obtainment of a full-fledged model of a complex power system, including ultrahigh voltage substation models, it is necessary to focus on powerful multiprocessor systems that have internal data buses of at least 1 GB supporting IEC standard 61850 in respect of the process bus and enable streaming of quick messages (GOOSE). Such software is RTDS, which is manufactured by the company with the same name in Canada (Winnipeg) and applied in dozens of countries worldwide.

The RTDS is designed specifically to simulate operation modes of power systems and test the secondary switching equipment intended for control and protection. Multiple analog and digital channels of input and output signals are transmitted via optical links and allow making diverse connections of equipment under test with the simulator with high accuracy.

In 2015, the formation of the DSS TS infrastructure was completed; a training center (hereinafter the Special Classroom) was added to the commissioned sections of the site (CT and VT at the 110 kV switchyard, SSCC, RTDS).

The Special Classroom is fitted with computers and multimedia equipment designed for 10 trainees, with a designated place for the instructor, and is an integral part of the DSS TS, featuring a common communication environment (SSCC – laboratory part with TSF — the Special Classroom).

Additionally, the Special Classroom is intended for demonstrating the performance of DSS equipment, training, and testing the equipment designed in accordance with IEC 61850 (DSS components). A training curriculum has been devised for introducing the staff of operational, commissioning and design organizations to the DSS technology and approved by PJSC FGC UES.

R&D CARRIED OUT DURING THE DSS TS CREATION

From the standpoint of managing communication at the DSS, devices of all levels connected to the communication network are components of communication interaction along with the network equipment, such as switches, data reception and transmission redundancy units (Red Box devices), and transponders. Communication interaction across the DSS network is a process of reception and transmission of messages determined by communication protocols within the DSS in accordance with IEC 61850 standards. The required message formats and delivery time limits are regulated by a number of standards:

1. communication message formats — by IEC 61850-8-1/9-2LE;
2. total communication message transmission times — by IEC 61850-5;
3. time of message transmission directly through the communication network and the communication subsystems of the source and receiver — by IEC 61850-10 [2].

In the process of DSS TS creation, following JSC R&D Center at FGC UES technical requirements, JSC ITC Kontinuum developed a specialized instrumental system for multilevel testing of communications between RTDS components of the DSS. This toolbox includes two testing and simulation facilities (TSF) intended for enabling testing at all levels of the OSI/ISO (open systems interconnection) basic reference model, from the physical to application level:

- suite for the analysis of communicative interactions of DSS RTDS components [3];
- suite for the verification of dynamic behavior of communication interaction of DSS RTDS components [3].

With these suites, it is possible to determine the following characteristics of communication interaction:

LIST OF TEST BENCH EQUIPMENT

№	Manufacturer	Description	Subsystem
1	NxtPhase	NXVCT	Optical CT&VT
2	NPP Mikronika	S052-MUA	Analog signal BC
3	ITC Kontinuum +	CT&VT field converter	
4	NPP Mikronika	S052-MUIO	Discrete signal BC
5	IC Bresler	TL 2607.XXA	WAC (graded protections)
6	SEL	SEL-421	WAC (Breakers Control Automation)
7	Schneider Electric	Micom P444	WAC
8	NPP Mikronika	S052-PB	DCS
9	Landis&Gyr	ZMQ802C	AUMIS
10	ITC Kontinuum +	PMU	SPM
11	NPP Mikronika	S055	DCS upper level
12	NPP Mikronika	SYNDIS-RV	SCADA

Note:
- BC means process bus coupler (analog/discrete);
- SCADA (Supervisory Control and Data Acquisition) is a set of programs designed for development or real-time operation of systems for acquisition, processing, displaying and archiving information on an object of monitoring or control.

Table 1

1. time of delivery of information messages in various operating conditions of the communication equipment;
2. reliability of delivery of information messages in various operating conditions of the communication equipment;
3. information message format and its conformity with IEC 61850-8-1/9-2LE;
4. information message transmission regulation;
5. information message publication delay (latency);
6. statistical analysis of message streams;
7. test traffic source (TTS);
8. test traffic receiver (TTR);
9. load traffic generator (LTG);
10. operator's workstation (WS).

Packages for analyzing and checking the dynamic behavior of communications between DSS RTDS components are built on a common engineering platform focused on the operation with high communication load levels typical for a digital substation. A typical computation error of temporal characteristics of communications stays within a few tens of nanoseconds, which allows determining with high accuracy the dynamic characteristics of communication, such as delay of publication and time of delivery of communication messages.

Following the technical guidelines of JSC R&D Center at FGC UES and JSC Energosetproekt, jointly with LLC Laboratory DEP, an adapter was designed (high voltage circuit breaker field converter, or HVCBFC) for operation with the HV breaker drive.

END-TO-END TESTING OF SECONDARY SWITCHING EQUIPMENT DESIGNED FOR THE DSS TECHNOLOGY

COMPATIBILITY TESTING OF EQUIPMENT FROM DIFFERENT MANUFACTURERS

First end-to-end tests were performed at the Digital Substation Test Site of JSC R&D Center at FGC UES under the Program approved by PJSC FGC UES (tests of the secondary switching equipment designed in accordance with IEC 61850 introduced by JSC Novointech).

Purpose of the tests:

– To test the technical solution for building the digital substation segment in accordance with the technical requirements of the "Creation of a smart grid at external power supply facilities of the Elga coal mine (Elgaugol cluster smart grid)" project at the 220/35/10kV Prizeyskaya substation on the 220kV Prizeyskaya-A OHTL.
– To verify the joint operation of IEDs from different manufacturers on the station bus and the process bus as per IEC 61850-8-1. Joint operation on the station bus means: successful interchange of GOOSE messages (an analog to discrete signals) among IEDs of different subsystems of the digital substation with satisfactory temporal characteristics of data reception and transmission. Joint operation on the process bus means that a process bus source from one manufacturer should publish a digital stream in the network in accordance with IEC 61850-9-2LE, and the process bus receiver from a different manufacturer should perform properly using the published data stream.
– To benchmark the behavior of three different digital stream sources as per IEC 61850-9 2LE and record their characteristics; test the technical solution of creating the process bus in accordance with IEC 61850 from two sources with different working principles: an optical current and voltage transformer, and a process bus coupler; verify the proper performance by IEDs of wide area control (WAC) subsystems, digital control system (DCS), automated utility metering information system (AUMIS), and synchronous phasor measurements (SPM) of their functions while working with the process bus created by an optical current and voltage transformer and process bus couplers in conformity with the functional requirements.

STRUCTURAL DIAGRAM OF JOINT OPERATION TESTING UNDER THE IEC 61850-8-1 PROCEDURE (GOOSE MESSAGES)

Fig. 4

COMPATIBILITY OF RETOM-61850 WITH DEVICES SUPPORTING THE IEC 61850 STANDARD FROM DIFFERENT MANUFACTURERS

№	IED Manufacturer	IED Name	Subsystem
1	Schweitzer Engineering Laboratories, Inc	SEL-421	WAC
2	IC Bresler	TOP 300	WAC
3	ABB	RET670	WAC
4	Alstom	MiCOM Alstom P645	WAC
5	Ltd EKRA Research and Production Enterprise	Ekra 2704 562	WAC
6	JSC ITC Kontinuum	PMU-101	SPM
7	Modern Measurement Systems, Inc.	DPM-121	IP

Table 2

The following equipment was used for the tests (Table 1).

Fig. 4 illustrates one of the test schematics for the DSS segment.

Below is a fragment of the test program for checking compatibility of DSS segment devices in transmission and reception of GOOSE messages.

Test procedure:

1. GOOSE message publication mode
– Exporting ICD/CID/SCD files.
– Concordance of the published GOOSE DataSet header with the ICD/CID file.
– Publishing GOOSE DataSet with different VLAN tags.
– Publishing GOOSE DataSet with FCDA-type data.
– Publishing GOOSE DataSet with FC-type data.
a) Data set with ST (status) functional limitation.
b) Data set with MX (measurement) functional limitation.
– Switching the device to test mode.
– Activating/deactivating the GoEna block.
2. GOOSE message reception mode
– Correct reception of GOOSE data set in normal and test modes.
– Behavior of subscriber IED in test mode.
– Behavior of IED on connection loss.
– Behavior of subscriber IED if key attributes of the message are changed.

A punch list pertaining to the equipment performance was compiled during the testing, since due to the deviations of the software from the standard, compatibility of data exchange was achieved not in all of the test modes. Reports on the experiments carried out during the testing were submitted to the customer who forwarded the punch list to the equipment manufacturer to resolve the issues.

> *The most significant tasks for which the DSS TS is intended include testing of the equipment designed in conformity with IEC 61850*

TESTS OF INNOVATIVE ENGINEERING SOLUTIONS FOR DSS TECHNOLOGY

LLC LISIS recommended a new conceptual approach to designing protection and emergency control systems: instead of a conventional automation system, which is a combination of multiple devices of different intended uses (WAC, EC, fault location, emergency event recorders), a unified integrated computational system needs to be created. Such a system is based on cutting-edge information technologies, implementing functional subsystems that are combined into a single software suite with unified data input points instead of multiple distributed hardware tools. This project is called iSAS [4].

While preparing the iSAS hardware and software package (HSP) for certification, tests were conducted at JSC R&D Center at FGC UES for combined operation of the computational system with other IEC 61850 devices and functional tests of wide area control and process automation subsystems of the 35 kV switchgear.

Development of the iSAS was initially intended for a pilot automation and protection project at the 35 kV switchgear of the 220 kV Elgaugol substation.

All tasks are performed by a single iSAS system installed at one server. Data exchange between the primary equipment with SAMU installed in cubicles and the computational system is performed through a communication environment.

In this project, the iSAS should provide control and protection for 13 connections and two sections of 35 kV buses.

The iSAS package was tested at JSC R&D Center at FGC UES in accordance with the test program.

As part of the project, a working prototype of the system was built with the following functionalities:

- Reception and processing of performance data from 20 connections in the IEC 61850-9-2LE format (Sampled Values).
- Control of the substation primary equipment with up to 20 connections by IEC 61850-8-1 protocols (GOOSE and MMS).
- Protection algorithms are implemented for switchgears of voltage class up to 35 kV (simultaneous protection of 20 connections):
- Current protections (phase-to-phase cutoff, overcurrent protection, earth fault protection)
- Voltage protections (over-/under-voltage relays)
- Differential protections (DBP)
- Remote protection of lines
- Configuration of the system using the Substation Configuration Language (SCL, IEC 61850-6)
- Graphical user interface for on-line control
- Alarm logging subsystem with a possibility of saving to a Comtrade file

The tests were performed in steady-state and transient conditions.

At the first stage, the following was checked in steady-state conditions:

- functions of data transfer by IEC 61850-8-1 protocol;
- functions of data reception by IEC 61850-9-2LE protocol;
- functions of automatic and operational equipment control;
- information display function;
- overvoltage relay function.

At the second stage of the testing, the following WAC and automation functions of the iSAS were checked:

- differential bus protection (DBP) of 35 kV buses 1 and 2;
- two-stage remote protection (RP) of overhead lines;
- two-stage definite time overcurrent protection (OCP) of overhead and cable lines;
- two-stage definite time overcurrent protection of the auxiliary transformer;
- two-stage definite time overcurrent protection (OCP) of the bus section breaker;
- two-stage definite time overcurrent protection (OCP) of local switches triggered by minimum voltage and negative sequence voltage;
- undervoltage protections;
- automatic load transfer on the bus section breaker;
- automatic re-closure of 35kV overhead lines;
- OL-1 circuit breaker failure protection;
- bus section breaker failure protection;
- emergency event recording (by oscilloscope functions and alarm log records).

Generally, when a new technology is introduced into operational practice, it is achieved through a pilot equipment trial tool

The network's three-phase model was built on the RTDS TSF.

The protection and automation functions were tested with simulation of short circuits of various types, including double short-circuits in different network points as well as with energized equipment. Duty cycles were tested both with an isolated operation of 35 kV sections and with the section breaker switched on. Transients in case of short circuits near the buses were accompanied with saturation of current transformers. On the whole, all of the tested protection and automation functions were working properly. Some individual imperfections of the software revealed during the testing were promptly rectified.

TESTS OF INDIVIDUAL DEVICES TO BE USED AT DSS

In addition to end-to-end testing at the DSS TS, individual devices and technical solutions are tested.

To carry out the commissioning when designing new equipment and creating a 'digital substation' at power facilities, it is necessary to use special test devices that can generate and receive streams of digitized instantaneous values (acc. to IEC 61850-9.2LE), send, receive, and analyze logic signals in GOOSE messages (acc. to IEC 61850-8.1), and measure the temporal characteristics of WAC, EC, and other devices.

One of such devices is the RETOM-61850 digital test unit designed by SPE Dynamics.

RETOM-61850 was tested at the Digital Substation Test Site of JSC R&D Center at FGC UES where the digital tester was examined for compatibility with other substation components and its features were benchmarked with foreign analogs available on the market.

The test results demonstrated that the RETOM-61850 digital test unit (technical specification TU 4042-032-13092133-2012) is compatible with other components of the digital substation of the test site of JSC R&D Center at FGC UES in terms of operation under protocols of IEC 61850-8-1 (GOOSE) and -9-2LE (SV).

The characteristics obtained from benchmarking the RETOM-61850 digital test unit (technical specification TU 4042-032-13092133-2012) with the Omicron CMC-256 Plus test installation and RTDS real-time simulator suggest that the RETOM unit is compliant with the stated features of compatibility with the IEC 61850 equipment.

SAMPLES OF CERTIFIED EQUIPMENT AND A FRAGMENT OF A LEVEL A CERTIFICATE

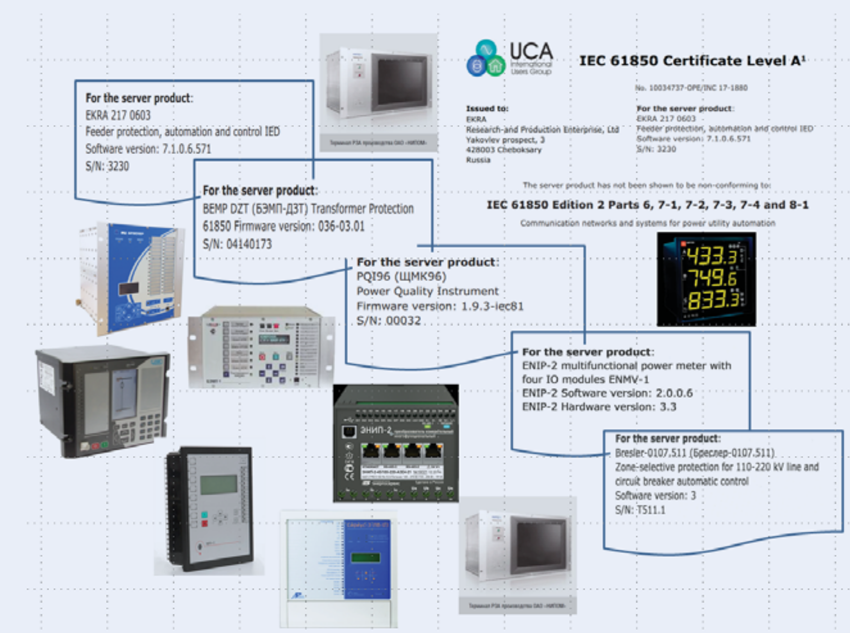

Fig. 5

CERTIFICATION OF MADE-IN-RUSSIA PRODUCTS INTENDED FOR DSS TECHNOLOGY APPLICATION

The DSS technology is based on IEC 61850, which interlaces the data models of primary (switching equipment, power transformers, etc.) and secondary equipment (wide area protection and automation, remote control, power metering, etc.) of electrical power facilities. The standard defines the rules of data exchange (protocols) between the equipment of different levels of the substation control system. Originally, the standard contained 10 chapters. Currently, it is being revised in order to include new types of secondary equipment and eliminate ambiguous interpretation of certain provisions. As of now, its first and second editions are applicable. One of the most important objectives of the standard is to ensure compatibility of equipment from different manufacturers. The product certification procedure is intended to achieve it.

