Resource Consumption Monitoring on the Basis of Devices of Demand Side Management in Smart Grids

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***Abstract*—The research is aimed at the development of digital models of resource consumption monitoring in Smart Grid systems on the basis of the innovative generation of devices of Demand Side Management – normalizers of AC voltage. There are considered variants of the use of digital technologies for solving the tasks of demand management, on the basis of collected data about the consumption of all kinds of resources. An approach to the use of the normalizer is offered for organizing active feedback. It allows to unite organizations, providing resources, and resource users into an integrated information system, at the same time the nodes of this system become elements of "Internet of Things". The expected effects may include: increase in the stability of energy system, increase in the accuracy of measuring consumed resources, as well as the solution of planning tasks and resources distribution tasks.**

Keywords—Smart Grids, Demand Side Management, Technological Innovation, the Normalizer of AC Voltage, Resource Consumption Management, Machine-to-Machine Interaction, Distributed Control System, Industrial Internet of Things, Digital Twin.

I. Introduction

Energetics is a life-supporting sphere of human activity. The state of energetics is a key factor, that determines the place of an enterprise, branches and the economy of the state in general and, as a consequence, its place in the world community.

However, a certain disbalance is evident between the rate of the development of generation and transition sector and end consumers in energy branch, from the point of view of management systems.

It is evident that the basis of managing any life-supporting system is information flows. In energetics, which is the fundaments branch of life maintenance, the information flows are transferred with the help of systems of automated management.

Common systems of automated management practically do not support data exchange with information systems beyond the perimeter of the enterprise and have limited computing resources. This, in its turn, leads to a number of restrictions of effective management on territorially distributed technological processes of the system of the class of Distributed Control System (DCS).

A real way out of this situation is, in the authors' opinion, a possibility of conjunctive (external) impact on the system, on the whole, from the part of end consumers, i.e. concrete objects – consumers of electric energy and other resources, which demands the development and introduction of innovative methods and devices of managing objects in the systems of Smart Grid, Smart Cities and Smart Homes.

The solution to this task, offered and researched in the paper, is based on developing digital models of resource consumption monitoring in systems of Smart Grid on the basis of devices of Demand Side Management – normalizers of AC voltage developed and produced under the trademark NORMEL™®© [4-29].

II. The Main Effects of the Use of Digital Technologies

For tasks which are solved with the help of systems of automated managing technological processes, it is becoming important to use digital technologies on the basis of microprocessor technique, namely technologies for processing large database, artificial intelligence, systems of distributed ledger.

The use of digital technologies has a system effect both for the branch, and for the state.

For the branch:

- predictive analytics of modes;

-planning preventive maintenance (preventive service);

- improving the quality of exploitation of basic and auxiliary equipment;

- forming database for realizing the functions of benchmarking.

For the state:

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- improving the quality of monitoring and prognosis of characteristics of technical and economic conditions of systems of electric supply, heat supply, gas supply, hot and cold water supply and water disposal, including physical wear index;

- improving the quality of monitoring the reliability of systems of life support in settlements, city counties;

- improving the quality of monitoring and coordinating measures on energy saving and increase in energy efficiency;

- developing measures on environmental protection.

To introduce through technologies of digitalization into systems of resource provision it is necessary to organize the transition of indications data from primary metering devices for recording such resources as electric energy, heating energy, hot and cold water, gas, which are transferred along digital connection channels to a unified informational analytical center. Under resources consumption the amount of electric energy consumed per a time unit is understood, as well as the amount of liquid, gas, which passes through the cross-section of a pipeline, channel, etc. At the same time, the amount of medium calculated in volume units is called volume flow and in mass units - mass flow. The measured parameters of the consumed resources are, correspondingly, as follows:

- electric energy – voltages, currents, cos φ;
- heat energy –enthalpy, the quantity of heat;
- water supply – water consumption, temperature;
- gas supply – gas consumption, pressure;

On the basis of the accumulated data with the help of a digital model of the enterprise one calculates real technical economic characteristics, toxic emissions, forecast analysis is made on efficient exploitation of the equipment and the introduction of new technologies. On the basis of the obtained data a possibility appears to carry out analytical calculations not only for one enterprise, but also for territorially distributed objects on the whole.

