# The Development of Simulation Model of Innovative Technology of AC Voltage Normalization for Introduction into Smart Grid System

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*Abstract*—**The paper presents research concerning the use of innovative technology of AC voltage normalization in eclectic energy system, based on automatic mode voltage control in immediate proximity to the consumer of electric energy and allowing to improve the processes of Demand Side Management and also to increase statistic stability of electric energy system.**

*Index Terms*--**Smart Grid System, Technological Innovation, Voltage Control, Energy Efficiency, Electric Grids, Demand Side Management, Simulation Models, Probability Properties of a Facility.**

## I. Introduction

The scientific research is directed at the development and perfection of simulation model of innovative technology of AC voltage normalization as a software basis for introduction into Smart Grid System.

The basis of the innovative technology of voltage normalization constitutes the patented method and device of Demand Side Management (DSM), based on the regulation of consumers' voltage [3. 4. 5, 6, 7, 8, 9, 10, 11, 12].

A significant advantage of the device in question, called “normalizer of ac voltage” is the following: inbuilt controllers allow to register different parameters of the mode of energy consumption. At present, normalizers of ac voltage have been installed in several thousands of facilities, which allows to collect and process statistical information, on which basis it is possible to build models of power supply of the facilities. The experience of the usage shows that integration (mass introduction) of innovative technology of voltage normalization in automatic systems of commercial accounting of power consumption and other consumable resources (heating, water, gas) allows to realize potential possibilities of ac voltage normalizers as primary nodes of collection, procession and transfer of information on a higher level of dispatching control. Besides, ac voltage normalizers can be used as a system of automatic collection of data and local control of peripheral devices, regulating life support of facilities, such as: systems of heat-, water-, gas supplies, water drain, ventilation, conditioning, watch and security systems, etc.

Random component presents a peculiar interest for managing electric energy system from the point of view of Demand Side Management. Equivocations of production program and the graph of energy consumption are typical for all facilities, to a larger or smaller extent. It is typical of all types of energy consumers. The random process of energy consumption is determined by multi-factor influence of the combination of effects. Studying probability and uncertainty factors allows to research the process of energy consumption more fully and to take it into account when developing simulation models for analysis of energy consumption of enterprises when grounding the installation of the device.

For any new technology from which a commercial effect is expected it is necessary to carry out a number of tests based on the corresponding models, namely:

1) a theoretical model of the idea realized by the authors, before the introduction of the technology;

2) an experimental physical model which allows to try out the technology on a real object or a special panel;

3) a mathematical model which gives the possibility to carry out simulation calculations while introducing the new technology by using mathematical formulas and computer technologies.

In the present paper the provisions of the last model are considered.

In the previous publications at UPEC 2015 [19] the authors presented the mathematical model built in the interactive system for modeling non-linear dynamic systems Matlab Simulink. The developed model allows to perform simulation calculations in cases of changes of consumers' load and also to take into account the differences in parameters of ac normalizers, to make statistical analysis of data and solve the tasks of correction and optimization of electrical grid modes.

The article presents the results of the research, besides the requirements are formulated for building a mathematical model of such a large consumer as Western Siberian railway. It will allow to improve the simulation model, developed by the authors earlier, for giving a qualitative evaluation of the effect connected with the mass introduction of ac normalizers into electrical power system.

## II. Innovative Technology of AC Voltage Normalization

For a wide introduction of the innovative technology, Scientific industrial enterprise LLC "AVEC" was set up in 2009 in Novosibirsk, at present it is the only enterprise in the world that produces and improves the innovative patented device for the management of electric power consumption called "normalizer of ac voltage" under the trade mark NORMEL™®© [8]. The scientific industrial enterprise LLC "AVEC" carries out scientific research work, research and development experimental-design work for improving the method and device together with Novosibirsk state technical university (NSTU) at the departments of Automated electric power systems, Automatics, Management, Industrial management and Energy economics, in the Centre of testing control devices and devices of managing the modes of electric power systems. The results of the research are presented in [13, 14, 15, 16, 17, 18, 19, 20].