The Russian industry that manufactures secondary equipment began mastering the DSS technology in the late 2000s. Today, numerous companies produce secondary switching equipment of various types that fully or partially conform to the

TESTING INFRASTRUCTURE OF JSC R&D CENTER AT FGC UES

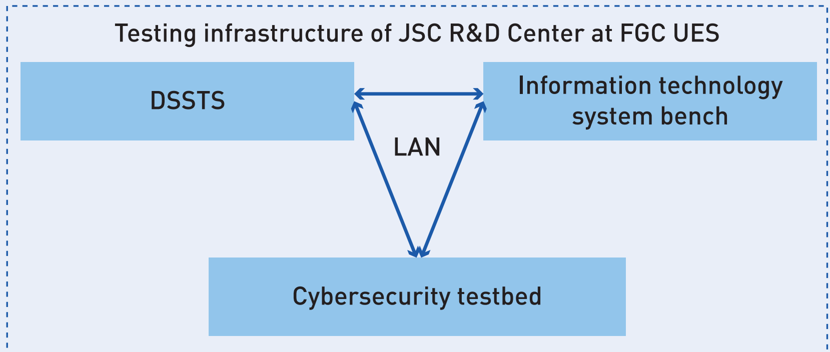

Fig. 6

IEC 61850 standard. To ensure compatibility of equipment at power facilities and guarantee uninterrupted data exchange between control system levels (in conformity with technical requirements), it should be certified for compliance with the standard in its first or second edition.

Utilities Communication Architecture International (UCA) Users Group (hereinafter UCAiug) defines the rules for checking (certification testing) manufacturers' equipment for conformity to the standard (chapter 10 of the standard determines the scope of testing). The international company DNV GL Energy (DNV GL) includes the UCA-accredited test laboratory KEMA Nederland B.V. (until October 2016 it was a stand-alone business unit responsible for certification of equipment built in accordance with IEC 61850) is authorized by UCAiug to develop testing software applied in certification tests.

Since 2014, KEMA Nederland B.V. (presently DNV GL Energy) has been cooperating with JSC R&D Center at FGC UES in the area of managing and conducting certification tests.

For this purpose, JSC R&D Center at FGC UES carried out a number of activities:

- acquired licensed testing software for certification testing;
- trained its staff in the fundamentals of the testing standard and methodology using the delivered software with assistance from the KEMA Nederland B.V. laboratory. After the training, the personnel completed tests (with positive outcomes);
- concluded an agreement on technical support and updates of the testing software.

These efforts qualified JSC R&D Center at FGC UES to perform preliminary testing of equipment for compliance with IEC 61850.

As part of the cooperation efforts, the parties have agreed that certification of equipment at JSC R&D Center at FGC UES will be made in two stages:

The first stage of preliminary testing will be carried out by the personnel of JSC R&D Center at FGC UES, while the second stage of certification testing will be carried out together with a DNV GL test engineer.

The second stage of certification testing will be performed together with the DNV GL test engineer and an applicant. If the certification tests are successful, the applicant (manufacturer of the products) will be awarded an international level A certificate allowing international distribution of products.

The international organization UCA will issue a level A certificate only if certification tests were carried out by an independent laboratory accredited by UCA (non-related with manufacturers or consumers of the products in question).

BRIEF DESCRIPTION OF BUSINESS PROCESSES OF PRELIMINARY AND CERTIFICATION TESTING

The certification process consists of several stages:

1. Preparation for testing conformance to IEC 61850 (pre-tests).

At this stage, the applicant will prepare documentation for the unit: complete a number of forms (PICS, PIXIT and MICS – determined by the standard), configure the unit, and submit it to JSC R&D Center at FGC UES.

Based on the documentation submitted to JSC R&D Center at FGC UES, a testing plan will be devised and presented to the applicant for approval. Once the plan is approved, preliminary tests are performed, errors in the implementation of the standard are identified, and test reports are submitted for elimination of deviations, if any (this is an iterative process). After the flaws are remedied, the next stage, which is certification testing, will begin.

2. Certification testing

In accordance with the certification testing plan, the unit's software is tested for conformity with the standard. The scope of certification tests is determined in the list set forth in chapter 10 of IEC 61850 (tables 1-33) [6] and the approved testing plan. At this stage, the DNV GL test engineer and the applicant's representative are present. Reports are generated for each type of a test during the testing process.

3. Documentation

At this stage, a report on the tests performed is compiled and the wording of a level A UCA certificate of conformance is formulated. The certificate is sent in an electronic format to the applicant for review. Once the applicant has approved the certificate's wording and confirmed its accuracy, the updated draft certificate along with the certification test report will be forwarded to UCA. The international organization will examine all materials and, if its resolution is positive, register the certificate in the UCA database and DNV GL register.

Positive test results grant the applicant a right to:

- have the tested unit registered on the UCA website;
- have the tested unit registered in the DNV GL register that is accessible to third parties. The register contains a list of equipment items and suppliers with IEC 61850 conformity confirmed by DNV GL;
- use the accompanying test report to provide detailed documentation to third parties or buyers of the product.

During the period of cooperation of JSC R&D Center at FGC UES with DNV GL, secondary switching equipment (WAC terminals, connection controllers) of more than 10 Russian companies was certified (Fig. 4, Table 1).

Devices of all levels connected to the communication network are components of communication interaction along with the network equipment

4. Testing infrastructure of JSC R&D Center at FGC UES

Today, JSC R&D Center at FGC UES is working on expanding its testing infrastructure in order to carry out functional tests on automated systems and units of power facilities based on the Digital Substation technology. It aims to create a full-scale testing cluster consisting of a testbed for information technology systems of a substation, comprising samples of products from leading plants in Russia and worldwide and a dedicated DSS TS communication link.

To ensure DSS information security, a substation cybersecurity testbed has been created, with a mission to research information security, check the data protection means for compatibility with process automation TTS specimens, carry out personnel training, and analyze the software security of the secondary equipment utilized at an electrical grid facility (Fig. 6).

CONCLUSION

JSC R&D Center at FGC UES has established a real Competence Center in the field of development of the Digital Substation technology. The Center is a platform for specialists and experts in the Digital Substation technology and a site for development of measures and testing of engineering solutions for implementation of the DSS technology in power facilities with minimal costs, with implementation of the experience of best research organizations:

1. The DSS Competence Center of JSC R&D Center at FGC UES is reinforced with a test site built at the operating experimental substation, enabling field tests and real-time simulations of the disturbances that occur in the adjacent electrical network and at the facility itself. This, in its turn, makes it possible to considerably shorten the time of implementation of new technologies when testing the functional performance of equipment and to analyze an array of options of LAN for substations of any voltage class.
2. The active test site created by JSC R&D Center at FGC UES enables simulation of disturbance impacts applied to the equipment under test to verify the claimed technical characteristics of secondary equipment designed for the DSS technology implementation.
3. The R&D efforts made during the establishment of the DSS TS for the purpose of designing and test-

ing pilot specimens of equipment operating in accordance with IEC 61850 laid the basis for designing core commercial equipment.

4. End-to-end functional tests of DSS automation and protection systems performed at the DSS TS allow obtaining standard engineering solutions for the implementation of the DSS technology at utilities of various voltage classes, which may considerably shorten the time of trial operation. Furthermore, the results of end-to-end testing and the proven standard solutions lead to more affordable design solutions with no need to create any additional experimental 'digital' circuits of secondary switching equipment at pilot power facilities.
5. JSC R&D Center at FGC UES, by order of PJSC FGC UES, is working on developing standard technical solutions for digital substations with different degrees of automation using computer-aided design systems aimed at reducing the cost and the lead time of utility designs.
6. The most important practical component of the DSS TS activity is certification of secondary equipment of Russian companies for IEC 61850 conformance and assistance with obtainment of a UCA level A certificate to promote their products on international markets.
7. A promising application task of the DSS TS is to use the site as a testbed for ensuring information security of power facilities. A trial specimen of the DSS cybersecurity software and hardware package was tested at the DSS TS in 2017.
8. Activities planned at the DSS TS include training workshops and conferences for industry-related personnel with utilization of the test site's resources and expansion of its functional capacities. The Second International Conference "Digital Substation. Standard IEC 61850" is to be held in 2019 (hosted by JSC R&D Center at FGC UES, jointly with DNV GL, and with support from CIGRE Russian NC).

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COMPANIES THAT CERTIFIED THEIR SECONDARY SWITCHING EQUIPMENT FOR CONFORMANCE TO IEC 61850-8-1 SERVER (ED. 1/2)

No. no.	Year	Company	IEC 61850-8-1 server (Ed. 1/2)	Number of terminals	UCA certificate
1	2015	LLC Energoservice (Arkhangelsk)	1	1	Level A
2	2015	Ltd EKRA Research and Production Enterprise (Cheboksary)	1	1	Level A
3	2015	JSC MRZ (Moscow)	1	1	Level A Level A
4	2015	JSC IC Bresler (Cheboksary)	1	2	Level A
5	2015	LLC NPP Bresler (Cheboksary)	1	1	Level A
6	2015	JSC Radius-Avtomatika (Zelenograd)	2	1	Level A
7	2016	JSC NIPOM (Nizhni Novgorod)	1	1	Level A
8	2016	JSC CHEAZ (Cheboksary)	2	1	Level A
9	2016	JSC Electropribor (Cheboksary)	1	3	Level A
10	2016	JSC Tecon-Engineering (Moscow)	2	1	Level A
11	2017	Ltd EKRA Research and Production Enterprise (Cheboksary)	2	3	Level A
12	2017	LLC PLC Technology (Moscow)	2	1	Level A
13	2018	LLC Svey (Yekaterinburg)	2	1	Level A
14	2018	JSC VNIIR (Cheboksary)	1	1	Level A

Table 3

ASYNCHRONIZED MACHINES FOR THE ELECTRIC POWER INDUSTRY

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Synchronous generators are traditionally used in the electric power industry. Asynchronized machines are a new class of electrical machine valve systems that have a series of advantages over conventional synchronous machines. Asynchronized machines have been widely used in thermal and hydro power stations, wind power plants, and networks as reactive power compensation units.

Keywords: asynchronized machine; doubly fed machine; turbine generator; hydrogenerator; synchronous condenser; energy storage.

Asynchronized turbine generator T3FAU-160-2U3 with 160 MW capacity at unit 11 of CHP-21 by Mosenergo

GENERAL PROVISIONS. DESIGN, EXCITATION, CONTROL

In the 1950s, on the initiative of and under academic supervision of M.M. BOTVINNIK, D.Eng.Sc., development and practical application of asynchronized machines (ASMs) in the power industry became a focus of special efforts in the USSR. Headed by VNIIE (presently JSC R&D Center at FGC UES), the activities were conducted at a number of scientific and design institutes and factories [1,2].

Later, approximately in the early 1980s, design, development and operation of ASMs were carried out by the world's leading companies: Mitsubishi, Toshiba, Hitachi, ABB, Alstom, Siemens, and others. In western literature, these machines are known as double fed asynchronous machines.

An ASM, in contrast with a synchronous machine, contains not one but two or three excitation windings on the solid rotor that are arranged at an arbitrary angle to each other and whose magnetizing force may be different. The excitation windings are fed from reversible rectifiers, i.e., frequency converters built from power electronic hardware components. The structural diagram of an ASM is shown in Fig.1.

With a rotor speed of 3000 rpm and 1500 rpm, the ASM is built with an unlaminated rotor, while a laminated rotor is used for a speed of 1000 rpm or lower.

An ASM with an unlaminated rotor is operated in a steady-state condition with synchronous speed (slip s=0), since with nonsynchronous speed the rotor's solid block losses would increase substantially.

ASM STRUCTURAL DIAGRAM

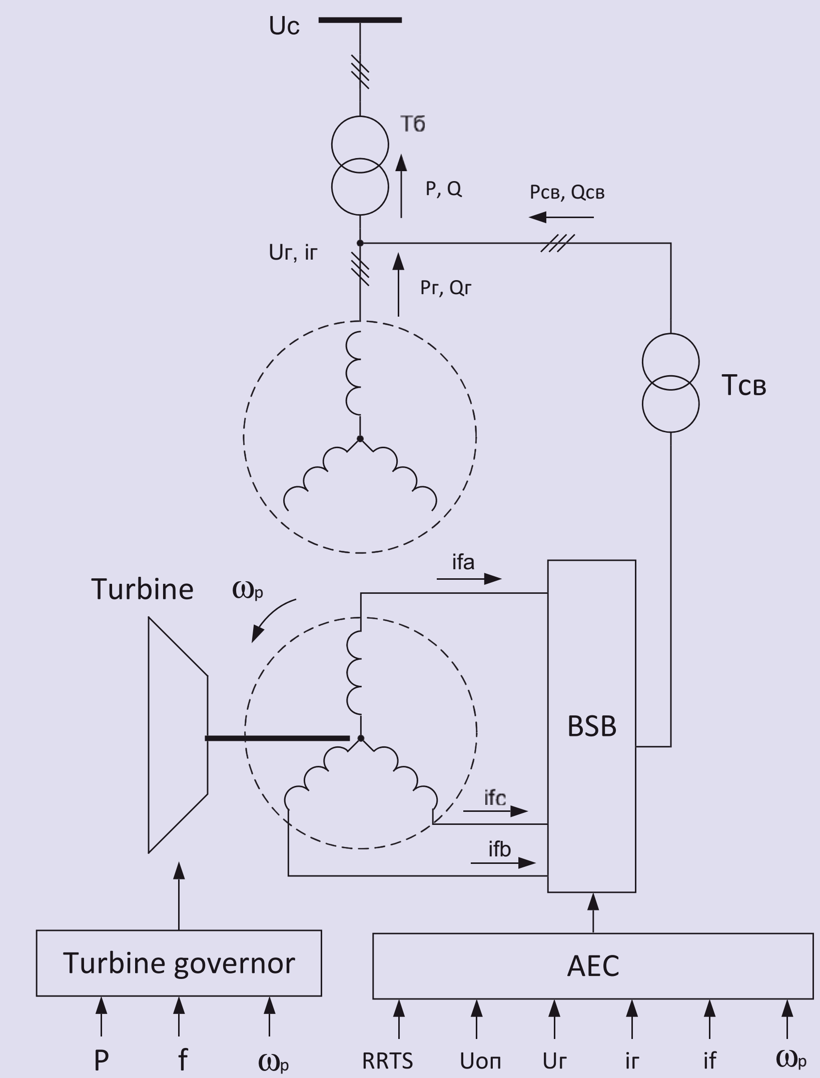


Fig. 1

An ASM with a laminated rotor can operate in a wide range of rotor speed settings. Fig. 2 shows a possible classification of ASMs.

ASMs utilize the so-called vector excitation control principle[1] where the following duty parameters are controlled separately and independently of each other: active power or electromagnetic torque and reactive power or machine voltage. The excitation voltage output frequency of an ASM (ω_f) is formed as the difference between the mains frequency (ω_c) and the rotor speed (ω):

$$\omega_f = \omega_c - \omega = s\omega_c,$$

where $s=(\omega_c-\omega)/\omega_c$ is slip of machine.

[1] In some publications this control principle is called an asynchronized control principle [3]

If the rotor speed and the mains frequency are identical, the output frequency of the excitation system converters is zero, and the rotor rotates with synchronous speed. At $\omega_c \neq \omega$ the machine's rotor rotates with non-synchronous speed, while the frequency of stator currents and voltages remains unchanged and equal to the mains frequency. This means that in an ASM the rotor speed and the mains voltage frequency are "unlinked" from one another, which determines a series of advantages of ASMs over synchronous and asynchronous machines.

Fig. 3 shows a vector diagram of ASM operation through reactance (x) to infinite buses (U).

Active power (electromagnetic torque) and reactive power of an ASM that has two excitation windings correspond to:

$$P = M \cdot \omega_c = \frac{UE_q}{x} \sin\delta - \frac{UE_d}{x} \text{cc}$$

$$Q = -\frac{U^2}{x} + \frac{UE_q}{x} \cos\delta - \frac{UE_d}{x} \sin\delta \quad (1)$$

Emfs $E_q = x_a \cdot i_{fd}$ and $E_d = x_a \cdot i_{fq}$ are induced in the ASM stator by excitation currents i_{fd} and i_{fq}.

