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Distributed System for Data Acquisition and Management of Electric Energy Consumption

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***Abstract* - This document presents the new model of distributed consumers of electricity powering - named Power Modes. There is presented a conceptual model of an IT hierarchical distributed system for data acquisition and evidence the state of the controlled distributed object – the electric energy consumption. The authors will try to show that the proposed model of the IT system is accurate to solve the problem of the electric energy consumption management. In this context the proposed solutions are written into the DSM methods of power system balancing [1]. The competency of the paper is the presentation of the prototype system of intelligent metering which is developed and claimed for a patent protection [2, 3].**

***Keywords* - Intelligent Metering, DSM, Power Modes Model, Hierarchical Systems, Distributed Control Systems**

I. Research Area Description

The electric energy consumption is subject to equation of power balance (1), where power demanded by consumers P_{EC} is balanced by power of generators P_G and where aspects of power looses ΔP_{SL} and power grid cooperation with neighbor's grids P_{EX} are included too. In stable this equation is quite easy to be maintained, but it is obvious that the processes occurring in the power grid are dynamic:

$$P_G + P_{EX} - P_{EC} - \Delta P_{SL} = 0 \,. \qquad (1)$$

The main issue of the equation balance is unpredictable nature of consumers, both in short and long term of demand prediction. That the consumers are responsible for demand side of power balance, but they could not consume more energy that the supply side is able to distribute. The area of author interests is demand side ability for power balance, especially in situations of energy deficit. Therefore it is written into a set of DSM methods [1].

The solution is oriented to offset the deficit by turning off some redundant electrical-devices in the chosen group of consumers. Reference [4] presents a result of research of the consumer preferences and priorities of electric energy consuming limitations in situations of power deficit. The results were the base for a new model of consumer power development. The model is called "Power Modes" and has been published in [5]. The power modes allow for differentiation of consumer priorities of functions served by their devices and to remote and gradually pulling off, with the users acceptance. The solution presented in this paper is designed to increase the electric energy stability of managed consumers and to decrease the power deficit in a managed power system.

II. Power Modes Model

A. Definition of Power Modes Model

Power modes model is defined as extraction of the state-of-art of consumers powering [6, 7, 8]. Currently the consumers are powered with no possibility to diverse quality parameters of energy consumed. In the most they have no choice to be powered or to be not in lack of electricity situations. The model of power modes is defined to resolve that issue.

The volume E means quantity of electric energy delivered and consumed by electrical-equipment of consumer and it is associated with an abstract parameter Q, which indicates the risk of the energy E not to be delivered. Thus, the function of power mode TR is composed of two components:

$$TR = f(E, Q) \,, \qquad (2)$$

where Q describes a set of quality parameters associated with the mode TR and E represents classical model of consumer powering:

$$E = \sum_{j=1}^{n} P_j \cdot \Delta t'_j \text{ and } \Delta t'_j \in T \,, \qquad (3)$$

and n - represents number of managed consumer's electrical-equipments, P_j - power of j'th equipment,

$\Delta t'_j$ - time of work of managed equipment, which works during the researched time T.

The conception of power modes model do not reduce the value of electricity consumption. It is just reorganizes the conditions of energy consumption into some defined quality sets Q_n:

$$E = E(TR) = E(TR_1) + E(TR_2) + \ldots + E(TR_n), \quad (4)$$

and

$$Q_1 \neq Q_2 \neq \ldots \neq Q_n. \quad (5)$$

This conception is graphically presented at fig. 1.

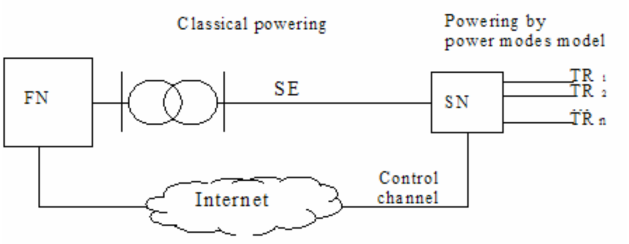

Fig. 1. Graphical presentation of power modes model conception; SE – distribution grid of power system; SN – son node (a consumer localization); FN – father node (a distributor localization); TR1…TRn – powering grid reorganized according to power modes model [5].

B. Function of Power Modes

For better understanding of the power modes model we introduce some basis functions for first $n = 3$ of TR and we set default names of them.