### *A. The essence of the method and device*

The essence of the innovative patented method and device of Demand Side Management (DSM), based on regulating the customers' voltage, consists in the use of voltage regulating transformer, which capacity is considerably less than the capacity of the load. The winding of low voltage (LV) of this transformer is switched to the grid phase in series with the load. The winding of high voltage (HV) is switched into the regulating grid. According to the second law of Kirchhoff, the load voltage is equal to the vector sum of the grid voltage and EMF, induced by the winding of high voltage in the winding of low voltage of the above said transformer. As aforesaid, load voltage, current and capacity in the load and in the grid change. Due to the used patented circuit design, the efficiency factor of the innovative device in question is 99.78 %. The known devices regulating customers' voltage don't have such an efficiency factor.

### *B. The main technological distinguishing features of the method and device*

It is necessary to highlight two main distinctive features of the innovative method and device of DSM for regulating (normalizing) customers' voltage, which differ them from commonly known methods and stabilization devices.

The first distinction of normalizers from stabilizers, keeping the level of voltage in the limits strictly set by the operating value, consists in the fact that the innovative device of DSM, within the operation range of input voltages, keeps input voltages in accordance with International Standards for the norms of power quality, i.e., for example, 220 B ± 5-10% in the countries of CIS, 230 B ±10% in the countries of EU. [1,2]

The second distinctive feature of the normalization circuit is the regulation of output parameters of the grid through the induction of differently directed electromotive forces of low voltage in thick winding of transformers, integrated into phase circuits, from the side of thin windings of high voltage through changing the polarity of their connection.

### *C. Normalizer of AC Voltage*

During the recent years, 5 modernizations of the device of DSM have been made, the last of which led to the complete change of its circuit technology. The previous circuit technology did not take into account the peak values of currents and voltages in transient processes connected with the changes in the function mode of the normalizer. It was the factor restricting the value of the nominal capacity of the normalizer on the level 350 – 400kVA. The new patent decision, in which the device was called "Normalizer of AC Voltage" [11,12] for the first time, removed this restriction due to the removal (facilitation) of transient process modes through iterative changes during the transition from one work mode of the normalizer to another one.

Block scheme of the AC voltage normalizer is presented in Fig. 1.

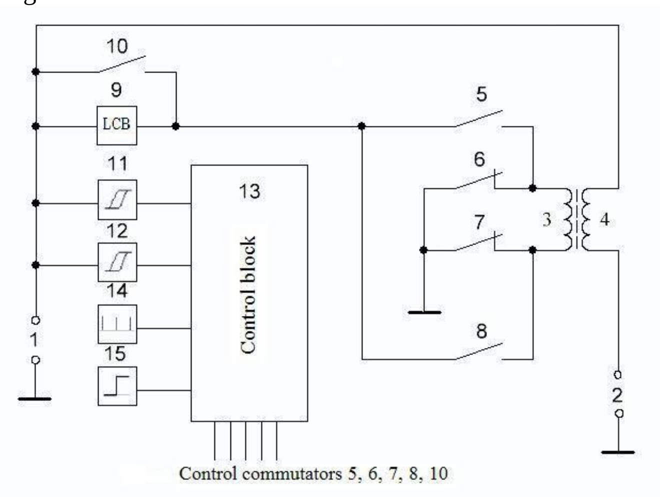


Fig.1 Normalizer of AC Voltage

AC voltage normalizer contains ***input terminal 1 and output terminal 2***, ***transformer with primary windings 3 and secondary windings 4***, the latter is switched by its first output to the first input terminal 1, and by its second output to the first output terminal 2, four ***commutators 5, 6, 7, 8***, connected by bridge connection; the primary ***winding 3 of the transformer*** is included into the first diagonal of the bridge connection, one of the outputs of the second diagonal of the bridge connection is switched to the second ***input terminal 1,*** which is also switched to the second ***output terminal 2.*** According to the offered invention, the normalizer is provided with ***limit current block 9*** *with the bridging commutator 10,* two ***hysteresis blocks 11 u 12***, ***control block 13,*** the second output of the bridge diagonal is switched to the input terminal 1 through ***limit current block 9***, parallel to which ***commutator 10 of bridging limit current block,*** outputs of ***hysteresis blocks 11 u 12*** are switched to the input of the control block, and the outputs of the control block are switched to the inputs of ***control commutators 5, 6, 7, 8, 10.***

The normalizer works in the following way.