Currents i_{fd} and i_{fq}:

$I_{fd} = \alpha \sin\delta + \beta \cos\delta;$

$I_{fq} = \beta \sin\delta - \alpha \cos\delta.$ (2)

Substituting (2) in (1), after rather simple transformations, the following is derived:

$$M \cdot \omega_c = P = \frac{U \cdot x_a}{x} \alpha$$

$$Q = -\frac{U^2}{x} + \frac{U \cdot x_a}{x} \beta \quad (3)$$

By changing α and β as necessary, independent and separate control of active and reactive power of the ASM is achieved. The vector diagram in Fig. 3 implies that $x_a \cdot \alpha = E_y$, $x_a \cdot \beta = E_x$, where E_y and E_x are projections of vector E onto the coordinate axes

CLASSIFICATION OF ASYNCHRONIZED MACHINES (ASMS)

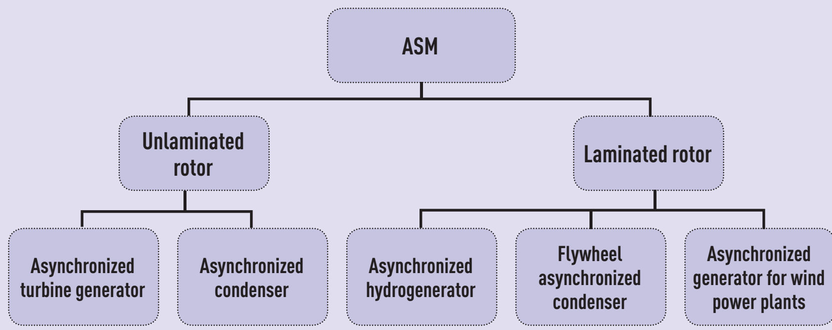
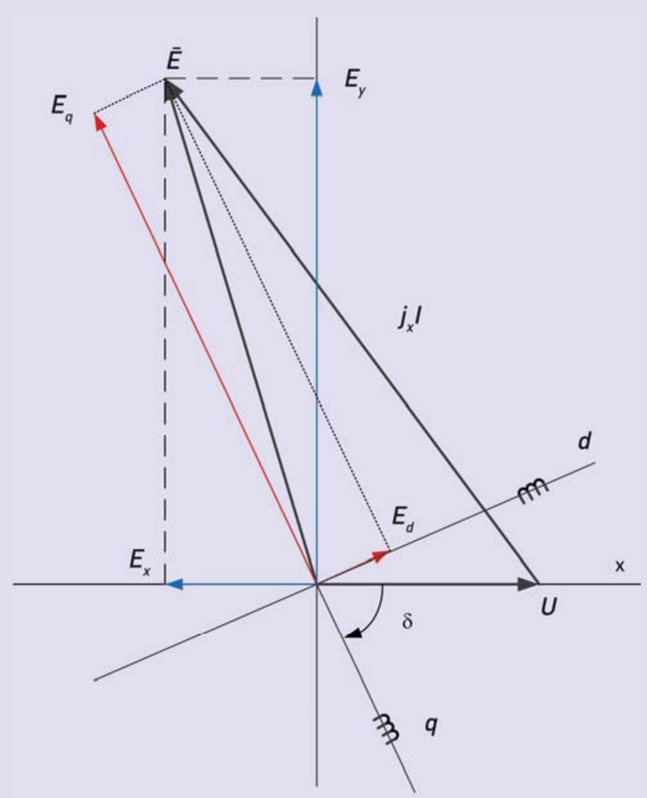


Fig. 2

ASM VECTOR DIAGRAM



E is ASM emf vector;
E_y, E_x are projections of vector E to "synchronous" axes *xy*;
U is power system voltage vector (reference vector);
E_q, E_d are projections of vector E to rotor winding axes.

Fig. 3

PERMISSIBLE DUTY AREAS OF ASYNCHRONIZED TURBINE GENERATORS (ASTG) AND HYDROGENERATORS (ASHG) COMPARED WITH SYNCHRONOUS TURBINE GENERATORS (STG) AND HYDROGENERATORS (SHG)

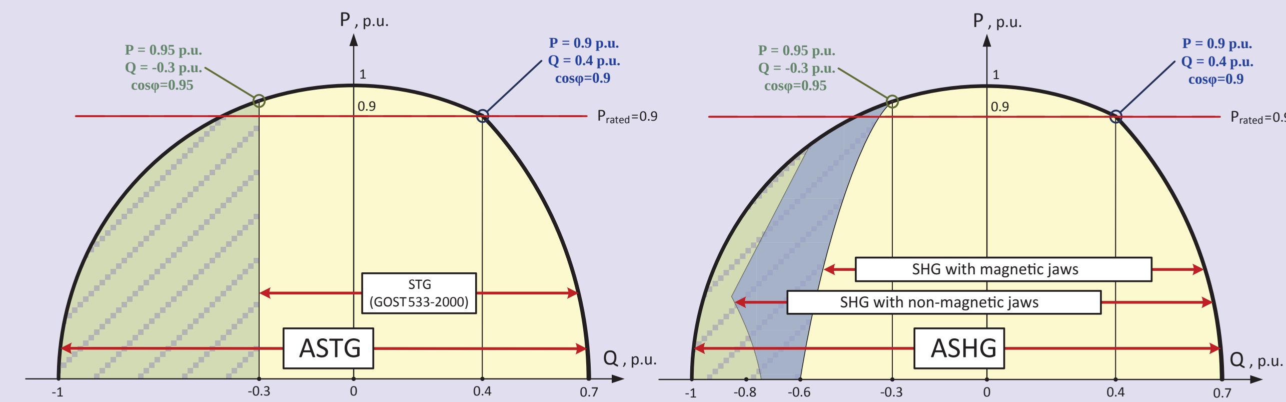


Fig. 4

BLOCK DIAGRAM OF ASM CONTROL

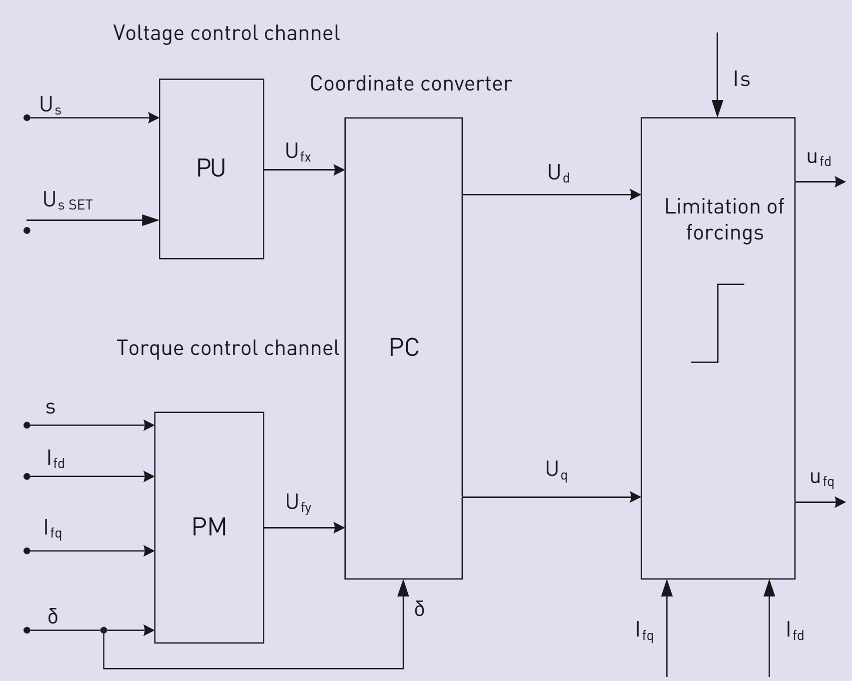


Fig. 5

that rotate synchronously with the power bus vector (U).

If the value of is

$\alpha = \alpha_0 - \alpha_1 \cdot \Delta s,$ (4)

where Δs is deviation from the steady-state slip value s_0, then from the equation of motion we get

$$T_j \frac{d\Delta s}{dt} + \alpha_1 \frac{U \cdot x_a}{x} \Delta s = 0 \quad (5)$$

The static stability condition according to the result obtained is written as:

$\alpha_1 > 0$ (6)

Hence, it can be seen that the static stability of an ASM is independent of the machine's duty parameters and is ensured at any possible values of active and reactive power of the machine. This means that it is possible to ensure stable operation of an ASM at any values of reactive power, from output to consumption. The operating areas of an ASM are limited only by the nominal stator and excitation currents (Fig. 4).

DEFINITIONS

Energy system stability area — the range of energy system operating parameters for which stability is guaranteed under disturbances.

Static stability of a power system is the power system's ability to return to the set mode after minor disturbances. Note: a minor disturbance is understood as a condition in which parameter fluctuations are incommensurately small compared to the values of these parameters.

Energy system static stability reserve — an indicator characterizing static stability of the energy system operating mode compared to extreme stability threshold.

Dynamic stability of a power system is the power system's ability to return to the set mode after major disturbances without going into asynchronous mode. Note: a major disturbance is understood as a condition in which parameter fluctuations are commensurate with the value of these parameters.

Asynchronous mode is a transitional operation mode of a power system, which is characterized by stable deep periodic fluctuations of the voltage, current and power, periodic changes in the EMF angle of power station generators, and a difference between frequencies in parts of synchronous zone while preserving electrical connection between them.

Disturbances in a power system are unintended changes in the operating conditions of an electric power system caused by short circuit, failure or disconnection of individual elements, etc., resulting in transition processes at power stations, in electrical grids and at consumer equipment.

A common structural diagram of ASM vector control is shown in Fig. 5.

Vector control has a positive effect on the limits of dynamic stability. For example, in case of a short circuit in the network, it is possible, in principle, by acting on the angular position of emf E or E', to turn the emf to the side opposite to the rotation of the rotor. This action depends, inter alia, on the degree of voltage forcing by ASM excitation, initial duty cycle, etc.

ASYNCHRONIZED MACHINES WITH UNLAMINATED ROTOR

TURBINE GENERATORS

As stated before, since turbine generators have an unlaminated rotor, operation in steady-state conditions with a slip would be disadvantageous because high rotor losses would occur. Therefore, in steady-state conditions, ASTGs are operated with synchronous speed. In addition, the electromagnetic moment and voltage are independently controlled in accordance with the control system described above.

It is a known fact that with synchronous turbine generators (STG) in under-excitation modes a lowest excitation limit (LEL) is introduced due to intense heating of the stator ends and a considerable reduction in static and dynamic stability margins.

For asynchronized turbine generators, the diagram of permissible duties in its left-hand section is limited only by the rated stator current. As can be seen from Fig. 3, asynchronized turbine generators have by far greater controlling capabilities in terms of reactive power consumption in comparison with synchronous turbine generators.

The technical and economic effects of utilization of asynchronized turbine generators are as follows:

1. No need for additional reactive power compensation devices (reactors) on station buses installed to prevent synchronous turbine generators from operating in reactive power consumption modes.
2. Improved reactive power duty cycles of synchronous turbine generators in a power station that operate in parallel with the ASTG by avoiding the modes that are unfavorable for the STG with reactive power consumption (or close to that).
3. More reliable operation of generating equipment in general.

As for the functional reliability of an ASTG itself, from the formal standpoint, its reliability should be lower due to a greater number of components that could fail (two excitation windings, two reversible thyristor converters, etc.). However, considering the ability to remain operable with limited functionality, an ASTG will offer unquestionable advantages.

First, in the event of failures in one of the thyristor converters it is possible to work with one excitation winding. In this case, the generator becomes a conventional synchronous generator. However, an ASTG is not disconnected from the network but remains in operation. Once the fault is rectified, on command from an operator the generator will again be switched to asynchronized mode with excitation by two windings.

Second, an ASTG can operate for an indefinitely long time without excitation. Operation of synchronous generators in case of excitation loss is limited by the time (max 30 minutes) and active power (max 60% of the nominal value), after which the generator will be disconnected from the network. In most practical cases, the wide area protection is designed in such a manner as to disconnect the generator from the network immediately. Due to electromagnetic asymmetry of a synchronous generator's rotor in asynchronous mode, considerable variations of voltage, current, and electromagnetic torque would occur. In an asynchronous turbine generator, the rotor is electromagnetically symmetrical; the generator's cycle parameters are stable during operation without excitation. An ASTG in these modes can run continuously with active power up to 75–80% of the rated one.

The advantages listed above have been much needed in the Mosenergo system. In 2002, to improve the controllability of modes in terms of maintaining the required voltage levels and controlling the reactive power flows, as well as to enhance the power system stability and reliability, JSC Mosenergo installed ASTGs in a number of power stations.

The first stage in the introduction of such machines consisted in the installation of Russia's first industrially operated ASTG at CHP-22 by JSC Mosenergo. In December of 2003, a prototype ASTG of the T3FA-110 2U3 type was put into trial operation at CHP-22, station unit No. 8, manufactured by JSC Power Machines — the Elektrosila plant.

The ASTG is operated both in reactive power output and consumption modes. In consumption modes, the generator is normally operated during night hours and round-the-clock on weekends. The average level of reactive power consumed is 30÷–40 MV·A under a lowered active load. Two challenges were addressed simultaneously: to maintain the required voltage on the station buses and to prevent unit 7 running in parallel with the synchronous turbine

THE DAILY SCHEDULES ON THE REACTIVE POWER OF ASYNCHRONIZED TURBOGENERATORS NO. 33 AND NO. 43 OF TPP-27 MOSENERGO FOR WINTER AND SUMMER DAYS

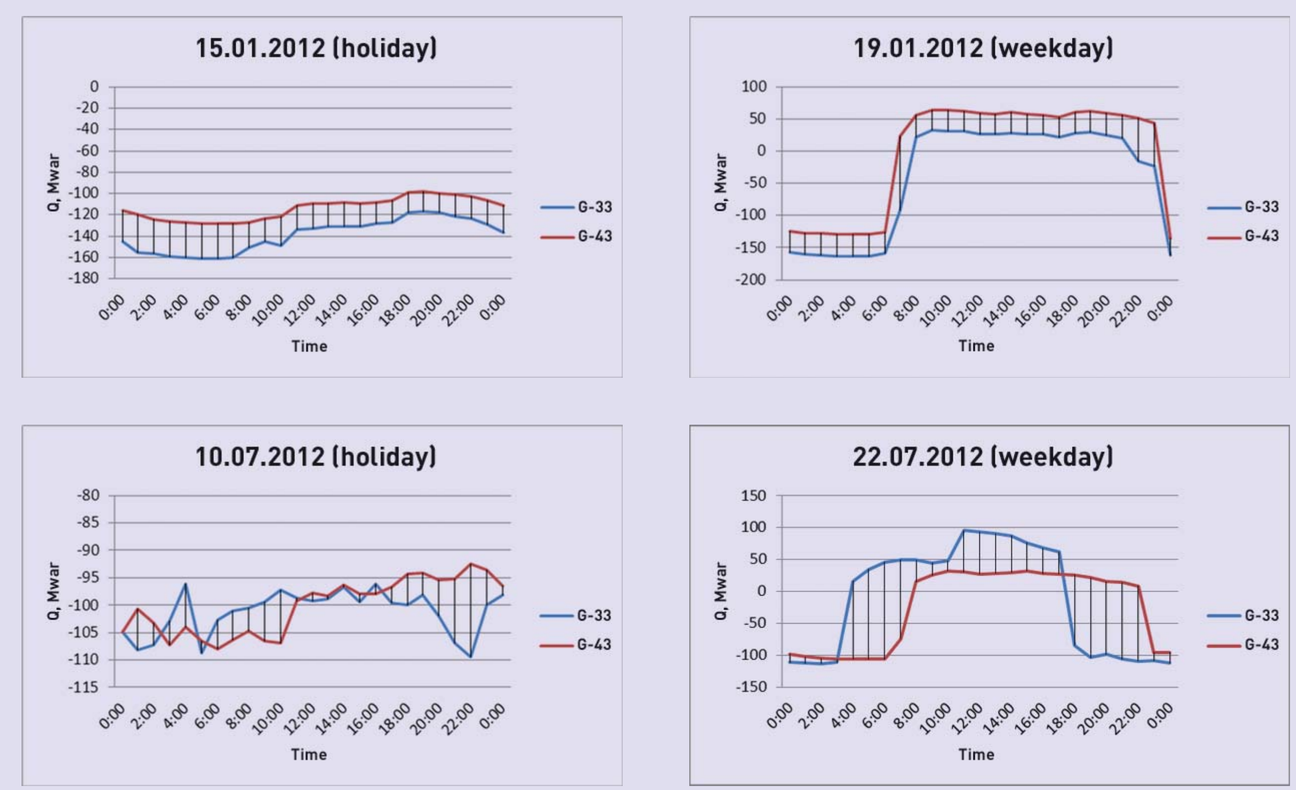


Fig. 6

AVERAGE REACTIVE POWER VALUES AND AVERAGE SERVICE HOURS OF OPERATION IN REACTIVE POWER OUTPUT AND CONSUMPTION MODES

Month	Station number	Q sign	$Q_{average}$, Mwar	Hours
January	33	+	14	161
		–	–128	580
	43	+	28	248
		–	–116	333
July	33	+	49	303
		–	–97	348
	43	+	–96	439
		–	36	336

Table 1

TECHNICAL CHARACTERISTICS ASC-100-4

Name of parameter	Value
Rated power, MV·A	100
Reactive power, Mvar	±100
Stator voltage, kV	20
Stator current, A	2,900
Rotor winding current:	
on axis d, A	2,200
on axis q, A	740
Speed, rpm	1,500
Total compensator losses, kW	1,500
Cooling	All-air

Table 2

generator from operating in reactive power consumption modes that are damaging.

