Modes Control of Smart Power Grids Based on the Usage of the Innovative Method and Device of Demand Side Management

Dmitry A. Klavsuts
Graduate student of the Novosibirsk State Technical University, Novosibirsk, Russia
dklavsuts@gmail.com

Irina L. Klavsuts
PhD in engineering, Associate Professor of Management of the Novosibirsk State Technical University, Novosibirsk, Russia
ira.klavsuts@gmail.com

Anastasia G. Rusina
PhD in engineering, Professor of Automated Power Systems of the Novosibirsk State Technical University Novosibirsk, Russia, Professor of Electrical Networks and Electrotechnics of the National Research Tomsk Polytechnic University, Tomsk, Russia
anastasiarusina@gmail.com

George L. Rusin
PhD in engineering, Associate Professor of Management of the Novosibirsk State Technical University Novosibirsk, Russia
gelerusin@gmail.com

***Abstract*- In the paper there are considered issues of modeling modes of control of Smart Power Grids based on the usage of the innovative method and device of Demand Side Management.**

***Index Terms*--Smart Grids, Demand Side Management, Innovative Technology, Energy Efficiency, Energy Saving, Address Modeling, Virtual Circuit, Voltage Regulation, Dynamic Stability of Power System, Static Stability, Distributed Generation, Simulation Modeling.**

I. INTRODUCTION

Nowadays the changes of the technological basis for power production – formation of smart power grids – lead to revaluating the place and role of power generating industry, to new approaches in achieving the goals of its development. Innovative components of Smart Grids transform an electric grid from a passive equipment of transport and energy distribution into an active element of the system, change the functions and the role of consumers, their transition to active participation in managing the electric system, which increases its efficiency.

At present the development of electric power system is determined to a large extent by the tendency towards decentralization of power production and wide spreading of distributed generation. The distributed generation in Russia is, as a rule, co-generation (synchronous generation) on different types of fuel, small hydropower stations (HPS), switched to power networks 110/35-10/6 kV, with capacity up to 25 MWt, as well as electric power systems with distributed generations, working independently (IES-independent electric systems).

Electric grids with distributed generation and IES are not sufficiently automated, therefore, it is not sensible to use technologies of planning and managing electric grids modes, employed in centralized electric grids, because they are based on a detailed digital model of electric power systems (EPS), reflecting the grid topology, parameters of all elements, which leads to the growth of dimensions of the tasks to be solved, the complication of the control system.

Thus, there arises a necessity to develop and introduce the whole complex of new technologies, providing favorable conditions for integration of distributed generation into existing electric power systems or creating distributed power systems working independently.

The presence of the distributed generation considerably changes circuit and mode properties of electric power systems (EPS) and, first of all, distributed electric grids, which were passive before. At that, the solution of some tasks connected with providing valid mode parameters will be simplified, whereas other solutions will become more complicated.

First of all, the presence of distributed generation changes the power flow in the adjacent distributing grid. The expected positive effect in this case is the decrease of losses, deloading of the transmitting network and, thus, increase of its transfer capacity and also the increase of voltage level. However, switching of distributed generation can not only fail to improve the situation, but, with incorrectly determined points of switching the distributed generation in the grid, can also deteriorate the mode situation.

The distributed generation considerably complicates the task of controlling the modes of centralized power system due to some uncertainty of working mode, sensitiveness of generating equipment to external effects and, as a consequence, to frequent switching out.

Besides, the distributing network, with the appearance of generation in it, acquires properties of the bulk electric system, becoming a system which demands the solution of the same tasks as the tasks for the bulk electric system, namely to provide reliable and safe functioning and, therefore, to control the stability of electric grid mode.

There are widely discussed such questions as the influence of distributed generation on the stability of parallel work of power systems, methods of organizing dispatching control.

978-1-4673-9682-0/15/$31.00 ©2015 IEEE

The necessity is pointed out to create adaptive and flexible models of controlling working modes of the area of distributing grids.

Today the most part of distributed generation equipment works in autonomous mode, because switching to existing electric grids is hindered by both economic and administrative barriers. Nevertheless, as with building bulk electric systems, it is, undoubtedly, more economically profitable to combine some generating units in one general system or switch them to existing electric grids for organizing reservation, rather than maintain required reserves totally by the owner.