The input voltage through input terminals 1 comes to hysteresis blocks 11 and 12. In the initial condition there is logical 0 at the outputs of blocks 11 and 12. When the input voltage on the upper threshold of block 11 was exceeded, for example 223 V at the output of block 11, logical 1 is set up. When the input voltage is reduced lower than the upper threshold and on the condition that the output of block 11 is equal to logical 1, and also if the input voltage is higher than the low threshold of block 11, for example 220V, then the output of clock 11 does not change its state and remains equal to 1. With the further reduction of input voltage up to the voltage low threshold, and lower, logical 0 is set up at the output of block 11.

Hysteresis block 12 works in a similar way. In the initial state logical 0 is set at the output of block 12. With the reduction of input voltage lower than the low threshold of block 12, for example 209 V, logical 1 is set up at the output of block 12. With the increase of input voltage higher than the low threshold, and on the condition that the output of block 2 is equal to logical 1, and also if the input voltage is lower than the upper threshold of block 12, for example 212 V, the output of block 12 does not change its state and remains equal to 1. With the further increase of input voltage up to the upper threshold of block 12 and higher, logical 0 is set up at the output of block 12.

Control block 13, controlling commutators, analyses the outputs of hysteresis blocks 11 and 12 and operates commutators 5, 6, 7, 8 and 10. Initially we suppose that commutators 5, 8 and 10 have normally open-loop contacts, and commutators 6 and 7 – normally closed.

If the output of hysteresis block 11 is equal to logical 1and the output of hysteresis block 12 is equal to 0, the system goes into the mode “REDUCTION”. For this, in periods of time set up by the control block, commutator 5 closes, commutator 6 opens, commutator 10 closes. When the outputs of hysteresis blocks 11 and 12 are equal to 0, it means that the input voltage of the network is normalized, and the system goes into the mode “TRANZIT”. To go into the mode “TRANZIT” in periods of time set by control block, commutator 10 opens, commutator 6 closes, commutator 5 opens.

If the output of hysteresis block 12 is equal to logical 1, and the output of hysteresis block 11 is equal to 0, the system goes into the mode “INCREASE”. For this in periods of time set by the control block, commutator 8 closes, commutator 7 opens, commutator 10 closes. When the outputs of hysteresis block 11, 12 are equal to 0, it means that the input voltage of the network is normalized, and the system goes into the mode “TRANZIT”. To go into the mode “TRANZIT” in periods of time set by the control block, commutator 10 opens, commutator 7 closes, commutator 8 opens.

The offered sequence of switching commutators provides the continuity of current flows in the normalizer, thus excluding voltage and current surges, which improves the reliability of the operation of the device.

In the same way, to operate the primary winding there are required commutational elements on current about $K_T$- times less, than the current flowing in the load, where $K_T$ is the ratio of the value of the voltage of the primary winding to the value of the voltage of the secondary winding. For example, $K_T = 230 / 13 = 17{,}7$. This factor begins to play a large role with the increase in capacity consumed by the load. In the offered normalizer all commutational elements are located exactly from the side of the primary winding, which allows to use simpler and more reliable commutational devices and improves the reliability of the operation of the device on the whole.

If the normalizer is provided with ***timing block 14***, at the output of this block, in certain periods of time, for example from 2 to 30 seconds, short enabling pulses appear, which come to control block 13 operating commutators. At that, control block 13 is allowed to change its state only once during one enabling impulse. Due to this mechanism commutational losses in the system, which could appear on the condition of input voltage being near the borders of hysteresis, decrease. The reliability and time resource of the system increase. Especially significant it is when electromechanical devices, for example, contractor, are used as commutational elements.