The second stage of ASTG implementation consisted in the commissioning of additional three turbine generators in 2007 and 2008. Turbine generators T3FAU-160-2U3 with 160 MW capacity were installed in steam and gas units (CCGT) with a total unit capacity of 450 MW at CHP-27 (units 3 and 4) and CHP 21 (unit 11) (Fig. on p. 60) [4].

Table 1 lists average values of reactive power and average service hours for operation in reactive power output and consumption modes of asynchronized turbine generators T3FAU-160-2U3 at CHP-27 by Mosenergo (station No. 33 and 43). Fig. 6 shows daily reactive power trends for winter and summer periods.

In December of 2009, 320 MW asynchronized turbine generator T3FSU-320-2U3 was put into operation at unit 3 of the Kashira power plant.

All generators were designed and manufactured by JSC Power Machines — the Elektrosila plant.

ASYNCHRONIZED REACTIVE POWER COMPENSATORS

One of the vital elements of modern electrical grids is reactive power compensators. They help not only maintain the voltage levels in network nodes but also reduce network losses by selecting the best operation mode.

Electric machine reactive power compensators, in contrast to static devices, can withstand short twofold overloads, which can only be achieved for static devices by doubling the installed capacity. Another important feature is stability to possible pulse overvoltages in the lines (e.g. due to lightnings). Electric machine compensators don't generate higher harmonics to the network.

JSC R&D Center at FGC UES jointly with JSC Power Machines — the Elektrosila plant designed, manufactured and commissioned asynchronized reactive power compensators of the ASK-100-4 type with 100 MVA capacity [5]. The experience with asynchronized turbine generators was taken into account during their design and manufacture.

With two excitation windings with an excitation system and vector control, such compensators have new features and advantages in comparison with conventional synchronous compensators with one excitation winding:

1. Wider reactive power control range between +100 Mwar and –100 Mwar (for conventional synchronous compensators it is between +100 Mwar and –40 Mwar).
2. Prompt reactive power/voltage control actions owing to the possibility of reversing currents in the excitation windings.
3. Improved damping of the duty parameter fluctuations in case of disturbances in the network.
4. Enhanced survivability owing to the possibility of standby operation in case of failures in the excitation system.

Two ASK-100-4 compensators were installed at the Beskudnikovo substation in Moscow. Basic technical data are given in Table 2.

ASYNCHRONIZED MACHINES WITH LAMINATED ROTOR

ASYNCHRONIZED HYDROGENERATORS

Given today's operating conditions of electrical grids, it is critical to maintain the high quality of power as well as the reliability and controllability of a power system. Basic power quality indicators are frequency, levels and harmonic contents of voltages in power system nodes.

The most flexible and, consequently, most suitable power plants for frequency and capacity control in a power system are hydro (HPP) and pumped storage (PSP) plants. The rate of active power control in this type of power stations is determined by the speed of opening/closing of the guide vanes, being up to 500 MW/min, and is limited by the water hammer triggering conditions, control apparatus parameters, and other hydrodynamic characteristics.

These advantages of HPP and SPS have led to their wide application in the power industry. However, there are a number of challenges associated with both the electrical and hydraulic part of a hydraulic unit with a synchronous generator:

– decrease in hydraulic turbine efficiency at variable heads (loss of generation);
– presence of forbidden zones (unsteady flow) in the operation of hydraulic turbines;
– limited active power control rate;
– limited voltage and reactive power control in wide ranges;
– insufficient margins of dynamic stability.

Let us consider the efficiency of ASHGs with some examples.

INCREASED POWER GENERATION

Operational characteristics of constant speed hydraulic units are expressly dependent on the duty parameters (head and power of the turbine), with a small optimal performance zone where the efficiency is the greatest.

In an example of the PL 20/661 turbine, with the unit's synchronous rotation speed n_c = 62.5 rpm, the optimal efficiency zone lies within the limits between 20 to 32 MW at a head of 11.5 m and 30 to 38 MW at a head of 15.5 m (Fig. 7).

ASHGs with variable rotation speed, owing to the control of the unit's rotation speed by the highest efficiency criterion, allow expanding the optimal performance zone substantially. In the case above, if a synchronous generator is replaced with an asynchronized one with a variable speed of the unit ($59 \leq n \leq 77.5$ rpm), the optimal zone will be between 18 to 30 MW at a head of 11.5 m and 42 to 66 MW at a head of 20 m (Fig. 8). Therefore, operation with maximum efficiency becomes possible across the whole operational range of heads.

FROM HISTORY

Specific features of conventional synchronous turbine generators, conditioned by their operating principle, do not allow to solve a number of problems in the function of electrical power systems — for example, to ensure the necessary degree of stability, reliability and economy of systems operated in normal (steady-state) and transient (dynamic) conditions. The idea of creating better and improved generators as an alternative to synchronous turbine generators first emerged as far back as in the early 20th century in connection with development of collector cascades. But it was only in 1956 that the All-Union Electric Power Research Institute of the USSR, on an initiative of professor M.M. Botvinnik, began researching a new type of alternating current electric machines — asynchronized machines.

AVOIDANCE OF FORBIDDEN ZONES (UNSTEADY FLOWS)

A specific feature of propeller-type and mixed flow turbines, especially high-pressure turbines, is that at low loads such turbines have a range of cycles where operation is forbidden due to higher hydrodynamic stresses and vibrations caused by unstable flows (a forbidden zone). In Fig. 9 the forbidden zone is marked red. The respective limitation for a turbine running with partial capacities is specified by the equipment manufacturer on performance characteristic H_T–N_T.

By using variable speed units, it is possible to avoid the forbidden zone by transferring to a mode with the same turbine power lying outside the forbidden zone. Fig. 9 shows an example of avoidance of forbidden zones for the PR 20/811 propeller tur-

OPERATIONAL CHARACTERISTIC OF THE PL 20/661 TURBINE AT THE UNIT'S SYNCHRONOUS SPEED OF N_C = 62.5 RPM

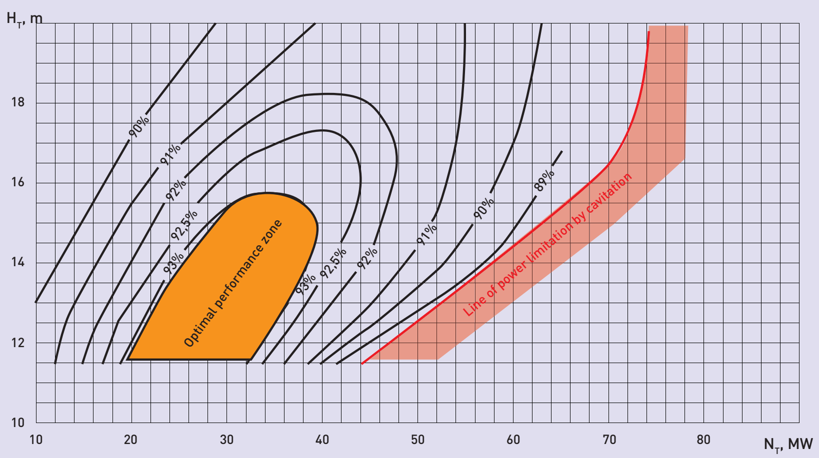


Fig. 7

bine with nominal speed n = 37 min^{-1}. In order to avoid the forbidden zone at initial speed n = 37 min^{-1}, it is necessary to increase the rotor speed by Δn = 5 min^{-1} at power NT = 11 MW and to decrease the rotor speed by Δn = 5 min^{-1} at power NT = 12 MW. The new mode points will lie outside the forbidden zone.

MOBILE ACTIVE POWER CONTROL

In a synchronous generator, the active power fed into the network can be changed only by controlling the turbine output. The rate of change of the electric active power is determined by the speed of control of the turbine's guide vanes.

In an ASHG, it is possible to control the active electric power independently of the mechanical power while varying the rotation speed within certain limits.

This allows virtually instantaneous control of the active power delivered/consumed in the network. With such control, the variation of active power of the machine's stator will substantially outstrip the variation of the mechanical power output of the turbine. The resulting imbalance between the electromagnetic and mechanical torques on the unit shaft will lead to braking/acceleration of the unit, and the power needed to accelerate the ASHG active electrical power control will be covered by changing the kinetic energy of the spinning masses of the rotor.

ENSURING DYNAMIC STABILITY

In order to compare the dynamic stability of synchronous and asynchronized hydrogenerators, benchmark calculations were made for generators of equal power in a generator — transformer — transmission line — infinite buses setup. Fig. 10 shows the trends of critical time of a 3-phase short-circuit on the station buses vs. reactive power.

It can be seen from the figure that the maximum short-circuit time for an SHG is about 0.2 sec, while for an ASHG it is 1 sec, since in a synchronous generator the rotor displacement angle increases as the short-circuit duration gets longer. The stability limit is reached when the ultimate angle is achieved at which the rotor cannot be slowed down. The displacement angle margin is decreased as the transfer to under-excitation modes progresses because the initial load angle is increased.

OPERATIONAL CHARACTERISTICS OF THE PL 20/661 TURBINE AT THE UNIT'S VARIABLE SPEED (59 ≤ N ≤ 77.5 RPM)

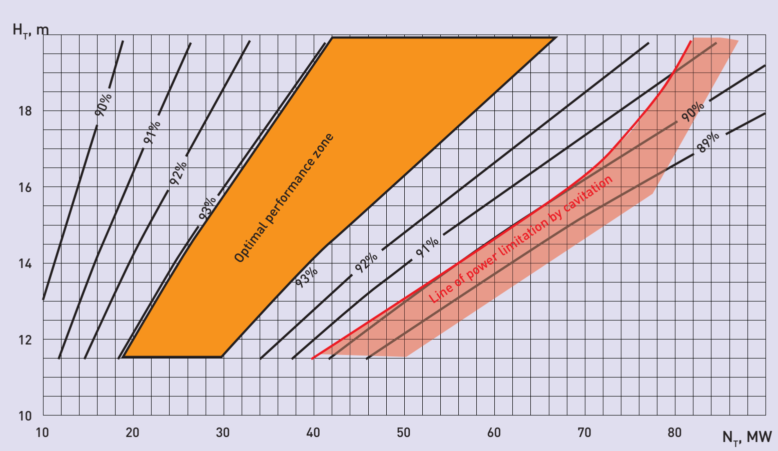


Fig. 8

AVOIDANCE OF THE FORBIDDEN ZONE FOR PROPELLER TURBINE PR-20/811 AT VARIABLE SPEED AND CONSTANT HEAD H = 6 M

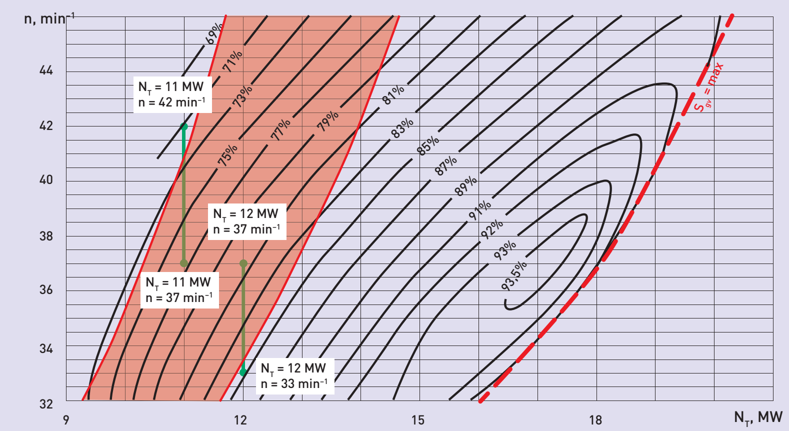


Fig. 9

CRITICAL SHORT-CIRCUIT TIMES FOR SHG AND ASHG

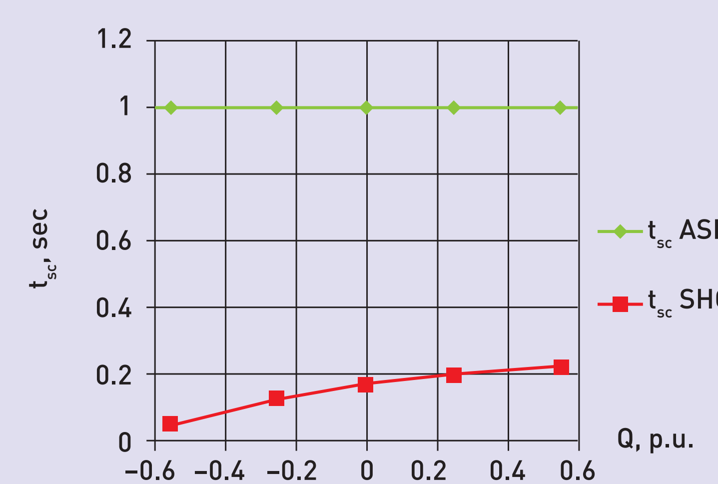


Fig. 10

In an ASHG, thanks to the possibility of prompt and independent active power control and variable rotor speed operation, the dynamic stability is maintained in the case of rated disturbances in the power system. Speed variation within the operating range during transients for an ASHG is not associated with loss of 'synchronism.' This explains the considerable margin of dynamic stability of an ASHG as compared with an SHG.

It must be noted that the world's first ASHGs with 40 MW capacity were designed and manufactured in the 1960s in the USSR at the Elektrosila plant. Presently, a 3 MW ASHG model with an excitation and control system has been manufactured and tested at JSC Power Machines — the Elektrosila plant, and a basic design has been drafted for a 200 MW ASHG.

In the past 20 years, a number of foreign companies manufactured and introduced over 20 ASHGs with unit sizes ranging from 80 MW to 420 MW.

FLYWHEEL ASYNCHRONIZED CONDENSERS

Asynchronized machines with a laminated rotor with a flywheel on the shaft can be used in the power industry as an electromechanical energy storage compensator.

Such a device is able, by varying the rotation speed and kinetic energy of spinning masses, to ensure the accumulation or generation of considerable energy. In addition, an FASC possesses all of ASC properties in respect of reactive power control.

Structurally, an FASC is designed as an electric machine with a symmetrical multiphase winding on a laminated rotor. The FASC rotor is connected to the network. Similarly to an ASHG, the installed capacity of the converter in the rotor winding circuit is proportional to the machine's full power (at the rated reactive and maximum permissible active power) and the rotation speed control range. A reasonable ratio of power of the machine and exciter is achieved with the slip range within ±10%.