The peculiarity of distributing network 6-10,35 kV is that there are considerable differences in the configuration and arrangement of networks depending on their intended use.

The control of limitations on static stability is necessary in extended distributing networks with due consideration of occurring changes of configuration in normal and post-fault modes, when the limit of transferred capacity can be considerably reduced due to the increase of the length of network sections between the points of switching the distributed generation, and also in the modes of maximum loads at limitations of generators on reactive capacity output.

.

In electric power systems (EPS) there is constantly solved a task of maintaining the voltage on substations (EPS) and consumers' substations. In the paper there is considered the task of voltage control in acceptable limits with the account of local zones of EPS or consumers at substations, as well as issues of controlling different modes of EPS.

Controlling energy efficiency is a strategic task of a global scale. One of the most important conditions of increasing the energy efficiency is the observation of quality standards of electric energy. In the world there are standards for the norms of power quality, for example, European Standard EN 50160: 2010 and the National Standard of the Russian Federation ГОСТ 54149-2010 identical to the former. Voltage is the most important parameter in the Standard for the norms of power quality and occupies the first place in order of importance. If the Standard is not observed, one cannot guarantee a normal work of equipment switched to the electric grid. It is really difficult to observe the standard, as the commutation of consumers occurs optionally. Mainly, the above said refers to electric power networks 0,4 kV, because more than 65% of consumers have power delivered from these networks. In the recent years, in Russia and in the world the conception of Smart Grid [20] is put forward, which is the main and key component of strategies and projects of increasing energy efficiency of electric power systems. Smart Grid is a complex of technical and economic measures including: monitoring power consumption, dynamic control of electric grids, regulation of demand response and demand side management.

The further development of smart power systems suggests that the functioning of power system will happen through close interaction between centralized and distributed generating capacities, integrated into the power system. The sources of distributed generation can be specified as MicroGrid or Virtual Power Plant (VPP). The control of MicroGrid can be realized through the system of EMS (Energy Management System), which accepts information about the current state of every power unit and transfers monitoring signals to it. The idea of Smart Grid suggests unification on technological level of electric grids, consumers and producers of electric power, including the objects of distributed generation (DG), into a unified automatized power system, which allows to monitor and control all the working modes of EPS on a real time basis. The realization of Smart Grid ideology is directed at the achievement of a qualitatively new level of its efficient functioning and development, and also the increase of system reliability and transfer capacity, increase of quality and reliability of power delivery to consumers.

One of the directions of the development of Smart Grid can become a new conception MicroGrid. The system MicroGrid most often includes the sources of distributed generation, energy storage devices and local consumers. An important feature of MicroGrid is the following: in spite of functioning within the frame of the distributing system, the system MicroGrid can automatically pass into an independent mode in the case of dysfunction in the grid and restore synchronic work with the grid after the liquidation of the accident, maintaining a required quality of electric power. Being autonomous or switched to the national electric power network, the objects of DG are located in the immediate proximity to consumers (towns, villages, plants) and produce power "on the ground", considerably reducing losses while transferring power along the lines and, thus, increasing electric supply to consumers. The production of electric power by the objects of DG will depend directly on the demand of local consumers, who, in their turn, will have a possibility to correct power supplies in accordance with their needs, which leads to the increase of their role in the management of electric power system. It should be noted that Smart Grid sees the consumer as an "active consumer", that is an active participant in load regulation, who is granted an opportunity to change independently the volume and functional properties (the level of reliability, quality, etc.) of the obtained electric power on the basis of balance of their needs and possibilities of power system, using information about the characteristics of prices, volumes of power supplies, reliability, quality, etc.

The role of MicroGrid can be played by residential areas or distant regions with the possibility to install local sources of small generation and power storage devices. Building up new districts demands considerable power resources, which not always can be obtained from the unified system of power supply (due to the work load of the network, limitations of power flow on ETL and supply transformers). Consequently, the issue of the necessity to use autonomous sources of power supply comes more and more often to the foreground, and those sources can become, in their turn, elements of MicroGrid.

II. Mathematic modeling of the innovation device of Demand Side Management

Within the framework of the conception of Smart Grid one of the ways to increase energy efficiency of electric power systems is Demand Side Management (DSM) by means of regulating consumers' voltage.