III. Variants of the Use of Cloud Calculating with the Use of Devices of Demand Side Management NORMEL™

According to the definition of the National Institute of Standards and Technologies (NIST), US, "cloud calculation" is a model for providing universal network access on demand to a commonly used pool of configured calculating resources, which can be quickly provided and introduced with minimum administrative efforts or interaction with a service-provider.

For using cloud calculations, it is necessary to organize a channel for transferring the values of measurable parameters of technological processes of the enterprise to calculating resources. For this it is necessary to transform data from primary (field) metering devices in the form of physical units (for example, voltage, current strength, temperature, pressure, resources consumption) into electric unified signals (for example, 4-20 мА) and then to digitize with the help of Analogous-Digital Transformer (ADT). A digitized physical unit can be transferred according to any open protocol of data transition. The protocol General Packet Radio Service (GPRS) on the basis of cellular networks Global System for Mobile Communications (GSM) is the most widely used for the tasks of telemetry. It allows mobile networks to be compatible with Internet. However, the standard GPRS on the basis of GSM has a number of restrictions on energy consumption of end devices and the distance of signal transition, which does not allow to quickly scale decisions, connected with “Internet of Things” (IoT). In this connection, a new standard was developed - Low-power Wide-area Network (LPWAN), which has the distance of data transition more than 10 km at low energy consumption, at that the data are transferred at a low speed (~10 Kbit/sec), but for the tasks of telemetry such a speed is admissible [30].

Thus, the values of measured parameters in digital form are transferred to cloud calculating resources, which are located beyond the perimeter of the enterprise.

Let us consider the main types of cloud calculating resources, which are rendered by the leading providers in this area, and which can be used for solving the tasks with the use of the devices of Demand Side Management – normalizers:

а) data storage;

б) the calculation of mathematical models;

в) presenting the results of calculations in the form of users’ interface, for example, on such devices, as PC, pad, smart phone, or for other informational systems.

Let us consider the variants of the use of cloud calculating resources in more details.

1) For the storage of permanently coming data from normalizer from the primary metering devices, one can use both classical relational database, and specially adapted database for the storage of time-series (time tagged data). On the basis of cloud resources, there can be launched services for collecting data from various informational systems both within the perimeter of the enterprise (SAP, 1C, etc.), and from various external sources of data, which are in open access for the following processing. At that the reliability of data storage on cloud resources is higher than on the servers, located within the perimeter of the enterprise, also the cost of service is reduced.

2) For constant calculating mathematical models on the basis of cloud calculations scalable resources are provided, which depend on the volume of calculation.

Mathematical models can be described in any available programming language (MatLab, Python, C#, C++, etc.) or various calculating platforms can be used, beginning with Excel and finishing with targeted calculation complexes.

The information from database is fed to the input of a mathematical model or complex, then calculation is made (other mathematical models can be included for sequence or parallel calculationя), the results of the calculation are recorded in the database.

Besides the use of mathematical models and calculation complexes it is possible to use services of machine learning, which allows to make logical conclusions on the basis of profound teaching, to develop services of recommendations in real time mode, to use provided libraries on artificial

intelligence. For the storage of calculation results it is possible to use document database.

According to the calculation results, the reports can be formed about the state of the equipment and technological processes, the notifications can be sent, for example, to smart phones or electronic mail, for this the corresponding services are also provided.

3) The results of calculations can be presented both in the form of interactive users' interface (graphs, tables, etc.), and in the form of open formats for machine-by-machine interaction in eXtensible Markup Language (XML), JavaScript Object Notation (JSON), etc. through Application Programming Interface (API), which is located on cloud resources.

The services provided on cloud resources are constantly expanding. For example, already at the moment, services for the work with devices in the conception IoT are available, namely, operational systems, the means of collecting and processing data, analytical instruments, distance management.

Due to scalable cloud resources, the restrictions on calculating resources, volumes of data storage are practically eliminated.

Due to highly competitive environment, the providers of cloud technologies reduce the barrier of the introduction of advanced through technologies. It allows not only to reduce the costs of the solution to standard calculating tasks, but also to develop new approaches of interaction for interested parties, representatives of authorities, science and business.

The joint use of the normalizer NORMEL™®© and cloud calculating resources allows to widen significantly the range of solved tasks.