For an FASC, a vertical structural design appears more preferable. In the conditions of ensuring the laminated rotor's strength, the synchronous speed of the rotor should be limited to 1500 rpm or lower.

An FASC can share active power with the network only briefly, within the change of kinetic energy of rotating parts with the speed varying in permissible limits. The peak active power can also be limited by the maximum current of the semiconductor exciter. As a first approximation, the maximum active power may be assumed equal to the rated reactive power.

An FASC, like any electric machine compensator, ensures balancing of reactive power and control of voltage. In addition, an FASC has a wider control range because it has no limitations in terms of stability in the reactive power consumption zone.

Additionally, an FASC improves the power system's stability and increases the capacity of transmission lines, stabilizing voltage not only by its magnitude but also by the phase, creating a 'rigid bus' effect. To enable this function, an FASC should have a power substantial for the power system (in Russian conditions, at a level of 100 to 160 MVA).

Besides the general functions of voltage control and stability improvement, FASCs can have specific applications, which are conditioned by prompt active power control and power sharing with the network in a given volume.

Asynchronized generator is a term introduced into scientific practice by Mikhail BOTVINNIK, a Soviet scientist and chess player, in 1955

For instance, when installed at consumer substations with abrupt variations of active loads, FASCs are able not only to stabilize the voltage level but also to fully or partially absorb active load fluctuations.

When installed in a large power system hub, a FASC will considerably improve the quality of post-fault transients by creating the 'rigid bus' effect, as it maintains not only the magnitude but also the phase of voltage in the point of coupling, absorbs (inasmuch as possible) fault interruptions, and reduces the probability of escalation. In view of the above, it is also recommended to install FASCs at intermediate substations of long bulk power transmission lines. FASCs deployed in this manner will ensure islanding of transmission, containment and damping of fault interruptions, and higher reliability and capacity of the TL.

In off-grid power systems, an FASC may also be utilized for frequency control.

CONCLUSION

1. Asynchronized machines are a new class of electrical machine valve systems that have a series of advantages over conventional synchronous machines.
2. Asynchronized machines are widely used in the power industry. In Russia, these are asynchronized turbine generators and reactive power condensers. In other countries, those are asynchronized hydrogenerators and wind power plant generators.
3. There are a number of areas where asynchronized machines may also be found usable: electromechanical energy storages, electromechanical AC back-to-back stations between power systems, and an electrical drive based on asynchronized motors.

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FAST-ACTING CONTROLLED SHUNT REACTORS TO BE UTILIZED IN THE UNEG OF RUSSIA AND ABROAD

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Controlled shunt reactors (CSR) are gaining increasing interest in the world today. For example, eight CSRs were installed in the Norwegian 420 kV power network in 2012–2013, with two more reactors in 2016. Seven CSRs were installed in 400 kV networks in Denmark in 2013–2015. Four CSRs were delivered in the USA in 2013–2015 to be installed in 345 kV and 143 kV networks.

Keywords: controlled shunt reactors; transformer-type controlled shunt reactors (TCR); CSR with on load tap changer control (OLTC).

Exterior view of the TCR at the Svetlaya 220 kV substation

Four CSRs were delivered in the USA in 2013–2015 to be installed in 345 kV and 143 kV networks

INTRODUCTION

Shunt reactors (SR) are required to maintain the work cycles of power networks on ultra-high voltage (UHV) lines operating in the modes of transmission of less-than-natural power; their purpose is to limit overvoltages. However, in order to transmit power up to the natural one along the same line, it is necessary to decrease the charge capacity compensation ratio [1]. The compensation ratio of a line can be changed in different ways: 1) by switching SRs on or off; 2) through indirect compensation by installing controllable synchronous compensators (SCs) in parallel with noncontrolled SRs; 3) by using controlled shunt reactors (CSRs). The first method is not widely accepted because of the overvoltages that occur when the reactor is switched. The second method had been widely used on UHV lines in the USSR (and later in Russia) until the time when more efficient (with no indirect compensation) controlled SRs were designed and introduced [1].

Besides limiting the voltages and increasing the power capacity of lines, CSRs allow to [1–3]:

1. Prevent synchronous generators from operating in the work cycles that cause deep consumption of reactive power;
2. Improve the static and dynamic stability of the power system;
3. Reduce the number of switching operations of static capacitor banks and decrease the number of switching operations of transformer OLTCs.

The tasks listed above are solved by using the so-called bus CSRs — reactors connected as shown in Fig. 1a. When connected to the line (Fig. 1b), specially designed CSRs can solve four additional tasks [4 7]:

1. Decrease the quasi-steady-state overvoltages of a line with one side of the line idling;
2. Avoid the aperiodic component in the currents of the CSR power windings and in the currents of the line circuit breaker when voltage-testing a transmission line;
3. Lower the arc fault current in the single-phase auto-reclosing (SPAR) cycle;
4. Prevent the resonant voltage spike potentially possible in open-phase modes of a CSR compensated line at a degree of compensation close to 100%.

Currently, two CSR types are in current operation in Russia: magnetically controlled shunt reactors (MCSR) [2, 9] and thyristor controlled shunt reactors (TCR) [3–9], whereas, normally, CSRs are utilized abroad, and they are close in their design to an OLTC transformer. The differences in the CSR control principles determine the differences in the response times of the reactors. For example, the time of power change from idling to nominal mode in a TCR is around 0.03 s, while for an MCSR it is usually about 0.3 s. In an OLTC-based CSR the time of switching from its technological minimum (50 % of the rated capacity) to nominal mode is approximately 300 s.

Design and functions of fast-acting thyristor-controlled transformer-type shunt reactors

TYPES OF CSR CONNECTION TO NETWORK

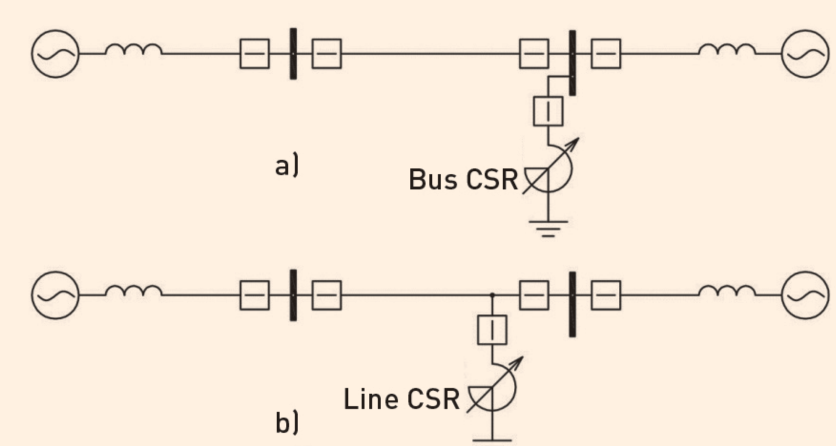

Fig. 1

The operational principle of fast-acting thyristor-controlled transformer-type shunt reactors (TCR) is based on varying the magnitude and duration of a current passing through the reactor in every industrial frequency cycle by means of pulse-phase control of thyristor valves. The theoretical basics of functions of a TCR (designed by G. N. ALEKSANDROV) are set forth in a textbook [3], and the experience of pilot implementation of a TCR in 2009 is summarized in a research paper [10]. The described reactor was designed without splitting the valve-side windings and with a compensation winding to which low-power harmonic filters were connected for the filtration of higher current harmonics.

In 2012, JSC R&D Center at FGC UES developed a technical concept of a 500 kV TCR with a new design that would require no higher harmonic filters and ensure an improved harmonic composition of the reactor current consumed from the network by using split valve-side windings (Fig. 2). The 500 kV TCR's electromagnetic component (EMC) consists of three separate phases, each comprising a core-type magnetic circuit, two power winding sections (PW1 and PW2) spread on the core legs, and a valve-side winding split in two (VW1 and VW2). The first leg holds the power winding section PW1 and the valve-side winding half VW1; the second leg holds the power winding section PW2 and the valve-side winding half VW2. Between the core legs, the magnetic flux is closed through end-face yokes. Valve-side winding halves VW1a, VW1b, and VW1c are connected in delta, while valve-side winding halves VW2a, VW2b and VW2c are connected in star. The TCR's valve part (VP) consists of two groups with three thyristor valves (TV) in each. The thyristor valves of both groups are connected in delta.

At present, the TCR equipment with split valve-side windings has been manufactured for the voltage classes of 110 kV, 220 kV, and 500 kV (Table 1), and three reactors are commissioned in Russian electrical networks, including such a critical facility as the receiving side of the Crimea Power Bridge, i.e., the 220 kV Kafa substation.

BASIC DATA ON THE MANUFACTURED TCRS WITH SPLIT VW

No.	Facility	Rated voltage, kV	Rated power, Mwar	Service years	Customer
1	Bystrinskaya 110 kV substation	110	25	Commissioned in 2017	PJSC MMC Norilsk Nickel
2	Svetlaya 220 kV substation	220	2 × 50	In operation since 2014	PJSC FGC UES
3	Kafa 220 kV substation	220	100	In operation since 2016	PJSC FGC UES
4	Pikhtovaya 220 kV substation	500	63	Commissioned in 2017	PJSC Rosneft
5	Mozdok-2 500 kV substation	500	180	Delivered to site in 2017	PJSC FGC UES
6	Ust-Kut 500 kV substation	500	180	Delivered to site in 2017	PJSC FGC UES

Table 1

CIRCUIT DIAGRAM OF A TCR WITH SPLIT VW

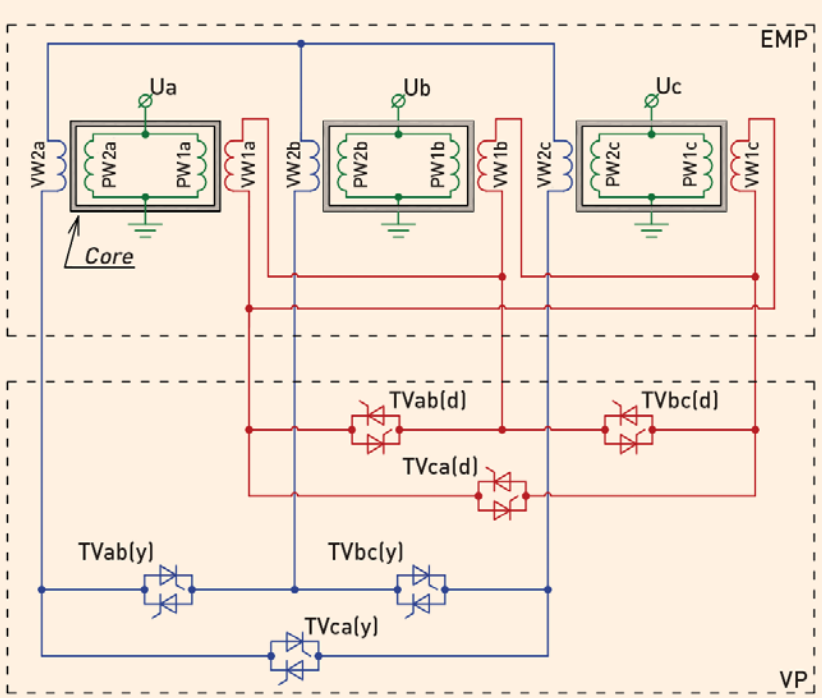

Fig. 2

In 2016, JSC R&D Center at FGC UES on order by PJSC FGC UES upgraded the TCR control system for the TCR to function as a line reactor and studied the operational modes of the line TCR and the network equipment.

The studies yielded the following findings:

1. The TCR with split valve-side windings connected in star and in delta allows decreasing the feed current and reducing the statistical average arc duration of a single-phase-to-ground fault in a transmission line. Equipping a transmission line with such a line TCR and line relay protection able to detect the extinction of the arc of a TL phase-to-ground fault will help reduce the SPAR cycle time (Fig. 4) [5]. For 500 kV lines with the statistical average length of 280 km, the use of a TCR can reduce the arc feed current in the SPAR cycle from 50 A to 15 A (Fig. 3, 4), which corresponds to the reduction of the estimated SPAR cycle time from 1.11 sec to 0.46 sec with 95% probability. Application of the given TCR design will enhance the SPAR efficiency and power system reliability.
2. Fast switching between TCR operation modes prevents the evolution of voltage resonance (Fig. 5) in an open-phase mode of the transmission line occurring after the arc extinction at a line compensation ratio close to 100% [6].
3. Pulse-phase control of TCR thyristor valves allows switching the TCR on without the aperiodic component in the currents of the reactor and the OHTL (Fig. 6). Utilization of a TCR on lines (instead of a SR) allows eliminating the cause of damage to the line breaker in the rated

DEPENDENCY OF SPAR DURATION VS. NETWORK PARAMETERS

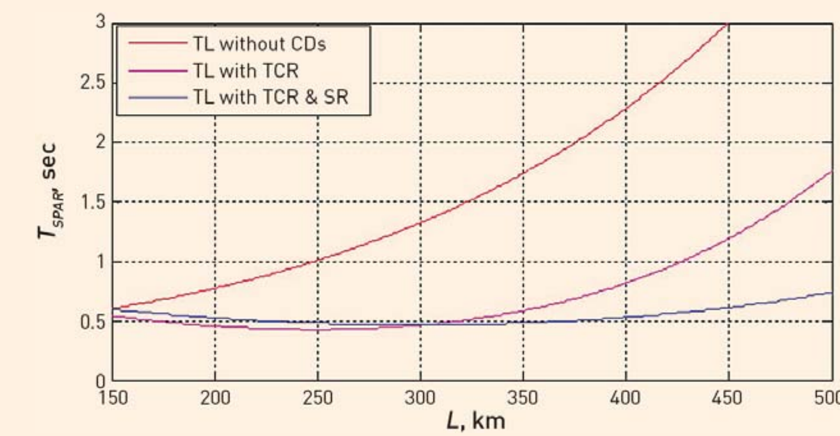

Fig. 3

TCR OPERATION IN SPAR CYCLE OF A 280-KM 500 KV LINE

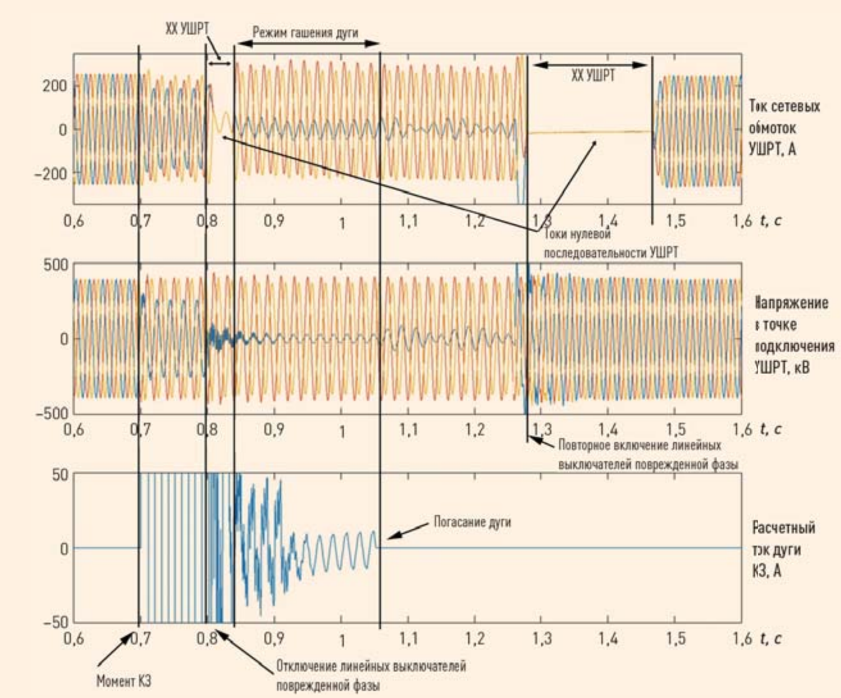

Fig. 4

"on/off" cycle without using any additional special measures such as controlled switching or using pre-insertion resistors [7].