The patented innovative method and device of DSM [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15] considered in this paper are based on the voltage regulation and allow to increase the energy efficiency of electric power systems within the framework of the conception of Smart Grid. As the practice shows, the use of the method and device of DSM allow to improve the quality of electric energy in accordance with the demands of the International Standard EN 50160: 2010, and also to save electric energy depending on the character of electric load from 5 to 25 %. Due to improvement of quality and reduction of power consumption the total economic effect can reach 50% and more by means of decrease of production faults, increase of life service of electric equipment, etc.

The invention is patented in the RF, the USA, CIS, EC, Ukraine, countries of ASEAN. The interest demonstrated to the invention in the world indicates the appearance of principally new methods and device of DSM, allowing to increase energy efficiency of electric power systems in different countries. For a wide adoption of the new method and device, the scientific industrial company LLC "AVEC" (Novosibirsk, RF) was set up, which at present is working at the production and improvement of the patented device of DSM under the trademark NORMEL™®© on the basis of research and development departments.

The essence of the method is in the use of a voltage regulating transformer which capacitance is much less than that of the load. The winding of low voltage (LV) of this transformer switches into the grid phase in chain with the load. The winding of high voltage (HV) switches into the regulating grid. According to Kirchhoff's second law load voltage is equal to the vector sum of grid voltage and EMF, induced by the winding of high voltage in the winding of low voltage of the above mentioned transformer. Accordingly, load voltage, current and capacitance of the load and in the grid change.

The innovative technology of DSM for regulating customers' voltage is successfully introduced in hundreds of enterprises, in residential and public buildings. Due to the used patented circuit decision, the coefficient of efficiency of the innovative device under consideration is 99.78 %

We should highlight the two main distinctions of the presented method and device of DSM for regulating (normalizing) customers' voltage from other commonly known methods and devices of stabilization.

The first distinction from stabilizing devices, that maintain voltage level within the bounds of pre-set values, lies in the fact that the innovative device of DSM, called by us "normalizer", keeps output voltages, in the framework of the operational range, according to the Standard, 230 V ± 5-10%.

The second distinctive peculiarity of the normalization scheme is the regulation of output parameters of the grid by using differently directed moving forces in thick windings of low voltage (LV) of transformers, integrated into phase chains, from the side of thin windings of high voltage (HV), through changing their polarity.

The implemented method and device of DSM for regulating customers' voltage give a number of advantages.

1) Regulation of customers' voltage occurs without disconnection of supply network, which removes problems connected with power commutations and corresponding transient processes as well as power interruption.
2) Due to the use of the patented scheme solution 95% of the capacitance is transferred by electric way and only 5% by electromagnetic. As a result, transformers are used which capacitance does not exceed 5% from the nominal capacitance of the normalizer. All this is done in a single phase way and automatically. It has a positive effect on cost, mass and size parameters of the equipment.
3) The absence of power commutation elements in the scheme of the innovative device of DSM (normalizer) creates conditions for its lasting and reliable work.

The research showed that the use of the patented method and device of DSM not only provides normal work of consumers' equipment, but also leads to the reduction of consumed power and losses in the grid, that is the effect from the use of the method and device is manifested not only on the low, but also on the high side of the network, including the sources of generation. While introducing the patented innovative method and device, the largest effect of increasing energy efficiency of the power system can be achieved if the power is transferred to the consumer by power supplying organization at maximum voltage value allowed by the Standard, and used by the consumer at the minimum voltage value allowed by the Standard. On the one hand, such regulation allows to provide normal functioning of consumers, and on the other hand, consumers will not use "extra" power, and the losses will be minimal. This approach can be used by most countries of the world.

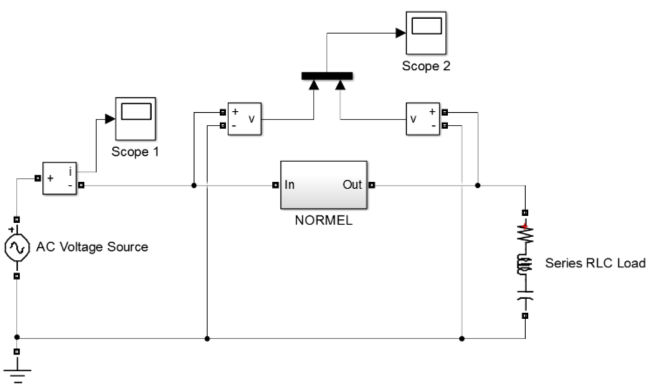
The creation of mathematic and physical models allow to organize virtual circuit with visualization of the device of DSM NORMEL™, which will make it possible to evolve a theoretical foundation of the use of the innovative device of DSM on the basis of the conception of Smart Grid. The results of calculations will allow to obtain new scientific data about the dependencies of the processes taking place in the complicated energy informational system, which, in perspective, can change technologies of designing, reconstructing and exploiting electric power networks and systems on the whole.