The normalizer can be also provided with delay unit 15. With switching the normalizer, logical 0 is at the output of ***delay unit 15,*** and the operation of the system is forbidden. When a certain time is achieved, for example, from 0 to 300 seconds, logical 1 appears at the output of delay unit, and the operation of the normalizer is allowed. It allows to exclude the overlapping of starter currents during the parallel operation of several normalizers due to setting different intervals for the delay units.

### *D. The advantages of the of the innovative technology of AC voltage normalization*

The previous research shows that the method and device of DSM based on the regulation of customers’ voltage have a number of advantages.

1) The regulation of customers’ voltage occurs without the disconnection of the supply main, which removes the problems connected with power commutations and transition processes caused by them and by disconnection of customers’ supply.

2) Due to the use of the patented circuit design, 95% of capacity is transferred by electric path and only 5% by electromagnetic path. As a result, the transformers are made which capacity does not exceed 5% from nominal capacity of the innovative device of DSM itself. The regulation of voltage occurs phase by phase and automatically. All this has a positive effect on mass-dimensional and price parameters of the innovative device of DSM.

3) The absence of power commutation elements in the circuit of the innovative device of DSM creates conditions for its continuous trouble-free service.

4) The use of the patented method and device of DSM, based on customers’ voltage regulation within the

requirements of international standards for the norms of power quality, not only provides normal work of the customer's equipment, but also reduces consumed capacity and losses in the grid. I.e. the effect from the use of the method and device is manifested both on the low and high sides of the grid, including the source, that is the electric power station. The economy of consumed capacity allows to lessen the load on supply grids, which enables to switch a considerable number of new customers without additional expenses.

5) The use of the patented method and device of DSM positively influences the mode of energy system due to neutralizing parasite reactive capacity, returned to the grid by customers.

6) The economic effect from the use of the innovative method and the device is manifested on the system level under the condition of its mass introduction and achieves 50 % economy of finances, there are also social and ecological effects connected with the production, transfer and consumption of electric energy.

### E. *Recommendations on the use of the innovative technology of AC voltage normalization in Smart Electric Grids*

The carried research shows that with the mass introduction of the patented innovative method and device of DSM into Smart Electric Grids the largest effect, connected with the increase in energy efficiency of the energy system, can be achieved if the electric power is transferred to the customer by the energy-supplying organization at the maximum value of voltage permitted by International Standards for the norms of power quality [1, 2], and the customer uses it at the minimum voltage value, permitted by these Standards. On the one hand, such regulation allows to provide normal functioning of customers, on the other hand, the consumers will not use "extra" capacity, and the losses will be minimal. Therefore, one of the tasks of reducing the consumption of electric energy and the increase in energy efficiency of energy systems consists in regulating consumers' voltage. This task is typical of most countries of the world, which requires the development of Simulation Models of Innovative Technology of AC Voltage Normalization as a Software Basis for Introduction into Smart Grid System.

## III. The Analysis of Power Consumption of Western Siberian Railway

The Western-Siberian railway as the consumer of electrical power has had historically a special strategic significance for Russia. This railway complex is a connecting link of a unified economic system and the most available transport for millions of citizens. Without accurate work of the railway transport it is impossible to organize a stable activity of industrial enterprises, timely supply of vital cargo to any part of the country.

The Western-Siberian railway (WSRW) is an important constituent part of the transport system of the country. It connects the center of Russia with its eastern regions, gives the possibility of an access to sea ports and borders with Asian countries.

The Western-Siberian railway is a special and quite large consumer of electric power. Only in Novosibirsk region the share of Electric Consumption of Electrified Railway Transport (ERWT) is about 15%.