4. Fast action of a TCR enables transferring the reactor into idle mode from any operational mode (also from the mode with the current lower in magnitude than the maximum permissible value of 80 A per GOST R 52565-2006) in shorter time than the industrial frequency cycle, which helps avoid dangerous overvoltages on the reactor breaker caused by current chopping. The transient oscillogram at the chopping of the highest possible TCR idling current with the voltages recovered across the circuit breaker contacts staying within the rated transient recovery voltage (TRV) of the breaker is shown in Fig. 7, from which it can be seen that successful opening of the circuit breaker is guaranteed [8]. As a result, when the reactor's idling current is chopped off, the TCR circuit breaker should merely meet the requirements of the applicable GOST R 52565-2006.

VOLTAGE TRENDS OF THE DAMAGED TL PHASE IN A SPAR CYCLE WITH DIFFERENT TCR CONTROL ALGORITHMS

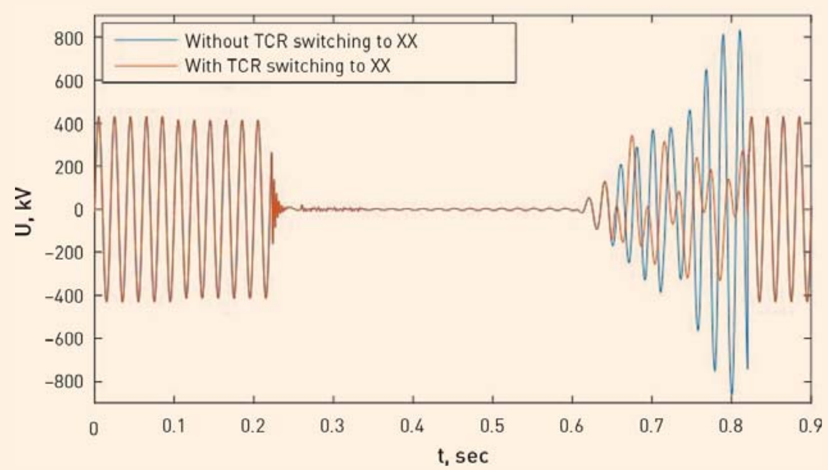

Fig. 5

TCR USE EXPERIENCE AND OUTLOOKS

The features of a TCR with split valve-side windings listed above have promising outlooks for the unit to be used as a line reactor. At present, the investment program of PJSC FGC UES provides for utilization of two line TCRs with split valve-side windings. The first facility is the 500 kV Mozdok-2 substation; the second is the 500 kV Ust-Kut substation. The electromagnetic segment of the TCR for those facilities is being manufactured by LLC Togliatti Transformer and OJSC Elektrozavod, respectively. Basic data on the manufactured TCRs with split VW are shown in Table 1.

As part of pre-commissioning of the line TCR, a program and procedures for network testing as well as guidelines for the trial operation of the TCR for the pilot facility '500 kV Nevinnomyssk — Mozdok OHTL with 500 kV Mozdok substation' were developed. Network tests of the TCR are conducted, in particular, to verify the proper performance of the TCR with RPA devices with an adaptive SPAR function in industrial production conditions and the efficiency of using the TCR to reduce the SPAR reclosing dead time.

As of now, Ltd EKRA Research and Production Enterprise, in pursuance of a cooperation agreement with JSC R&D Center at FGC UES, has performed tests on a real-time digital simulator (RTDS) to check the interaction of a linear 500 kV 180 Mwar TCR with split valve-side windings with line relay protection with an adaptive SPAR function. It has been determined that the adaptive SPAR and the main and standby line

INFORMATION

The operational principle of fast-acting thyristor-controlled transformer-type shunt reactors (TCR) is based on varying the magnitude and duration of a current passing through the reactor in every industrial frequency cycle by means of pulsephase control of thyristor valves. The theoretical basics of functions of a TCR are set forth in a textbook [3], and the experience of pilot implementation of a TCR in 2009 is summarized in a research paper [10]. The described reactor was designed without splitting the valve-side windings and with a compensation winding to which low-power harmonic filters were connected for the filtration of higher current harmonics.

protections implemented in cabinets SHE2710 582 (phase differential protection), SHE2710 591 (line differential protection), SHE2710 538 (directional differential protection) and SHE2710 521 (graded protection) operate properly on the lines equipped with the 500 kV line TCR with split valve-side windings, and that safety setpoints should be selected in accordance with applicable procedures.

Pulse-phase control of TCR thyristor valves allows switching the TCR on without the aperiodic component in the currents of the reactor and the OHTL

CSR ABROAD

Attempts to design various types of controlled shunt reactors abroad were made by BBC (now part of ABB Inc.). A 100 Mwar magnetically controlled shunt reactor for 10 kV was manufactured in 1955, and a transformer-type controlled shunt reactor (a TCR analog) was built in the 1970s.

Nevertheless, CSRs were not widely used abroad in the 20th century due to unacceptable losses, vibrations, and a number of other technical issues [2].

However, as noted in the paper by ABB specialists at the 2014 CIGRE session, today interest in CSRs is revitalized abroad [11]. In particular, eight CSRs were installed in the Norwegian 420 kV power network in 2012–2013, with two more reactors in 2016. Denmark installed seven CSRs in its 400 kV networks in 2013–2015. Four CSRs were delivered in the USA in 2013–2015 to be installed in 345 kV and 143 kV networks [12]. It must be noted that the CSRs listed above are designed as a non-controlled shunt reactor with taps through which the reactor's power can be changed using an OLTC device.

Some specific features of this CSR design are slow response, narrow control range (compared with CSRs made in Russia), and stepwise (not continuous) change of power. The time required to change the power from the lower boundary (50% of power) to the upper one (100% of power) may reach 5 minutes [13].

Today, some companies, e.g., Siemens [14], Trench [13], and Hyosung [14], are beginning to offer OLTC controlled CSRs. NREnergy (China) offers a transformer-type CSR that is closer in its design to a TCR but has a different principle of improvement of the harmonic composition of the reactor currents [16]. It is worth mentioning Afritech which offers a CSR based on the electromagnetic component of the Zaporozhye Transformer Plant [17]. It must be noted, however, that there are risks associated with the use of MCSRs due to the fact that the electromagnetic component of these reactors is manufactured at the Zaporozhye Transformer Plant (Ukraine).

Foreign manufacturers specify the following key applications for the CSRs:

CURRENT TRENDS IN TCR TV WITH THE CONTROL ANGLE SETPOINT CHANGED IN STEPS

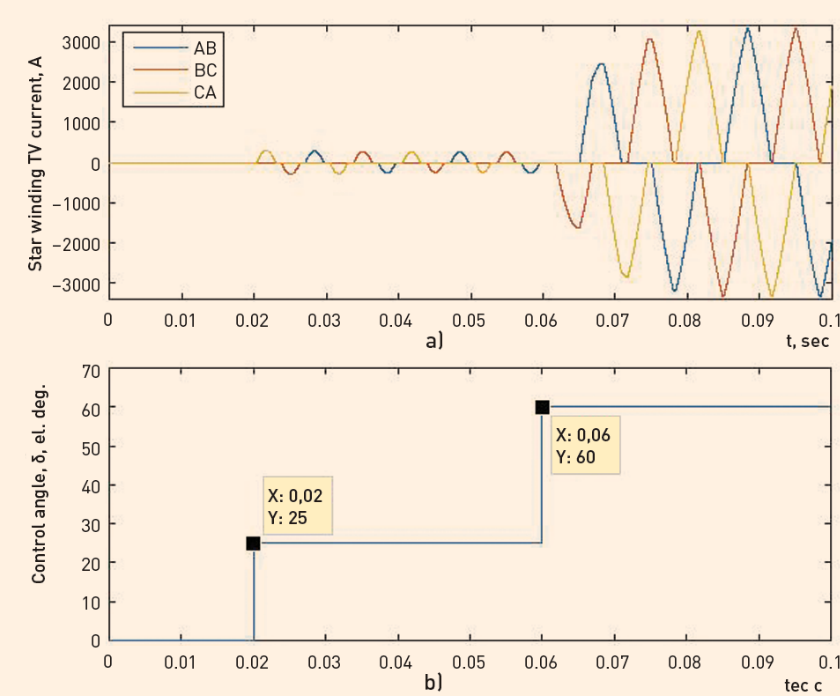

Fig. 6

VOLTAGE TRENDS OF TCR CIRCUIT BREAKER WHEN SWITCHING OFF THE REACTOR FROM IDLING WITH CURRENT CHOPPING

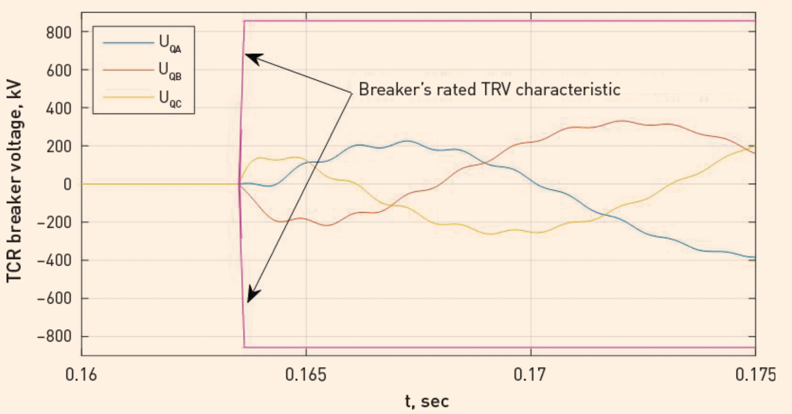

Fig. 7

Pulse-phase control of TCR thyristor valves allows switching the TCR on without the aperiodic component in the currents of the reactor and the OHTL

1. Voltage stabilization in a distributed generation network [12, 13].
2. Voltage stabilization of variable loads fed by long overhead or cable lines [12, 13, 15].
3. Reduction of line losses [14].
4. Increase of transmission line capabilities [14, 16].
5. Compensation of the arc feed current for higher auto-reclosing efficiency [16].

CONCLUSION

Today, there is a revitalized interest in CSRs in the world. The experience accumulated by PJSC FGC UES in the area of application of CSRs is the most advanced in the world. Russian fast-acting CSRs offer many technical advantages (wider power control range, faster response, wider spectrum of tasks solved) in comparison with foreign analogs and can potentially be in demand on the global market.

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COMPUTER-AIDED SIMULATION FOR DEVELOPMENT AND MANUFACTURE OF PLASTICALLY CRIMPED CONDUCTORS AND DESIGN OF TRANSMISSION LINES

For publicity purposes

This article describes the results of applying computer-aided simulation at all stages of creation of plastically crimped conductors used in overhead transmission lines, including optimization of the conductor design to achieve the service properties required by consumers and to determine the technological parameters of production. Computer-aided simulation allows reducing the time of designing and the cost of experimental works in respect of the manufacture and certification of conductors.

Keywords: computer-aided simulation; finite element method; plastically crimped conductors; deformation; conductors for high-speed lines; design; strength; modulus of elasticity.

Innovative products for infrastructure project developed by LLC Energoservice

Leonid GUREVITCH
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INTRODUCTION

Plastic crimping of helical conductors with linear contact of wires between adjacent layers yields better mechanical, aerodynamic and operational properties (higher strength, modulus of elasticity and self-extinguishment of oscillations, reduced load from wind pressure and ice coating) owing to denser grooming of wires in the conductors and a smoothened surface profile [1-2]. Specialists of LLC Energoservice (Moscow) and Ltd Metsbytservis (Moscow) have designed plastically crimped ground wires [3-5], steel reinforced aluminum conductors (ACSR) [6], and copper and copper-clad steel conductors [7, 8] for overhead transmission lines (OHTL), with their manufacturing technology mastered by the Volgograd branch of AO Severstal Wire Ropes (City of Volgograd). Non-insulated high-strength (ASHS) and high-temperature (ASHT) steel reinforced aluminum conductors [9] were designed in order to improve the cost-effectiveness and operational reliability of installation and reconstruction of high and ultra-high voltage overhead transmission lines. Their economic effect in the reconstruction of 35 to 750 kV power networks is achieved by increasing the network capacity, improving the reliability of power supply, and reducing the conductor heat and corona losses (during the comparative tests on the conductors of identical diameter at the HV EMC test laboratory of JSC R&D Center at FGC UES, owing to the smoothened profile, the corona start voltage of an ASHS conductor per STO 71915393-TU 120 2013 was 5.7 % higher than for an AS conductor per GOST 839-80).

On the basis of the performance tests carried out in a specialized organization, the MK-type plastically deformed copper catenary wire was recommended for the electrification and power supply of JSCo RZD.

COMPUTER-AIDED SIMULATION IN OPTIMIZATION OF CONDUCTOR DESIGN

Thanks to a deeper understanding of the physical processes occurring in the manufacture and operation of conductors, computer-aided simulation allowed optimization of their design with regard to consumer demands and reduction of the labor input of their implementation by:

- optimizing the geometry of OPGW strands and technological parameters of plastic deformation that ensure integrity of the optical module [10];
- establishing the distribution of temperature fields across the OPGW section with differing duration and amperage of a short circuit current [11] and the magnitudes of electromagnetic effects with alternating current in steel reinforced aluminum conductors of the ASHS type, which has shown that the direction of a layer of aluminum strands with an even number of layers has virtually no impact on the heat release in the steel core provided that reliable electrical contacts are formed between the strands by plastic crimping [12];
- demonstrating the possibility to further reduce the dimensions

ULTIMATE TENSION FORCES FOR A COPPER-CLAD STEEL CONDUCTOR: 1 TO 4 ARE RESPECTIVELY FOR MK HSL-4; MK-HSL-4-A; MK-HSL-4-B; MK-HSL-4-C

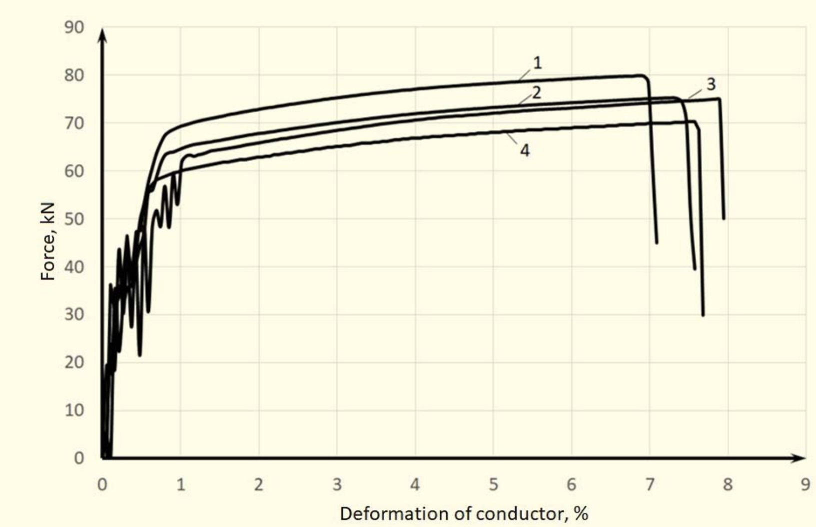
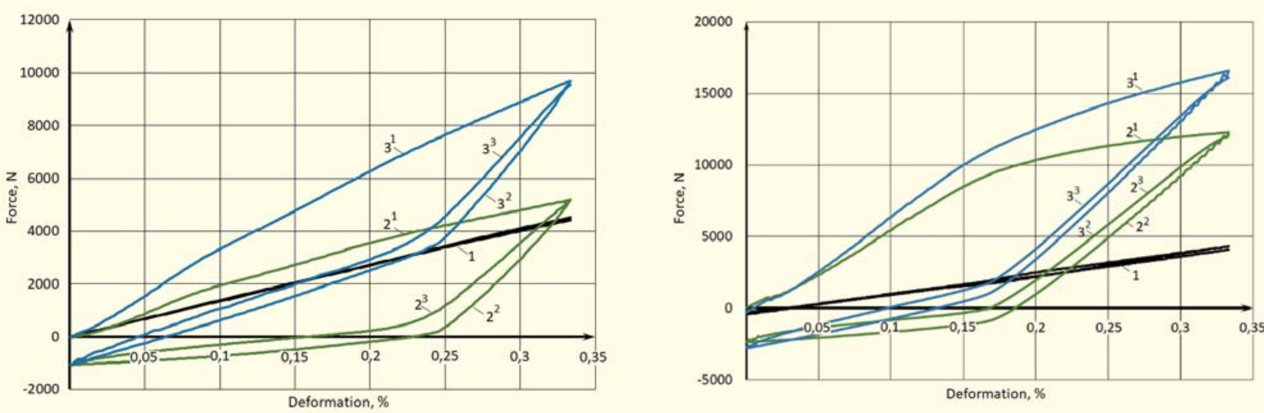


Fig. 1

VARIATION OF FORCES ALONG THE AXIS IN THE ELEMENTS OF COPPER-CLAD STEEL UNCRIMPED (A) WIRE AND AFTER CRIMPING (B)



a) b)

1^1, 1^2 and 1^3 — in central steel strand; 2^1, 2^2 and 2^3 — total force in copper strands; 3^1, 3^2 and 3^3 — total force in steel and copper strands; 1^1, 2^1 and 3^1 — pre-stretch; 1^2, 2^2 and 3^2 — compression to initial length; 1^3, 2^3 and 3^3 — ultimate tension

Fig. 2

of ACSR conductors by using an already twisted conductor before plastic deformation and by applying pre-crimping of the steel core. The new design of the plastically crimped, high-strength metal core has made it possible to increase the core strength by 35 % to 45 % and reduce the nominal conductor diameter with similar cross-section areas of the conductive part as compared with the ACSR conductor per GOST 839-80 and, as a result, to decrease the tower loads caused by the conductor weight and wind-induced vibration [15].