In the paper there are considered principles of building a mathematical model with using the innovative method and device of DSM in the electric power system with smart grid technology. The mass use of the devise of DSM NORMEL™ when the latter works in the mode of voltage pull-down leads to the following results:

a) the decrease of the level of power consumption of consumers equipped with the device of DSM;

b) the decrease of the levels of currents supplying electric lines and loads and, as a consequence, the reduction of the level of power losses on all the length from the generating source to the final consumer ;

c) the increase of stability of the work of generators in



EPS due to the decrease of consumed and, as a result, output capacity.

For creating the mathematical model there was chosen an interactive system for modeling nonlinear dynamic systems MahLab SimuLink (Fig. 1).

As the parameters of the device and loads in the nods in the grid change, the modeling was called address modeling [2, 16].

The developed address model enables to carry out simulation calculations at varied loads and also to take into account differences in parameters of the device of DSM.

III. Calculation and Analysis of Smart Grid Modes with the Use of The Device of DSM

The efficiency of the use of device of DSM NORMEL™ for managing normal modes of EPS depends on the kind and structure of load, on voltage class, on the distance and the type of an electric station. The use of the device is considered on the example of different types of electric stations.

In Russia thermal stations comprise not less than 70% of all other stations in the structure of energy power balance, as Russia is one of the coldest countries of the world. Combined heat and power station have a relatively small territorial zone of connection with consumers of electric energy. In the structure of thermal stations' load there are consumers with complete economic self-dependence (fish farms, green houses, sub-consumers). The use of the innovative device of DSM is effective for consumers, as energy consumption can be reduced, and, consequently, expenses on electric energy can be reduced too.

The main load of substations is lightning and heating. At large CESs (condensation power station) the consumption of super high and high voltage substations can reach several MW. The use of innovative device of DSM at CES is promising for the realization of energy saving program.

The authors believe that the effect can be reached with the mass use of the device of DSM near hydro electric power stations, as this kind of stations is city-forming. And always

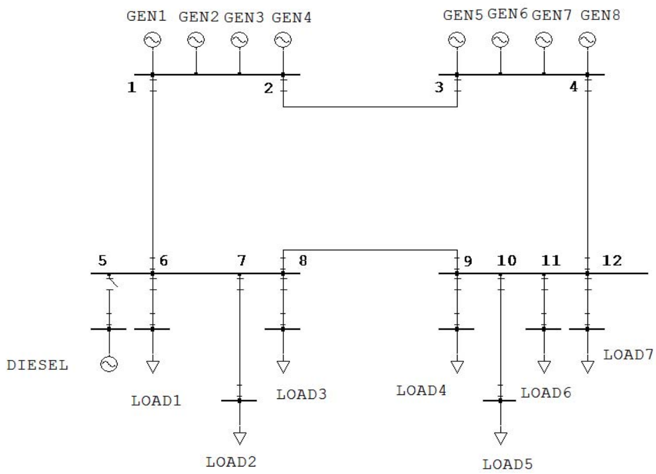


Fig. 2. Calculation model of Micro Grid

in the region of the hydro electric power stations there is a settlement which is a consumer on station buses. Besides in the region of a hydro electric power station big industrial enterprises are built (forest industry complex, aluminum smelter) that can be considered a large fast response load.

Modeling of MicroGrid was realized on the example of a local source power supply in a community of Novosibirsk power system (electrical power unit) (Fig. 2).

The calculation of the steady-state mode was carried out in the program complex EUROSTAG because of the fact that it enables to realize the further adoption of the previously developed model of the innovative device in MathLab Simulink.

The electric power unit includes 9 gas piston power generating installations (GPI) with the capacity of 1,98 MWt each (one installation is in reserve). To guarantee the reliability of power supply for consumers a reserve power source is provided: two diesel engine plants (DEP) with the total capacity of 2,17 MWt.