IV. Resource Consumption Monitoring on the Basis of Devices of Demand SideManagement with the use of Digital Technologies.

Papers [16-29] describe in details the results of researches and many-year experience of practical usage of technology, including the patented method and device of Demand Side Management – the normalizers of A**C** voltage, developed and produced under the trademark NORMEL™®© of Scientific Industrial Enterprise LLC "AVEC" (Novosibirsk, RF).

The devices – normalizers are switched to electrical input of buildings, constructions, industrial equipment, street lights, i.e. to all energy consumers.

Let us enumerate the effects of the use of normalization technology.

1. The mass use of the method and devices in electric energy systems of many countries allows to maintain in practice International Standards on the Norms of Electric Energy Quality, identical in different countries of the world, for example:

- Standard EN 50160: 2010 (NEQ) – the standard of the countries of the European Union - *«Voltage Characteristics in Public Distribution Systems»;*

- Standard GOST 32144-2013 – inter-state standard of Armenia, Belarus, Kyrgyzstan, Russian Federation, Tajikistan, Uzbekistan – *"Electric energy. Electromagnetic compatibility of technical means. Norms of quality of electric energy in the systems of electric supply of public grids";*

- corresponding standards in any regions of the world.

2. The consumption of electric energy according to the meter is reduced from 7% to 24%, depending on the character of electric load with the preservation of conditions for normal work of the equipment.

3. The working time of technological equipment, household and light appliances increases significantly.

4. The losses in the electric grid reduce not less than by 10%, which increases the possibility of switching additional equivalent capacities to the electric energy system, that is, the increase in transfer capacity of electric grids takes place.

5. The mass use of technology in electric energy systems reduces the consumed power and allows to increase the stability of work of synchronous generators at power stations due to the increase in their stability to short circuits, voltage fluctuations, other transition modes, on the whole the stability and the reliability of energy system increase.

6. The period between the reconstruction works in electric grids increases significantly.

7. The devices - normalizers can be integrated into the automated system of managing the electric energy system, as they possess all information channels, necessary for this.

It is known that in modern systems of resource supply every supplier of different resources creates their own system of collecting, recording, managing and transferring the information to a higher level of dispatching. Thus, to some extent, here occurs duplication of most elements of these systems. At the same time, it's becoming apparent that there is a problem of heterogeneity of applied metering devices as far as their functionality and the used communicational interface are concerned. It results, eventually, in making a unit of a corresponding resource more expensive, which leads to considerable material expenses, first of all, for consumers of all these resources. In addition, an effect of growing technical complication emerges, which reduces the reliability of the work of the system on the whole. All these problems prompt looking for new solutions to the task of regulating resource consumption.

The essence of this innovative decision is in the following: to provide the operation of the normalizer with new functions preserving at the same time all its positive features:

a) collecting, recording, managing and transferring the information to a channel, preferable for the supplying organization, for further dispatching on a higher level;

b) providing feedback with dispatching systems of resource-supplying organizations with a possibility of distant managing supplying organizations (managing valves, dampers (air ventilating flaps), frequency converters of electric engines), i.e. automation of managing systems by operating devices;

c) providing systems of video observation, safety and fire alarm with similar possibilities, etc.

The distinctive feature of the normalizers of a new generation is the possibility of collecting data from primary metering devices of measuring technological processes of the enterprise (current, voltage, temperature, consumption, etc.) and the transition of collected data along digital channels of connection to the DPC on the basis of calculating resources of the enterprise or cloud technologies. It allows to solve a new class of tasks, connected with the increase in the efficiency of technological processes:

- to calculate real technical and economical characteristics, toxic emissions on the basis of accumulated data, with the help of digital double of the enterprise;

- to carry out forecast calculations concerning the economic exploitation of the equipment and the introduction of new technologies;

- to reveal factors, increasing/decreasing energy efficiency;

- to diagnose remotely the equipment of technological processes of the enterprise;

- to form database for realizing the functions of benchmarking, i.e. exchange of experience and introduction of the best practices.

Block-diagram of the work of the device of Demand Side Management – normalizer with the use of digital technologies is presented in Fig. 1. The principal structure diagram of intelligence blocks of the device of Demand Side Management NORMEL™®© is presented in Fig. 2.