- developing a method for evaluation of the impact of wind load on OHTL conductors of different designs using computer-aided simulation of air flowing with a specific velocity through the space with a conductor located within based on the Navier-Stokes equation. Simulation at different air stream velocities typical for wind zones I and III and a special wind zone as per PUE-7 has shown that the wind pressure on a plastically crimped ASHS conductor is 25 % to 40 % lower than the wind pressure on standard AS conductors with a comparable current-carrying capacity [13]. The smoother contour and smaller diameter of ASHS conductors effectively reduce the dead zone behind the conductor and the higher pressure zone before the conductor. The wind load on ASHS conductors with a more streamlined geometry is on average 33 % lower, which allows minimizing stress on the transmission line towers and mounting higher capacity conductors during overhauls on the existing towers.

One of the latest advancements in the utilization of FEM is the creation of a copper-clad steel catenary and contact wires of high-speed lines (HSL) for the railway transport. The main requirements to a catenary are higher tension and, respectively, higher mechanical strength of contact wires and carrier wires, thermal and wear resistance, minimized weight of all structural elements with stricter requirements to their strength and durability, and reliable protection of those elements from corrosion for the whole period of service. Copper or bronze conductors are utilized in Russia and abroad in catenaries (bimetallic conductors can also be used). Application of the finite-element modeling methods of computer simulation [14] has allowed, through an optimized design of plastically crimped carrying and contact conductors made from steel core copper wires, increasing the carrying capacity of the conductor to ensure the necessary rupture strength in the specified dimensions. During the tension test of plastically crimped ø14 mm copper-clad steel wires in a specialized organization of JSC VNIIZHT, the breaking force

was equal to 80.6 kN. The carrier wire design is protected by Russian utility patent No. 171205 [9].

The utilization of FEM allows optimizing the MK-type conductor design to meet the specific needs of the designers of catenaries of different high-speed lines. For example, for the KS-400 catenary of HSL-2 Moscow-Kazan, special requirements apply to the wave propagation velocities on the catenary and carrier wire to ensure the necessary quality of current collection across the whole range of travel speeds up to 400 km/h. Oscillatory and wave effects in the catenary leading to poor current collection play a significant part in the process of dynamic interaction between the current collector and catenary as travel speed increases. The shear wave velocity on catenary conductors, which decreases as the bulk weight increases, should be about 1.5 times greater than the current collector travel speed. The calculation shows that for a catenary with the HSL-4 MK wire tested at JSC VNIIZHT the maximum travel speed of electrified rolling stock should not exceed 393.26 km/h, and for the HSL-4 MK carrier wire — 372.57 km/h. The reason is that the bulk weight of the HSL-4 MK wire is 17 % to 21 % higher than that of less strong wires JMH-120, Br2F 120, and CuNb-120, which are recommended for use in the KS-400 project. To reduce the bulk weight, variants of HSL-4 MK wires were used with a reduced cross-section area of copper strands of the outer layers, which led to reduction of the plastically crimped wire diameter from 14 mm to 13.6 mm. As the finite-element modeling has shown, the change in the wire design led to some reduction in the estimated rupture force (Fig. 1), which, however, satisfied the minimum requirements for the carrier wires and contact wires of the KS-400 catenary of HSL-2 Moscow-Kazan (67.6 kN) in all of the simulated variants.

The FEM allows, as early as at the designing stage, determining the modulus of elasticity of conductors consisting of multiple strands with heterogeneous chemical composition and different twist options, which is an important operational characteristic that largely determines the sag of conductors at different tensions. For example, Fig. 2 illustrates the behavior in the elastic-plastic area of the copper-clad steel carrier wire before and after crimping at simulation of pre-stretching, compression to initial length, and re-stretching. Plastic crimping resulted in reduction of the wire elongation almost 1.5 times compared with the traditional wire stretched with the same stresses. The average corrected modulus of elasticity was about 23 GPa while pre-stretching an uncrimped wire and 39 GPa after plastic crimping.

CONCLUSIONS

The utilization of finite-element simulation allowed creating a system of online designing of conductors as required by the operating organizations. Their applicability was verified by experimental studies of products in certified organizations of PJSC ROSSETI and JSCo RZD that confirmed the estimated characteristics of the products and accuracy of the models

The long-term set of works allows demonstrating in a separate case study the possibility of applying digital technologies at all stages, from product development and testing to design and implementation.

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FOOTBALL ENERGY

AUTHOR:

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ENERGY OF THE UNIFIED
GRID JOURNAL

To successfully host such an important international event as the FIFA World Cup is a challenge that requires efforts of dozens of agencies. FGC UES, the operator of Russian power grids, is one of the key organizations that ensured reliable power supply for the stadiums and training grounds, tourist, social, and transport infrastructure facilities.

FGC UES operates in 9 out of the 11 cities that were hosting the World Cup games and in virtually all regions where the participating teams were based. The only exceptions in both cases were the Republic of Tatarstan and the city of Kaliningrad.

On the eve of the tournament, FGC UES implemented an array of measures that improved the reliability of power supply: performed the necessary repairs, strengthened the duty shifts, trained the staff, raised the security level of facilities, and enforced the monitoring of substation and OHTL equipment performance.

FIFA has strict requirements to the quality of power supply for the soccer arenas — no delay or postponement of a game due to electricity problems would be acceptable. Electricity supply was organized with the use of backup power sources to prevent outages. Even earlier, when making arrangements for the 2014 Olympics, FGC UES designed the same power supply scheme for the Fisht stadium in Sochi, which hosted four games of the FIFA World Cup. Two independent power facilities were utilized for that purpose: the 110 kV Imeretinskaya and Ledovy Dvorets substations.

The key games of the tournament — the opening game, the bronze playoff, and the final — took place in Moscow and St. Petersburg. The electricity supply of both megalopolises is arranged in a circular path that minimizes the risk of blackouts: if one of the 'links' fails, the necessary power is transmitted from other units.

Substation 110 kV Imeretinskaya

The Moscow energy ring consists of nine ultrahigh voltage substations, an outdoor switchgear at one of the combined heat-and-power plants, and transmission lines over 376 km long that link them together. Since 2006, FGC UES has been reconstructing the energy ring in stages. About 71 bn rubles were invested in the project, with another 9.3 bn rubles expected to be invested by 2021.

One of the milestones is the end-to-end reconstruction of the 500 kV Ochakovo substation whose performance is essential for the power supply of Luzhniki, Moscow's major sporting facility. In anticipation of the World Cup, efforts were made to boost the reliability of another 'link' of the ring: the 500 kV Zapadnaya substation. This provided uninterruptible supply of electricity to the Otkritie Arena and other infrastructure facilities of the tournament, including the FIFA International Broadcast Center.

Reliability improvement projects were also implemented in other cities hosting the World Cup games. For instance, new differential line protection equipment was installed at the 220 kV Solnechnaya substation in Samara, and five 110 kV circuit breakers were replaced at the 220 kV Kirovskaya substation. After the World Cup, this equipment will supply power not only to Samara's sports arena with extensive infrastructure but also to the Gagarin Center Technopolis, which is expected to be built in the vicinity of the stadium.

> *FGC UES operates in 9 out of the 11 cities that were hosting the World Cup games*

ENERGY OF UNIFIED GRID

AUGUST — SEPTEMBER 2018, 4 (39)

PROSPECTS OF USING HTSC CABLE LINES FOR LONG DISTANCES ENERGY TRANSFER

V.E. SYTNIKOV, T.V. RYABIN, R&D CENTER AT FGC UES, JSC (RUSSIA), S. YAMAGUCHI, YU. IVANOV, CHUBU UNIVERSITY (JAPAN)
Keywords: Superconducting cable line; power bridge; transmitted power; cryogenic station; critical current; gigawatt.

The location of powerful electric power sources (nuclear power plants, hydroelectric power stations, wind farms) at great distances from large cities and electric power consumers, leads to the need to transport large energy flows over considerable distances. At the same time, the traditional scheme of power distribution assumes the use of high-voltage cable or overhead transmission lines (220-750 kV), which is stipulated by the desire to minimize energy losses during its transportation. This necessitates the creation of high-voltage step up and step down substations and leads to significant energy losses during its transportation and to alienation of large areas of land. The use of superconducting cable lines will significantly improve the efficiency, reliability and environmental friendliness of long-distance transmissions. With the current level of superconducting and cryogenic technology development, it is possible to create long superconducting cable lines for transportation of energy over distances of tens and hundreds of kilometers. The power of a single DC line can reach several gigawatts at a voltage of 100-200 kV, and the energy losses in it will be significantly lower than in traditional cable or overhead power lines. In our assessment of long cable lines, we will consider DC transmission lines, since any AC cable lines have a length limitation due to the charging currents which lead to a decrease in power at the far end of the line.

This paper will briefly present the results of two largest projects in the world for construction of superconducting DC lines cooled by liquid nitrogen. This is the project to create a 1.0 km line in Hokkaido (Japan) and the project to build a 2.5 km line for the electrical network of St. Petersburg (Russia). Both projects are designed for a transmitted power of 50 MW at a voltage of 20 kV. Based on the experimental and theoretical results obtained by research groups in implementation of these two projects, the possibility of building energy bridges using superconducting technologies was shown for above-ground and underwater options. Estimates of transmission power, total length of the line and maximum distance between the cryogenic stations, energy losses and the required power of a cryogenic plant will also be presented. It will be shown that, it is possible to create superconducting transmission lines with a power of about 10 GW in almost any length. At the same time, cryogenic stations should be located along the line with a maximum step of 20 to 60 km. The possibility of increasing the distance between cryogenic stations by improving the thermal insulation of cryostats will be discussed.

<pages 36–44>

DIGITAL SUBSTATION TEST SITE

I.A. KOSOLAPOV, V.V. BOYKOV, Y.I. MORZHIN, S.G. POPOV, R&D CENTER AT FGC UES, JSC
Keywords: digital substation; IEC 61850; DSS test site (DSS TS); process bus; station bus; testing and simulation facility; real-time digital simulator (RTDS).

The introduction of the new technology "Digital substation", into the operational practice based on the IEC 61850 standard, is usually carried out through the pilot deployment of equipment. This technology is radically different from existing substation automation systems, primarily because traditional cable connections between primary and secondary equipment are replaced by segments of the local area network (LAN) of the substation. The exchange of information between the primary and secondary equipment is carried out in digital form, including the secondary equipment connected through digital interfaces. Typical solutions for the organization of communications within the substation are in the process of formation, therefore new equipment is introduced fragmentarily to accumulate operational experience and test technical solutions. To test a variety of technical solutions for the formation of a "process bus" and "station bus" it is necessary to conduct research at special test sites, rather than in existing electrical substation.

Creation active polygon based on the existing experimental substation with the ability to simulate disturbing effects in the adjacent electrical network and on an energy facility in real time using test-modeling complexes (such as, for example, Real Time Digital Simulator-RTDS) can significantly reduce the development phase of a new Technology to verify the functional characteristics of equipment and to test various options for building LAN (typical solutions) for substations of various voltage classes.

After carrying tests on the polygon out in sufficient volume will subsequently significantly simplify the task of implementing the «Digital Substation» technology in the power grid complex, while verifying typical solutions for building LANs for objects of different voltage classes.

One of the most important areas for the advancement of Technologists "Digital substation" for implementation at power facilities is the verification of equipment for compliance with the IEC 61850 standard, i.e. its certification. Certified equipment for compliance with the IEC 61850 standard of various manufacturers will ensure its joint operation at the power facility.

<pages 46–58>

ASYNCHRONIZED MACHINES FOR ELECTRIC POWER INDUSTRY

Y.G. SHAKARYAN, P.V. SOKUR, R&D CENTER AT FGC UES, JSC, N.D. PINCHUK, O.V. ANTONUK, V.Y. NOVOZHILOV, POWER MACHINES, PJSC, Y.D. VINNITSKY, RUSELPROM, JSC
Keywords: asynchronized machine; doubly fed machine; turbine generator; hydrogenerator; synchronous condenser; energy storage.

Synchronous generators are traditionally used in the electric power industry. Asynchronized machines are a new class of electrical machine valve systems that have a series of advantages over conventional synchronous machines. Asynchronized machines have been widely used in thermal and hydro power stations, wind power plants and networks as reactive power compensation units.

Asynchronized machines are a new class of electrical machine valve systems that have a series of advantages over conventional synchronous machines. Asynchronized machines are widely used in the power industry. In Russia, these are asynchronized turbine generators and reactive power condensers. In other countries, those are asynchronized hydrogenerators and wind power plant generators. There are a number of areas where asynchronized machines may also be found usable: electromechanical energy storages, electromechanical AC back-to-back stations between power systems, and an electrical drive based on asynchronized motors.

<pages 60–70>

FAST-ACTING CONTROLLED SHUNT REACTORS TO BE UTILIZED IN THE UNEG OF RUSSIA AND ABROAD

A.M. MATINYAN, M.V. PESHKOV, V.N. KARPOV, N.A. ALEKSEYEV, V.A. PADALKO, A.V. ANTONOV, R&D CENTER AT FGC UES, JSC, P.Y. BULYKIN, IEDS GROUP, MOSCOW, JSC
Keywords: controlled shunt reactors; transformer-type controlled shunt reactors (TCR); CSR with on load tap changer control (OLTC).

Controlled shunt reactors (CSR) are gaining increasing interest in the world today. For example, eight CSRs were installed in the Norwegian 420 kV power network in 2012–2013, with two more reactors in 2016. Seven CSRs were installed in 400 kV networks in Denmark in 2013–2015. Four CSRs were delivered in the USA in 2013–2015 to be installed in 345 kV and 143 kV networks.

Today, there is a revitalized interest in CSRs in the world. The experience accumulated by PJSC FGC UES in the area of application of CSRs is the most advanced in the world. Russian fast-acting CSRs offer many technical advantages (wider power control range, faster response, wider spectrum of tasks solved) in comparison with foreign analogs and can potentially be in demand on the global market.

<pages 72–78>

COMPUTER-AIDED SIMULATION FOR DEVELOPMENT AND MANUFACTURE OF PLASTICALLY CRIMPED CONDUCTORS AND DESIGN OF TRANSMISSION LINES

ENERGOSERVICE, JCS
Keywords: computer-aided simulation, finite element method, plastically crimped wires, deformation, wires for highways, construction, strength, modulus of elasticity.

It is described the results of applying computer-aided simulation at all stages of creation of plastically crimped conductors used in overhead transmission lines, including optimization of the conductor design to achieve the service properties required by consumers and to determine the technological parameters of production.