Please imagine that the standard of powering being offered for the consumers now includes some risk r_s of energy deficit[1] and the consumers pay for it some price x_s. Lets name this situation as "*standard mode*" TR_s. The mode TR_s represents typical condition Q_s of electricity consuming, e.g. lack of energy risk r_s, price of energy x_s; which are accessible for the consumers now.

Lets imagine that there are some consumers who are interest in increasing the electricity stability, for all or for a part of their electric equipment park. This consumers will pay even more for the consumed energy x_p (extra price) than in standard mode:

$$x_p > x_s, \quad (6)$$

[1] There is no doubt what is the energy deficit from, just imagine one day with lack of electricity [9]

just for decreasing of energy deficit risk.

It is sensitive that the consumers parts their electric equipment park for groups. For one group the consumers are interest in decreasing the lack of electricity risk and for the other – they aren't.

Now imagine that the consumers have a choice what price x_s or x_p they will pay for the energy consumed by one of their equipments – just by choosing one of power modes: standard mode TR_s or lets name it "protect mode" TR_p. The equipments powered in the TR_p mode have low risk of energy deficit:

$$r_p << r_s, \quad (7)$$

but the price x_p is higher than in TR_s mode (6), so the consumers will select which of the equipments are very sensitive for them and which of the functions realized by this equipment are so important for them that they decide to pay more in protect mode that in TR_s mode. But they are sure that the equipment powered in TR_p mode will work with no problems.

For last part of the equipments, which do not play so important functions for their owners, the owners would choose the TR_s mode. If some lack of electricity situation will occurs, that is no problem, the equipments powered in TR_s mode will stop their work and start again if the electricity backs.

Lets introduce one more power mode – named "*economical power mode*" TR_e. The equipments powered in TR_e mode consume very chip energy, but the risk r_e of lack of electricity in this mode is quite high:

$$r_e >> r_s. \quad (8)$$

The risk (8) is a consequence of economical construction of TR_e mode. The electricity is distributed to the consumers' equipments powered in this mode only if there is enough of energy in the power system (SE), e.g. at the time of valley-load, or if there is power overcapacity in the SE grid as effect of some abnormal demand decrease – a big consumer have to reduce his electricity consumption because of some breakdown. At the other time of a day (e.g. peak load) this mode is turned off.

At the TR_e mode we could look from a different side. An electricity distributor offers some part of his supply power in the TR_e mode, for lower price x_e than in TR_s mode:

$$x_e < x_s . \quad (9)$$

The distributor sets one condition in a tariff contract, that he may turn off the TR_e mode any time at a day he wants, but e.g. not more than twice and not for longer than for 2-3 hours each time. What this construction gives for the distributor? He could segments his clients onto some profile groups [10] and by managing of the TR_e mode on/off between groups he could control the power deficit. The demand side of equation (1) is a function of the electricity price [11] so, by dispersion of quality parameters Q of power modes, the energy supplier could realizes the demand side response methods [12] for the equation (1) balancing. The power modes model should also increase the competitions of the producers and distributors of the energy, what is important especially in free energy market economy [13, 14].

What this construction gives for consumers? This consumers who decide to power their electrical equipments (or a part of them) in the TR_e mode will do it cost-effective (9), but with higher risk r_e than in the TR_s mode (8). But the risk x_e should not be a problem, because that the consumers decide which of their equipments work in the TR_e mode. So they ought to choose this equipments which are not lack of electricity sensitive, e.g. storage heaters, pumps of fields/gardens irrigation etc. There is no mater when this stuffs do their work, it is just important that the work is done.

III. Intelligent Metering and Control System

The processed research of state of art of metering and control systems offered by the producers shows that there is no dedicated system for the power modes model implementation. So, there was necessity for develop such a system ourselves. The invention in its embodiment is presented at a diagram figure (see, fig. 2), in schematic view of the key elements.