As a load to the normalizer, they switch the equipment of the enterprise for managing technological processes, namely, actuating mechanisms, such as compressors, heaters, pumps, indicated as M in Fig. 1. Power supply circuits are not shown in the block diagram. In intelligent blocks of the Normalizer of AC Voltage, control signals are formed, directed at actuating mechanisms, indicated by lines from the normalizer to M, and metering devices of technological processes of the enterprise are switched, which are indicated as T, P, F, L in Fig. 1.

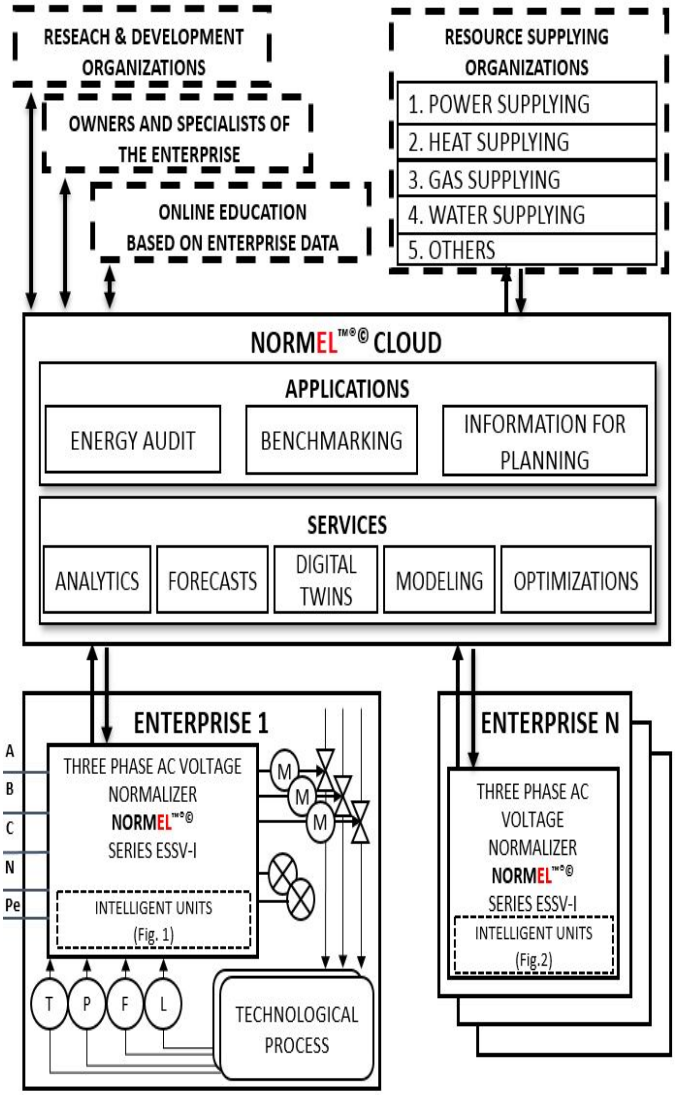
With the help of the module of data transition (GSM, LPWAN), indicated in Fig.1 with arrows from “Enterprise” to “Cloud NORMEL”, the information is transferred to the Data Procession Center (DPC), which can be located both within the perimeter of the enterprise, and beyond its perimeter on the basis of cloud resources in “Cloud NORMEL”. At that, the normalizer acts as a server, which periodically in quires for data transition.

The data start to be transferred after successful authorization. Such an approach allows to increase the safety and to reduce the costs of resources while transferring data.

When the channel of data transition is temporarily absent, the normalizer can store the collected data from metering devices for the following transition after the connection channel is restored.

In the principal structure diagram of intelligence blocks of the device of Demand Side Management NORMEL™, presented in Fig. 2, a part of blocks is permanently included into the configuration of the voltage normalizer, namely: link block, normalizer control block and indication block. The task of these blocks is to provide the work of the normalizer.

Intelligent blocks include additional blocks of relay, simistors, analogous and digital input/output. Additional blocks do not influence the work of the load, switched to the normalizer, do not introduce any changes into the structure of acting technological processes of the enterprise. The volume and type of measuring signals determine the composition of additional blocks in the normalizer. The main task of the modules is to collect data about the technological process and their transition for the following procession. All calculation tasks are transferred to DPC with the help of a modem.