An important element in simulation modeling of MicroGrid is loads in nods. Modeling the loads in nods was realized in accordance with their static characteristics. With the accuracy sufficient for practical calculations, load characteristics can be written in the form of the second-degree polynomials. In the program complex EUROSTAG (which was chosen for modeling calculations of the grid mode MicroGrid) for building dependencies of active and reactive capacities on frequency and voltage, the following expressions (1) and (2) are used:

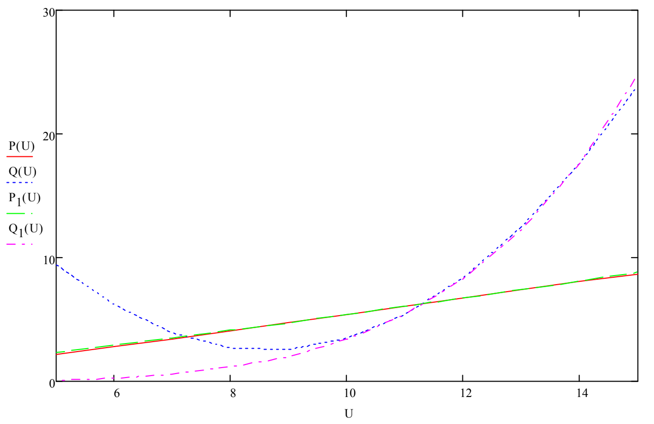


Fig. 3. Static characteristics of municipal household load

$$P = P_0(U/U_0)^a(f/f_0)^g, \quad (1)$$
$$Q = Q_0(U/U_0)^b(f/f_0)^d. \quad (2)$$

For simplification of calculations coefficients g and d are taken to be equal to 0, and coefficients a and b were determined with the help of graphs presented in Fig. 3 on the example of household municipal loads.

From Fig. 3 it is seen that the graphs are identical in the area from 10 kV to 14 kV. Thus, coefficients α and β for modeling in the program complex EUROSTAG are equal to 1.2 and 4.9 accordingly.

In the result of the calculations the authors faced the following problem: the available programs do not allow to calculate the grid mode with the voltage class 0,4 kV, but it is the class at which the device of DSM NORMEL™ is working at present.

That is why in the department AEPS of NSTU an original program, called NET, was developed for calculating the normal mode, which enables to estimate such a grid . The test circuit for making calculations on the address model is given in Fig. 4.

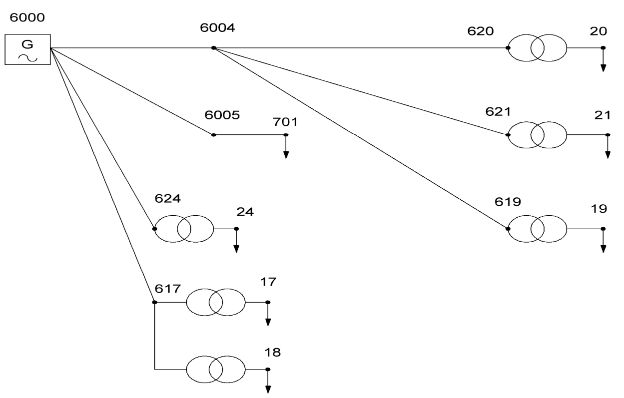


Fig. 4. Test circuit for calculating the normal mode

Depending on the voltage parameters of the grid, the depth of voltage regulation by the device of DSM NORMEL™ can vary from 2,5% to 20%, which is solved by means of using NORMEL™ of different modifications. In accordance with this, the modeling results depend directly on the choice of regulation parameters of the device NORMEL. The device of DSM is installed in the nods 17-21 and 24. In the program NET the device is realized as two-winding transformer (620-20, 621-21, 619-19, 624-24, 617-17, 617-18) with a nominal transformation coefficient equal to 1 and the possibility of voltage regulation by means of additional winding at the regulation range ±5% with the change of voltage of the low winding of transformers 10/0,4 kV. In Table1 the data are given on voltage regulation when the device works in the mode of voltage pull-down.