The system for measurement and control of electrical energy consumption [2, 3] has n separated tracks TR_1, TR_2, TR_3, …, TR_n, preferably three tracks, which are connected with powering line L1 through controllable current relays P_1, P_2, P_3, … P_n, which are controlled by microprocessor-based data collection and processing system 3. The microprocessor-based data collection and processing system 3 has a feedback channel 4, which is the communication channel to exchange data with an external operator through the IP protocol. The microprocessor-based data collection and processing system 3 is connected to the electronic systems LE_1, LE_2, LE_3, … LE_n for measuring the consumption of electrical energy at each track TR_1, TR_2, TR_3, …, TR_n individually. The microprocessor system of control and data records has an LCD screen 6 to display actual information of the system for measurement and control of electrical energy consumption status and has a set of buttons 7 for interacting with user by displaying context menu on the LCD screen 6. The supply of power to the tracks TR_1, TR_2, TR_3, …, TR_n is controlled either manually using the buttons PR_1, PR_2, PR_3, … ,PR_n or automatically via the microprocessor-based data collection and processing system 3 by switching on/off the controllable current relays P_1, P_2, P_3, … ,P_n.

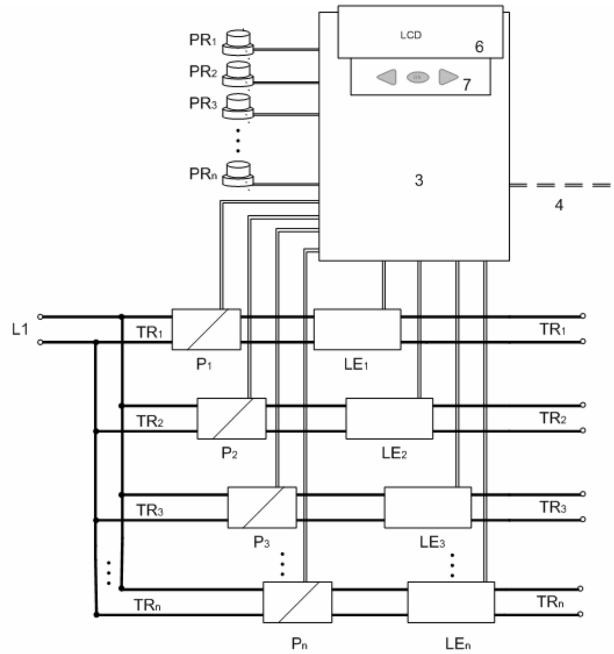

Fig. 2. Schematic view of the key elements of the system for measurement and control of electrical energy consumption [2, 3]

The positive effect of the invention is that the system for measurement and control of electrical energy consumption allows for separation, from a uniform power line on the primary side, to n tracks at the secondary side, preferably three tracks, which are qualitatively different from each other and thus allows for practical implementation of the proposed method of electrical energy supply by the power modes model.

IV. Model of Hierarchical Control System

It is assumed that it is possible to model such a hierarchical control system (HCS) which accurately reflect the physical structure of the controlled object. This assumption is dictated by the fact of participation in a controlled structure many various physical objects (e.g., institutional users, smart buildings, groups of clients, businesses, institutions of higher level of confidentiality, etc.). Where it is necessary to allocate rights of access to the data stored within the HCS repository. It is due to trade secret protection and respect for the freedom of nodes making up the object structure. For example, if the consumption of electricity in a large office building - the parent node, consists of multiple use of sub-nodes – sub-hirers of office space, clients. Then the information about structure of electric energy consumption within the office building is denied to the supplier. Of course, the value of aggregate consumption of electricity by whole office building is already set up for energy suppliers and it is not a secret.

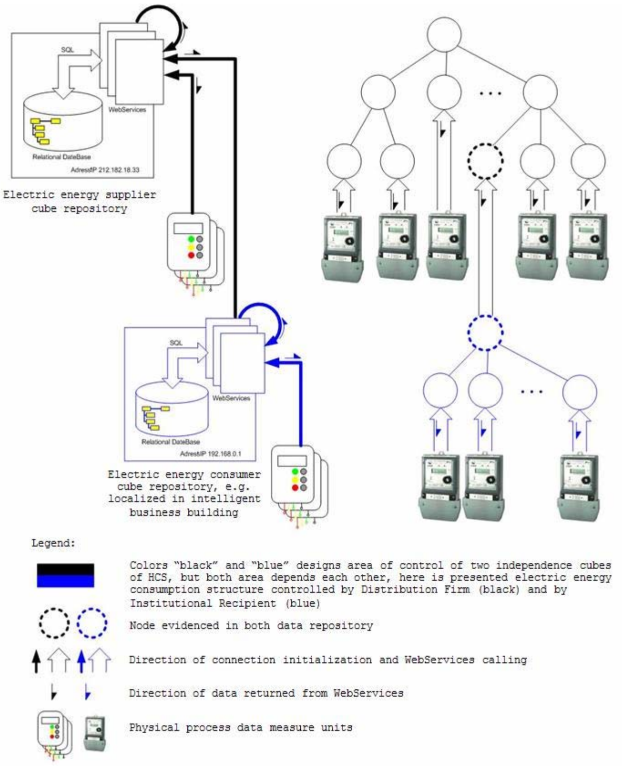

Fig. 3. Hierarchical and distributed structure of controlled object, which is mapped into model of HCS system for object control.