Notes:
M – actuating mechanisms (Motors, Actuators);
T , P , F , L - Devices of Commercial / Technical Metering of Water Supply, Heat Supply, Gas Supply, Oil supply.

Fig. 1. Block-diagram of resources consumption monitoring on the basis of devices of Demand Side Management with the use of digital technologies.

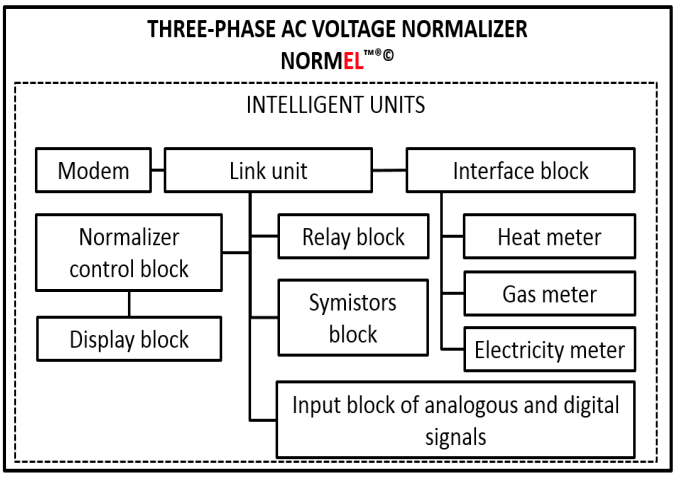


Fig. 2. Principal structure diagram of the configuration of intelligence units of the device of Demand Side Management NORMEL™.

The configuration of other blocks depends on the type of the solved task. The interface block allows to switch various devices (metering devices) to open interfaces, for example, R-485. Relay and simistors blocks allow to optimize monitoring the impact on the technological process. The block of input of analogous and digital signals allows to collect data from primary metering devices (sensors of temperature, pressure, resources consumption). The modem carries out the task of reception and transition of data between the DPC and the normalizer.

A perspective task is the provision of interaction between normalizers, and the DPC. Machine-by-machine interaction can improve the quality of the work of the normalizer and the technological process, due to the work in pro-active mode, more objective assessment of efficiency (cost effectiveness) of the work on the basis of a large data volume. Under a large data volume is understood not only the data obtained directly from the devices of collecting information about resources consumption inside the object, but also the data from external sources, having both technical character, describing the basic parameters of supplied resources, but also informational statistical character, for example, the data about energy prices, demand and supply for the manufactured products, etc.

Using the normalizers of a new generation, a possibility emerges to bring out a part of informational functions of automated control system of the enterprise in DPC, fulfilling the main functions of management and technological protection, and a part of informational fucntions can be delegated due to the remote procession of data from primary metering devices.

Delegated fucntions of automated management systems may include: the registration of events, informational, calculating and analytical functions, protocoling information.

Delegating informational fucntions, the enterprise gets the following advantages:

- the costs for maitaining the corresponding infrastructure (specialists, programming-technical complexes) reduce;

- risks of losing data reduce;

- the costs and terms of introducing new technologies reduce;

- diagnostics of technological processes is realized in automatic mode;

- the development of recommendations on increasing the efficiency is realized by highly qualified specialists on the basis of collected data.

CONCLUSION

This paper considered expected effects from the use of digital technologies, the scheme of work of the normalizer with the configuration of intelligence blocks, which allows to organize machine-by-machine interaction. Such an approach allows to unite a network of normalizers through Internet and regard them as a part of Internet of Things (IoT). A new class of tasks is described, which can be solved by collecting data from normalizers in the unified center of data procession.

The new generation of normalizers is able to realize functions of collecting, processing and transition of information on all types of resources supplied to consumers, with the possibility to use wireless technologies (GPRS, LPWAN). Using in normalizers the feedback with organizations, supplying resources, gives a possibility of remote management of all resources. Thus, the new generation of normalizers can fulfill new functions.

In the authors' opinion, the creation of the system of data collection on a low (object) level with the possibility of their transition to a higher level has a deep sense in case when the functions of active feedback, designed for regulating parameters of resources consumption, is realized. Thus, the question is not only about the realization of the function of Smart Grids System inside the object, but also about active interaction with the systems of resources supply on the whole.

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