TABLE I
RESULTS OF CALCULATIONS OF SIMULATION MODELING IN THE PROGRAM NET

№ of the nod	Before regulation, kV	After regulation in the nod 18, kV	After regulation in the nods 17-21 and 24, kV
20	0.41	0.41	**0.389**
21	0.41	0.41	**0.389**
19	0.41	0.41	**0.389**
24	0.411	0.411	**0.391**
17	0.411	0.411	**0.39**
18	0.412	**0.391**	**0.391**

In the program NET the regulation goes on not in the automatized mode.

Automatization can be obtained through combining the mathematic model MathLab Simulink and the program complex Eurostag for realizing the simulation modeling. It is supposed also to build up a physical model of Micro Grid on an electric dynamical model of electric power system of NSTU [17].

IV. INCREASING ECONOMIC EFFICIENCY OF THE WORK OF EPS USING THE INNOVATIVE METHOD AND DEVICE OF DSM

The researched innovative method and device can be used as the system of mode regulation from the side of the consumer - Demand Side Management, which will considerably influence the dynamic management of power networks. With the mass introduction of the method and device of DSM NORMEL™ the identification of the virtual circuit EPS for mode control and the analysis of operating modes of EPS, both normal and transitional, become simpler.

The authors considered theoretically a new approach for determining the influence of capacity change and losses decrease in the network in concentrated nods of loads on the work of electric power stations. When studying static and dynamic stability of the electric power system, the question of determining load resistance arises. In practical calculations the resistance is taken as similar and equal to 0,35 r..n.u. (relatively nominal units) and depends on nominal capacity and nominal voltage of the load. Further, it is supposed to use the developed model for creating methods for determining parameters of the virtual circuit of load and to optimize the use of the innovative

device of DSM. The use of these methods allows to specify the dynamic of parameters' change in the virtual circuit of load, and thus to affect the estimated limit on static and dynamic stability of system generators, since the device of DSM can be integrated into the automated system of EPS control, as it possesses all necessary informational channels for it.

The mass use of the device of DSM NORMEL™ will allow to obtain scientific, technical, economic, social, ecological effects: to exclude systems with NLTC on power transformers of distributing substations 10\\0.4 or 6\\0,4 kV, to increase equipment life, to reduce expenses on electric power consumption and repair of equipment, to decrease active power flow, to reduce expenses on fines for violating environmental law, etc. The carried out research will help systematize these indexes, bring them through statistical analysis and use them for solving tasks of correction and optimization of power system modes, taking into account tendencies of development of electric grids and electric power systems, and also to specify the production program of lines of devices, to evaluate the efficiency of investments in the mass production of the device of DSM NORMEL™ . Since the retrospective information of spreading any innovation does not exist in principle, the authors developed simulation models for prognostication. In the authors' opinion, the offered models will enable to formalize and specify the efficiency evaluation of adoption of innovative technologies into electric power systems within the frame of the conception of Smart Grid. Theoretical results of the work can serve to form the basics of innovative energy informational infrastructure, which is able to be the basis for complex control of the entire energy system for the conception of Smart Grid. The developed software and means of mathematic modeling for carrying out simulation calculations can be considered as the innovative platform for technological integration of electric and modern information networks.

V. Conclusion

The further development of the created mathematic model of the innovated device of DSM will enable to carry out simulation calculation with address modeling to analyze the modes of Smart Power Grids, to evaluate the efficiency of the use of the device in respect to indexes of loss minimization, energy saving, rational distribution of power along the network depending on the type and size of load capacity, and also to find out some dependencies of the affect of the device on the stability of Smart Grid.

Acknowledgements

The authors thank Feigin Lev Zalmanovitch for new ideas and Filippova Tamara Arsentyevna. They also thank the collective of the department "Automated power systems" of NSTU for the help in software implementation.

References

Dissertations:

[1] Klavsuts I.L., "Methods of demand side management in the power system," Ph.D. dissertation, Dept. Management Systems and Energy Economics, Novosibirsk State Technical University, 1999.

[2] Rusina A.G. "Development of the theory and methodology of the analysis of electric power systems to set the modes control" Ph.D. dissertation, Dep. of Automated Power Systems, Novosibirsk State Technical University, Novosibirsk, 2013.

Patents:

[3] Feigin L.Z., Levinson S.V., Klavsuts D.A. et al "Method and Apparatus for Regulating Voltage", U.S. Patent № 7 816 894 B2, filing date 06.20.2007 date of publication - October 19.2010.