The proposed model of HCS system is based on an independent and fully functional "cube" of the separate data repository [15]. The "cube" by the method of web service offers the necessary functionality that allows it to "behave" as both a parent node of the hierarchy, as well as child node. The possibility of operation of such "cubes" of HCS in different – geographically dispersed – locations, results from the way of communication between "cubes" of the system. There is a relation between slave node and parent node by calling web service methods (see, fig. 3). The competition of the proposed HCS model is fact that the claimed intelligence system of energy consumption metering and control has implemented web *post* and *get* methods, and in this way it is ready for WebServices methods of the HCS system.

V. Summary

The proposed model allows for introduction of power priorities for consumer's electrical-equipments by the importance of their functions. The relevance of the functions carried out by the data device is evaluated by each consumer individually. The relevance of functions and priorities assigned to power mode / groups of electrical equipments can be changed over time. The introduction of changes in the object model simplifies the task of control facility and takes into account the dynamics of the electric energy stability problem under control.

Reference [16] presents the results of researches of ability and effectiveness of power modes manage in the households consumers group in the context of electric energy stability.

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References

[1] F. Janicek, P. Simunek, S. Fecko, J. Breza, A. Hanzel, *Electrical power system sustainability through Demand Side Management and technology foresight.* 19th World Energy Congress, Sydney, Australia 2004, p. 3-15.

[2] D. Bober, *System for measurement and control of electrical energy consumption*. Application number P 384716, Polish Patent Office, date of receipt 17.03.2008.

[3] D. Bober, *System for measurement and control of electrical energy consumption*. Application number EP09461503.6, European Patent Office, date of receipt 17.03.2009.

[4] D. Bober, *Electric energy consumption control in the situations of power deficit*. Energy Market, Thematic Issue, No I(III) Feb. 2009, p. 47-54, (in Polish)

[5] D. Bober*, The electric energy customer powering by power modes*. Energy Market, No 1(74) Feb. 2008, p. 27-32, (in Polish).

[6] D. Bober, *The influence of bidirectional data interchange on the curve of electric energy demand smoothing*. Energy Market, No 2(69), Apr. 2007, p. 19-25, (in Polish).

[7] E. Sroczan, *Modern technical equipment of single-family house*. *Electrical installations*. State agricultural and forest publisher, Poznan 2004, (in Polish)

[8] E. Sroczan, *Application of IT system to optimize the cost of the electricity supply*. Energy Market, no 1(74) Feb. 2008, p. 18-22, (in Polish)

[9] A. Gabrysiak, *One day with lack of electricity*. Around the power, Termedia, April 2005.

[10] G. Matejko*, Improving the segmentation of electric energy consumers*. PhD dissertation. Lublin University of Technology, 2007, (in Polish)

[11] H. Kapron, *Financial profits of a monopolistic energy supplier in a local energy market*. Energy Market, No 3(46), Mar. 2003, p. 31-33, (in Polish).

[12] S. Borenstein, M. Jaske, A. Rosenfeld, *Dynamic pricing, advanced metering and demand response in electricity markets*. Berkeley University: http://www.ucei.berkeley.edu/PDF/csemwp105.pdf, October 2002.

[13] H. Kapron, Theory of competitions of energy distribution companies, Energy Market, No 1(26), Jan. 2000, p. 2-8, (in Polish).

[14] H. Kapron, *Energy market, producers' competition*, Energy Market, No 6(73), Jun. 2007, p. 13-16, (in Polish).

[15] D. Bober, *The hierarchical system of distributed objects works control*. Annales Informatica, UMCS, Lublin 2009, in press.

[16] D. Bober, *The hierarchical system of the electric energy consumption control*, PHD dissertation, Lublin University of Technology 2008, (in Polish).