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cigré Russian National Committee

PROGRAMME PAPER OF RUSSIAN MEMBERS

OPENING CEREMONY			ROOM	LEVEL
Sunday 26 August	16:00	OPENING CEREMONY: – CIGRE President Opening Speech – Keynote Speaker: Mrs. Audrey ZiBELMAN, CEO, Australian Energy Market Operator Future electricity markets and business models	Grand Amphithéâtre	0
		– Welcome drinks	Hall Ternes	1
TECHNICAL MEETINGS SCHEDULE				
Monday 27 August	8:45 — 12:00	Opening Panel: The future sustainable power system: organic, disruptive and secure	Grand Amphithéâtre	1
		Opening Panel: The future sustainable power system: organic, disruptive and secure	Grand Amphithéâtre	1
	14:30 — 18:00	Workshop - Large D isturbances: Part 1: Market disturbances Part 2: System disturbances	Bleu	2
		NEW! Conference: Integrated power system: changing from consumers to prosumers	Grand Amphithéâtre	1
	14:30 — 18:00	Poster Sessions A1 & B4	Hall Ternes	1
Tuesday 28 August	8:45 — 18:00	A1: Rotating electrical machines	Havane	3
		B4: HVDC and power electronics	Grand A mphithéâtre	1
		C4: System technical performance	Bordeaux	3
		C6: Distribution systems and dispersed generation	Bleu	2
	9:00 — 12:30	Poster Sessions A3 & B5	Hall Ternes	1
	14:30 — 18:00	Poster Sessions C5 & D1	Hall Ternes	1
Wednesday 29 August	11:00 — 14:00	Next Generation Network Forum	342A	3
	8:45 — 18:00	A3: High voltage equipment	Bordeaux	3
		B5: Protection and automation	Grand Amphithéâtre	1
		C5: Electricity markets and regulation	Havane	3
		D1: Materials and emerging test techniques	Bleu	2
	14:00 — 15:30	B4 & CENELEC Workshop: System aspects of HVDC grids		
	9:00 — 12:30	Poster Sessions A2 & B3	Hall Ternes	1
	14:30 — 18:00	Poster Sessions C2 & D2	Hall Ternes	1
Thursday 30 August	11:00 — 14:00	CIGRE Women in Engineering Forum	342AB	3
	8:45 — 18:00	A2: Transformers	Bleu	2
		B3: Substations	Grand Amphithéâtre	1
		C2: System operation and control	Bordeaux	3
		D2: Information systems and telecommunications	Havane	3
	15:30 — 17:00	A3 & B 4 Workshop: DC circuit breakers		
	9:00 — 12:30	Poster Sessions B1 & C1	Hall Ternes	1
	14:30 — 18:00	Poster Sessions B2 & C3	Hall T ernes	1
Friday 31 August	9:00 — 12:00	B3 Workshop: Safe working in substations		
	8:45 — 18:00	B1: Insulated cables	Bleu	2
		B2: Overhead lines	Grand Amphithéâtre	1
		C1: System development and economics	Bordeaux	3
		C3: System environmental performance	Havane	3
	9:00 — 12:30	Poster Sessions C4 & C6	Hall Ternes	1

ACTIVITY OF THE RUSSIAN DELEGATION

TEMA	AUTHORS	REPORTS
A1 — PS3	Yu.G. SHAKARIAN, P.V. SOKUR, "R&D Center @ FGC UES" JSC, Yu.K. PETRENIA, N.D. PINCHUK, M.B. ROITHARTS, "Power Machines" PJSC, S.N. LENEV, A.D. GRITSENKO, "Mosenergo" PJSC, F.A. POLIAKOV, D.V. KUZNETSOV, "Electroservis-NTSG" LLC Russia	Operation experience of asynchronized turbine-generator sets in the Moscow power system
A2 — PS2	V.S. LARIN[1] , D.A. MATVEEV[2], A.Yu. VOLKOV[1] [1] FGUP VEI, [2]NRU MPEI Russian Federation	Application of winding natural frequency deviation patterns and high-frequency models for FRA interpretation
A3 — PS1	A.R. ROTBLUT[1], D.V. CHERNOSKUTOV[1], A.S. BUNKOV[1], A.P. LABUT[1], M.I. KARMAZIN[1], K.A. RYZHKOV[2] [1] JSC "ELMASH (UETM)", [2] JSC "Research and Development Center of Federal Grid Company of Unified Energy System" Russian Federation	Research and Development of Switching Performance of Gas Insulated Disconnecting Switch of Switchgear
A3 — PS3	M. YANIN, JSC PROFOTECH Russia, Dr. Thomas Heid Maxwell — CONDIS® metering products & solutions Switzerland	Extending metering technology limits with new approach to combined instrument transformers using IEC61850-9-2LE protocol
B1 — PS3	V.E. SYTNIKOV, T.V. RYABIN, S.E. BEMERT, JSC Research and Development Center at Federal Grid Company of Unified Energy System Russia, S. YAMAGUCHI, Yu.V. IVANOV, Chubu University Japan	On the Possibility of Using High-Temperature Superconductor Cable Lines in Creation of Long-Length Interconnections
B2 — PS2	E. LYPUNOV, A. ELISEENKO, Russian Federation Federal Grid Company of the Unified Energy System	Protection of metal towers of overhead power lines from corrosion: nondestructive diagnostic methods and recommendations for additional secure
B3 — PS2	T. RYABIN, E. DAVYDOV, Research and Development Center of the Federal Grid Company of the Unified Energy System Joint-Stock Company Russia, A. MOLSKIY, A. YEPIFANOV Federal Grid Company of Unified Energy System PJSC Russia	Development and verification of new technologies to reduce auxiliary power consumption for the needs of 220-750 kV substations
B3 — PS2	Y.V. ZHILKINA, A.M EPIFANOV Federal Grid Company of Unified Energy System, Moscow, Russia	Organization of the service in the power industry (example of Federal Grid Company of Unified Energy System)
B4 — PS3	A.V. DROZDOV, A.N. KISELEV LLC "SAURUS ENERGO" Russia Federation, I.A. KOSOLAPOV, Yu.G. SHAKARIAN, M.V. PESHKOV, Yu.A. DEMENTIEV, Research and Development Center of the Federal Grid Company of the Unified Energy System Joint-Stock Company Russia Federation	Operation experience of back-to-back HVDC station based on voltage source converters for interconnection non-synchronous power systems with significant voltage distortion
B4 — PS1	K.B. GUSAKOVSKY[1] , N.G. LOZINOVA[1] , O.V. SUSLOVA[2] , E.U. ZMAZNOV[1] [1] JSC "NIIPT" Russia, [2] JSC "STC UPS" Russia	Operating experience and ways to improve reliability of Vyborg back-to-back HVDC link (in connection with the 35th anniversary of the commissioning of the first converter unit)
B5 — PS1	A.V. ZHUKOV, E.I. SATSUK, SO UPS JSC, Russia	Experience of emergency automatics use in UPS of Russia
B5 — PS2	D.A. ZHUKOV, A.P. MOROZOV, PJSC RusHydro, Russia	Experience of implementation, testing and operation of digital measuring transformers, merging unit devices, power-system protection and automation devices realizing IEC 61850 process bus for the generator-transformer unit of Nizhegorodskaya HPP

PROGRAMME PAPER OF RUSSIAN MEMBERS

TUTORIALS		
Monday 27 August	8:30 — 10.20	B5: Challenges and solutions for the maintenance of fully digital substation
	10:40 — 12:30	B4: HVDC planning, technology selection and specification
	14:00 — 15:50	A2: Transformer ageing, failures, and forensics
	16:10 — 18:00	D2 : Framework for EPU operators to manage the response to a cyber-initiated threat
Tuesday 28 August	8:30 — 10.20	C1: CIGRE feasibility study of a global electricity network
	10:40 — 12:30	D1: Guidelines for altitude correction of pollution performance of insulators
	14:00 — 15:50	A3: Switching equipment
	16:10 — 18:00	C5 : Global overview of demand response markets and regulations
Wednesday 29 August	8:30 — 10.20	C4: Recent advances in the application of synchrophasor technology
	10:40 — 12:30	C2: System operation emphasising DSO/TSO interaction and coordination
	14:00 — 15:50	C6: Application of battery storage systems in distribution systems
	16:10 — 18:00	B3 : Contemporary cost-effective substation design
Thursday 30 August	8:30 — 10.20	B2: Experience with the mechanical performance of non-conventional conductors
	10:40 — 12:30	A1: Revisiting the fundamentals of magnetic saturation
	14:00 — 15:50	B1: Fault location on land and submarine links
	16:10 — 18:00	C3: EMF — time to reassure

SOCIAL EVENTS			LOCATION
Sunday 26 August	17:00 — 18:30	Welcome drinks for opening ceremony — Attendees only!	Level 1
Monday 27 August	18:00 — 20:00	Cocktail dinner	Level 1, 2 & 3
Monday to Friday	AM & PM	Coffee breaks will be held each mid-morning and mid-afternoon	
Thursday 30 August	19:30 — 23:00	Cocktail dinner at " Cité de la Mode et du Design" For fully registered delegates and companions — invitations to be collected at the "Delegate's reception Desks"	34, quai d'Austerlitz 75013 Paris

TECHNICAL EXHIBITION			LOCATION
Monday	9:00 — 20:00	For more details on the technical exhibition: www.cigre-exhibition.com	Level 1, 2 & 3
Tuesday to Thursday	9:00 — 18:00		
Friday	9:00 — 16:00		

ASSOCIATION MEETING		
Monday 27 August	13:15 — 14:15	Presentation of the results of the General Assembly of June 30, 2018

ACTIVITY OF THE RUSSIAN DELEGATION

TEMA	AUTHORS	REPORTS
B5 — PS2	V.G. ALEKSEYEV, M.V. VAZYULIN, M.D. ILYIN, S.G. POPOV, JSC "Research and Development Center of the Federal Grid Company of Unified Energy System" Russia, A.S. KIRILLOV, A.A. KUZMIN, S.A. PEREGUDOV, A.A. SERDTSEV, "Continuum" Engineering Technical Center CJSC Russia Pierfrancesco CIOCI, Niels HEIJKER DNV GL — Energy Netherlands	IEC 61850 Standard-Based Integrated Tests and Certification of Secondary Switching Equipment on the Digital Substation Test Site of R&DC FGC UES JSC
B5 — PS1	A.V. ZHUKOV, E.I. SATSUK, D.M. DUBININ, O.L. OPALEV, T.G. KLIMOVA, A.I. RASCHEPLYAEV, SO UPS JSC, NRI MPEI	Methods for determination of parameters variation of the electrical mode of the power system and their use for the power system control objectives
C2 — PS2	V.A. DIYACHKOV, R.M. TIMOSHENKO, SO UPS, JSC Russia	Monitoring and decision support systems — ways to improve power system electrical mode control effectiveness
C3 — PS1	N.B. RUBTSOVA, S.YU. PEROV, Federal State Budgetary Scientific Institution "Izmerov Research Institute of Occupational Health" Russia, A.YU.TOKARSKIY Joint Stock Company Research and Development at Federal Grid Company of Unified Energy System Russia	Ecological and Occupational Electromagnetic Safety of Power Grid Facilities Improvement
C3 — PS1	A.M. ABDURAKHMANOV, K.A. ZIMIN, B.N. RYABCHENKO, A.Yu. TOKARSKIY, JSC "Research and Development Center of the Federal Grid Company of Unified Energy System" Russia, N.B. RUBTSOVA Federal State Budgetary Scientific Institution "Izmerov Research Institute of Occupational Health" Russia	Solving the Environmental Electromagnetic Safety Issues in 110–500 kV AC Cable Power Lines
C4 — PS3	M.G. GADZHIEV, E. A. GULEVICH, J.V. SHAROV, The Federal Budgetary Institution of Higher Education "National Research University" MEI" Russia, V.N. RYABCHENKO, JSC "Research and Development Center at Federal Grid Company of Unified Energy System" Russia	PMU placement in an alternating current network 110-220 kV for identification of the mathematical model of the Kaliningrad Region power system mode
C4 — PS1	M.A. SILAEV. V.N. TULSKY, National Research University "Moscow Power Engineering Institute" Russia	Intermittent voltage unbalance and its impact on large power asynchronous motor operating modes
C6 — PS2	K.K. DENSHIKOV, A.Z. ZHUK, Joint Institute for High Temperatures of the Russian Academy of Sciences, Russia, S.N. BARZUKOV (SSK), A.N. NOVIKOV, N.L. NOVIKOV, T.Yu. ZHORAEV, The Research & Development Center for Power Engineering (RDCPE) Russia, S. A. KHARITONOV (Power Electronics of Siberia) V.A. KOLESNIKOV (SPT) Russia	Experimental Studies of the Energy Storage System to Provide Multi-Level Integration of Generating Stations and Consumers
D1 — PS3	V.L. PELYMSKIY[1], V.V. BUZAEV[1], I.V. DAVIDENKO[2], A.N. MOISEICHENKOV[2], K.V. OVCHINNIKOV[2] [1] Public Joint Stock Company "ROSSETI" [2] Ural Federal University Russia	The improvement of DGA estimation by the criterion of maximum permissible concentrations of gases and their rate of growth
D1 — PS3	L.A. DARIAN (a), R.M. OBRAZTSOV(a), A.V. MAKSIMCHENKO (a), L.K. LE (b), a JSC "Technical Inspection UES" Russia	Evaluation of the paper insulation condition of power transformers based on the content of methanol dissolved in transformer oil
D1 — PS3	V.K. KOZLOV, M.Sh. GARIFULLIN, Kazan State Power Engineering University Russia	Using optical spectroscopy for quality control of mineral transformer oils
D2 — PS3	D.A. ZHUKOV, PJSC "RusHydro", Russia, O.A. FEDOROV, JSC "RTSoft" Russia	Development of information-analytical system for automatic fault analysis and relay protection performance evaluation
D2 — PS3	A.I. KHALYSMAA, S.A. EROSHENKO, Ural Federal University named after the first President of Russia B.N. YELTSIN Russian Federation	Intelligent life cycle management system model for the power network equipment

RUSSIAN NC YOUNG MEMBERS REPORTS AT THE 47TH SESSION OF CIGRE

1. Gracheva Natalya , Moscow Power Engineering Institute, Study Committee B5 "Protection and Automation".
   Paper "Comparison of Different Architectures of Digital Substation".
2. Polyakov Dmitry, Omsk State Technical University, Study Committee B1 "Insulated Cables".
   Paper "Residual Life Monitoring of XLPE-insulated Cables".
3. Ridel Alexander, Novosibirsk State Technical University, Study Committee A2 "Transformers".
   Paper "Partial Discharge Studies in Free Gas Bubbles in Transformer Oil".
4. Savvatin Mikhail, Moscow Power Engineering Institute/ System Operator of the United Power System, Study Committee C4 "System Technical Performance".
   Paper "Localization of low-frequency sources oscillations using data of the phasor measurement units and development of damping methods of low-frequency oscillations".
5. Loman Valentin, Novosibirsk State Technical University, Study Committee C4 "System Technical Performance".
   Paper "New way of high frequency transients protection".
6. Lyanzberg Andrey, Federal Grid Company of Unified Energy System, Study Committee B2 "Overhead Lines".
   Paper "Increase of the Overhead Line (OHL) capacity without additional construction".
7. Rogozinnikov Evgeny, Moscow Power Engineering Institute/R&D Center of Federal Grid Company, Study Committee D2 "Information Systems and Telecommunications".
   Paper "Intelligent Control System of Energy Distribution within Microgrid".
8. Rychagova Elena, Novosibirsk State Technical University, Study Committee C1 "System Development and Economics".
   Paper "Management of Maintenance and Repair for Transmission and Distribution Equipment to Ensure Operational Reliability".
9. Titov Dmitry, Skolkovo Institute of Science and Technology, Study Committee C2 "System Operation and Control".
   Paper "Monitoring system of icing intensity on power lines".
10. Kholodov Alexander, Moscow Power Engineering Institute/R&D Center of Federal Grid Company, Study Committee B5 "Protection and Automation".
    Paper "Adaptive Differential Protection for Shunt Reactor".

"Jobs of the Future in Power Industry" panel discussion