There are four kinds of electric power consumption in ERWT which differ significantly both in their behavior and the possibility of their analysis:

1. the consumption of electric power for the haulage of trains - 80%;
2. the consumption of electric power by the enterprises of railways -15%;
3. the consumption of electric power from electric grids of railways by external enterprises - 4%;
4. the domestic consumption of electric power from electric grids of railways - 1%.

Each kind of the consumption of electric power of ERWT has its peculiarities.

The authors offered a technique which reflects the complex of factors forming the consumption of electric power by railway transport.

Consumption of electric energy by railway transport can be divided into Non-tractional and Tractional consumption. In its turn Tractional consumption consists of Freight traffic, Passenger traffic and Commuter traffic. Factors such as Characteristics of traffic (Type of locomotive, Weight and length of train, Actual plan of traffic, Containment of cargo), Weather conditions and Characters of the area can also be taken into account.

Analyzing the technique, one can make the conclusion that the management of the electrical mode of such a large consumer as the railway increases dramatically the significance of the considered innovative technology of voltage normalization, since with its help the electric parameters of energy system modes can change flexibly. At that, it is supposed that this technology will be used for all presented varieties of consumption of ERWT.

Though all the above mentioned facts were obtained on the basis of consultations with a wide circle of experts on power generating industry of railways in Russia and Germany, still there is no absolute confidence that the complex of all the mentioned factors determines, in general, the consumption. One more peculiarity of the Western-Siberian railway is that it has the lowest amount of charge in order to keep this consumer, since there is a possibility that in the near future the railway will enter the wholesale market of electric power and capacity.

And finally, the railway transport has old devices of commercial account of electric energy, which only give general information of low quality, which is used only for the control of energy consumption and is not used for calculations.

The analysis of the Electric Consumption of Electrified Railway Transport showed:

1. The process of Electric Consumption of Electrified Railway Transport is a random one with a big amplitude of irregularity in time.

2. Due to a great number of consumers of railways (electric motive power of trains, enterprises of the railway itself, other enterprises which use electric power from electric grids of railways, domestic consumption of power from the grids of railways) and in connection with the use of old equipment for revenue metering of energy, they have difficulties with the collection of data on energy consumption of ERWT, their control and summarizing.

3. Since the power consumption of ERWT is influenced by a large number of factors, it is in fact impossible to build a factor model P (Ф1,…Фn). The only way is the interval estimation of cumulative impact of factors.

## IV. The Foundations for Creating a Block for Prognosticating Energy Consumption in the Frame of Simulation Model of the Technology of A. C. Voltage Normalizing

As it has been already said, the model for prognosticating electric energy consumption is purpose-oriented. The main attention is paid to the model used in commercial relations of enterprises and a power supply company (PSC). It influences the management of the modes of electric energy system (EES). Planning, purchasing and the following regulation of energy consumption in the large territorially distributed organization with various ways of consumption and multilevel hierarchy of management is a complicated multi-step process. It includes the following: forming prognostications of consumption, their coordination on different levels of management, the control of correspondence of factual energy consumption to the planned consumption, the analysis of causes of deviation, managing the consumption of electric energy. It creates rather strict rules for consumers of retail market. If their application is not correct, then PSC does not know its profit. The improvement of the system of prognostication is a significant problem both for consumers and PSC. Expenses of enterprises on payments for electric energy are constantly growing. In some enterprises these expenses reach 20%.

The enterprises solve various problems on the basis of prognostications of electric energy consumption. A part of the tasks refers to their internal activity:

- They determine the ways and methods of energy saving in order to reduce expenses on electric energy consumption.
- They normalize the values of energy consumption for revealing the efficiency of technological process and its separate operations.
- They develop special programs of interrelation with PSC, for example, the programs “Demand management”.
- They determine the strategy and tactics of competitive actions.
- They plan the introduction of new technologies and techniques, less energy demanding than the present ones.
- They carry out the diversification of products, changing the nomenclature and assortment of goods and many other things.

All these tasks are important and demand the prognostication of graphs of loads and energy consumption both in the whole enterprise and in its structure departments.