[4] Feigin L. Z., Levinson S.V., Klavsuts I. L. et al "AC voltage regulator with elements of protection and backup", RU patent № 2377630 C1 Russian Federation from 16.09.2008

[5] Feigin L.Z., Levinson S.V., Klavsuts I.L. "Alternating voltage stabilizer with protection elements" The international application for the invention № PCT/RU2009/000441 (PCT) of 16.09.2008.

[6] Feigin L.Z., "The device of voltage control of electricity-generating equipment" RU patent № 120499 Russian Federation from 23.09.2011

[7] Feigin L.Z., Feigin I.L., Klavsuts A.B., Klavsuts I.L. "The device (utility model) of modes control of the work of asynchronous motor" The application for the invention № 2014116596/07(026157) от 25.04.2014.

[8] Feigin L.Z., Feigin I.L., Klavsuts A.B., Klavsuts I.L,. "The device (utility model) of modes control of the work of asynchronous motor" The international application for the invention № PCT/RU2014/000669 of 09.09.2014.

Papers:

[9] Klavsuts D.A., Klavsuts I.L., Levinzon S.V. "Innovative method of demand side management" / 46-th International Universities' Power Engineering Conference - UPEC2011, hosted by South Westphalia University of applied Sciences, Soest, Germany \ Section- Innovation and Future Power System\\ 5th - 8th September 2011.

[10] Klavsuts D.A., Klavsuts I.L., Levinzon S.V. "New Method for Regulating Voltage an Ac Current" / 46-th International Universities' Power Engineering Conference - UPEC2011, hosted by South Westphalia University of applied Sciences, Soest, Germany \ Section-Section- Power Conversion\\ 5th - 8th September 2011.

[11] Klavsuts I.L., Levinzon S.V., Klavsuts D.A. "Integration Innovative Method Of Demand Side Management In Smart Grid" 47th International Universities' Power Engineering Conference – UPEC 2012, hosted by Brunel University Institute of Power Systems in the School of Engineering and Design at Brunel University, London, UK \\ 4th - 7th September 2012.

[12] Klavsuts D.A., Klavsuts I.L., Rusin G.L. "Aspects Of Evaluating The Efficiency Of Introducing Innovative Method And Technology Demand Side Management In Smart Grid System" \ 48 th International Universities' Power Engineering Conference – UPEC 2013, hosted by Dublin Institute of Technology, Ireland \\ Section- Smart Drids \\ 2th - 5th September 2013.

[13] Klavsuts I. L., Klavsuts D. L., Rusin G. L., Mezhov I. S / Perfecting business processes in electricity grids by the use of innovative technology of demand side management in the framework of the general conception of smart grids /. // 49 International Universities power engineering conference (UPEC), Romania, Cluj-Napoca, 2–5 Sept. 2014. – IEEE, 2014. – 4 p. – ISBN 978-1-4799-6556-4. - (UPEC).

[14] Klavsuts D. A., I. L. Klavsuts, T. V. Avdeenko / Providing the quality of electric power by means of regulating customers' voltage/ / // 49 International Universities power engineering conference (UPEC), Romania, Cluj-Napoca, 2–5 Sept. 2014. – IEEE, 2014. – 4 p. – ISBN: 978-1-4799-6556-4. - (UPEC).

[15] A. G. Fishov, D. A. Klavsuts, I. L. Klavsuts / Multi-Agent Regulation of Voltage in Smart Grid System with the Use of Distributed Generation and Customers [Electronic resource] // Electrical Engineering, Energy, Mechanical Engineering –

EEM 2014, pp - 761-767 - Mode of access: http://www.scientific.net/AMM.698.761.

[16] T.A. Filippova, V. V. Medvedkov and A. G. Rusina, "The calculation models of power and energy losses in commercial power transfer tasks", *Aktualne problemy w elektroenergetyce : XI miedzynar. konf. Naukowa*. – Polska : Politechnika Gdanska, 2003. –T. 1. – pp. 311-316.

[17] A. G. Rusina, G. L. Rusin and P. A. Akulshina, "Electrodynamic model of «an electric equivalent» of power plants energy characteristics" *Power engineering: efficiency, reability, safety : selected reports of all-Russian sci. and techn. conf.* – London : Red Square sci., 2014. – P. 17–22. – IBSN 978-0-9928299-1-9.