The probability analysis allows to estimate the impact of uncertainty on energy consumption and load. These estimates can be taken into account while developing prognostication models and can be used while planning.

Calculations of sample characteristics of energy consumption by railway are carried out in the packets of EXCEL and STATISTICA. From the obtained data it can be seen that daily load graphs have large irregularity. The range of capacities is more than 50%. Root-mean-square deviations of daily capacities are also considerable - 17 MWt, that is approximately 10%. (Fig. 2). Similar data are obtained for other months of the year. There is observed also a seasonal irregularity.

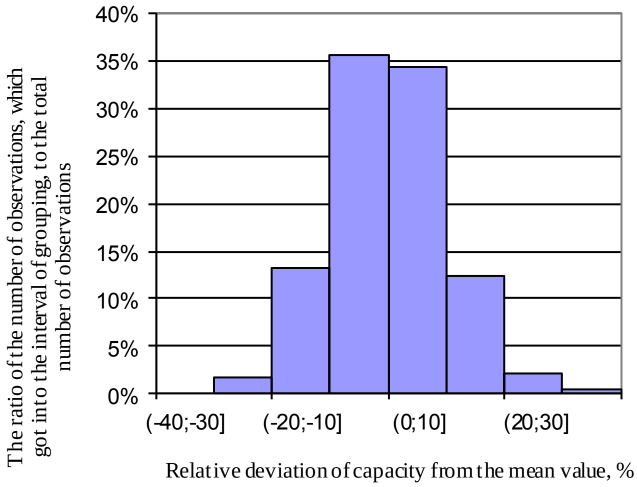


Fig. 2. Histogram of load deviations from the average value on Western-Siberian railway during the year of 2015

From the histogram it is seen that 36% of deviations of load capacity from the average value belong to the interval -10%...0%, and 34% of faults belong to the interval 0%...10%, that is, the most “popular” deviation is 10%. The frequency of deviations shows that 70% of deviations stay within the interval -10%...10%. This value can be taken for a certain threshold while developing the model for prognosticating load capacity of the railway. However, it is seen that in certain cases the deviations amount up to 30%..

The given analysis of energy consumption by the railway can be used for building an adequate model of a large load dispersed territorially. The given model will be used in the complex model of electric energy system with the use of ac normalizer.

## V. Conclusion

On the basis of the analysis of the processes of energy consumption by a large consumer, there will be carried out further perfection and detalization of a mathematical model for the innovative technology of normalizing ac voltage in Smart Grid System. As a result, an efficient mathematical model of a distribution net with the participation of an ac voltage normalizer will be obtained, which allows to carry out mathematical research concerning the respond of the ac normalizer to external disturbances (daily changes of load, as well as the correct presentation of loads by their statistical characteristics).

On the basis of the electro-dynamic model of the Department of automated power systems of Novosibirsk state technical university, physical experiments are carried out, which results will lead to a verified digital model of ac voltage normalizer.

The verification of the created mathematical model of ac voltage normalizer will also be carried out on the data, obtained from real objects on which the device is installed. As a result, the proof of the fidelity of the mathematical model of the ac normalizer will be obtained and the grounds for further research and all-round introduction of the device into Smart Grid System will be received.

The simulation calculations on test schemes and on the circuits of real energy systems allow to validate the mass introduction of innovative technology for normalizing ac voltage into Smart Grid System. This stage presupposes the preparation for validation of mass introduction of the innovative device of "ac voltage normalizer" into the real system of power supply with the purpose of providing the quality of power supply. The work performed will help improve energy saving of both separate consumers and the energy system in general.

The developed simulation models of the innovative technology of voltage normalization will be used as the basis of software for its introduction into Smart Grid System.

Theoretical results of the paper will serve for the formation of the grounds of innovative energy information infrastructure, which is able to be the foundation for complex control of the whole energy system on the basis of the conception of Smart Grid. The developed program means and means of mathematical modeling for carrying out simulation calculations can be considered as Innovative platform for technological integration of electric and modern informational networks.

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