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INTELLECTUAL REACTIVE POWER AND VOLTAGE CONTROL

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Abstract- In today's world intellectual control will play more and more actual role in energy-efficiency improvement, demand reduction, and better overall asset utilization. Such control can be effectively realized by wide application of Smart Grid technologies and devices. In this paper the analysis of Smart Grid concept is presented and the requirements of intellectual reactive power and voltage control, and also the main principles of its mathematical realization on the basis of artificial intelligence methods are considered.

Keywords: Intellectual Control, Reactive Power, Voltage, Smart Grid, Electric Networks, Neural Networks, Genetic Algorithm.

I. INTRODUCTION

At present, Russia is one of the most power-intensive countries. Specific power consumption of economy is practically three times above than in the Western Europe, twice above than in the USA and six times above than in Japan. Out-of-date equipment, irrational construction of the electric networks, low level of reactive power and voltage control, insufficient level of automation, low level of energy management and absence of real economic stimulus are far not the full list of factors which reduces the power efficiency of the enterprise.

However, recently it is developed as a positive trend in the task of improving energy-efficiency [1]. Under the new Energy Strategy of Russia until 2030, the Federal Law No. 261-F3 "On Energy Conservation and Improving Energy Efficiency and on Amendments to Certain Legislative Acts of Russian Federation" from 23.11.2009, the concept of long-term socio-economic development of Russian Federation for the period up to 2020 in the priority of science, technology and energy policy of the state is increasing energy-efficiency and making conditions for the development of the country's energy-saving technologies. Among prime measures in the field of maintenance of safety, reliability and efficiency of power objects necessity of innovative decisions, in particular Smart Grid has been designated.

II. SMART GRID CONCEPT

At present the problem of intellectual networks development takes a special place. In power companies of the USA and Western Europe the projects with Smart Grid elements are applied. Similar pilot projects are carried out in Russia though while this direction has not received a wide attention [2]. Irrespective of their location the large companies working in electric power industry often address to idea of Smart Grid as the technologies capable to raise the efficiency of power distribution. In the world there is a process of accumulation the information, formation of main principles of intellectual technological decisions.

For the first time the term Smart Grid has met in paper in 1998 [3]. In the paper name this term has been used for the first time by S. Massoud Amin and Bruce F. Wollenberg in their paper [4]. The first applications of this term have been connected with purely advertising names of the special controllers intended for operating mode control and synchronisation of the independent wind generators with the electric network. Then it began to be applied to a designation of microprocessor meters of the electric power capable independently to accumulate, process, estimate the information and to pass it by special communication channels and even through the Internet. Though such controllers and microprocessor meters have been developed and issued by various firms even before occurrence of the term Smart Grid. This term has arisen much later and at the beginning was used only in these areas. Only some years later its application has been extended to the systems of information gathering and processing, equipment monitoring in electric power engineering [3].

The only and standard interpretation of this term does not exist yet. In various publications Smart Grid are treated a little differently considering all the directions of the term application. So, according to European technological platform Smart Grid is «the electric networks meeting requirements of energy-efficient and economic functioning of power supply system by coordinated control and by modern bilateral communications between elements of electric networks, power plants, accumulators and consumers» [5]. The general functional-technological ideology of this concept, most full reflects the definition formulated by IEEE - Smart Grid as concepts of completely integrated, self-regulated and self-restored electric power system having network topology and including all generating sources.

The main both distributive networks and all kinds of consumers of the electric energy, operated by network of the automated online devices [6]; the US Department of Energy describes Smart Grid as «completely automated system providing a bilateral flow of electric energy and the information between different objects everywhere. Smart Grid because of the newest technologies, tools and methods fills electric power industry with the knowledge allowing sharply raising an overall performance of power engineering ...» [7]. NETL defines Smart Grid as a set of the organizational changes, new models, decisions in the field of information technologies and automation etc [6].

For the best representation of Smart Grid concept the comparative table of the modern electric network with so-called intellectual network is shown in Table 1.

Table 1. The comparison of the modern and intellectual networks

	Modern network	Intellectual network
Generation	Centralized	Centralized and distributed
System topology	Radial; generally one-way power flow	Network; multiple power flow pathways
Customer interaction	Limited	Extensive
Communications	None or one-way; typically not real-time	Two-way, real-time
Metering	Electromechanical	Digital (enabling real-time pricing and net metering)
Operation	Manual equipment checks, maintenance	Remote monitoring, predictive, time-based maintenance
Restoration following disturbance	Manual	Self-healing

It is expected that in the future generating sources will be more distributed, than concentrated as now. It is made by development of renewable energy sources, first of all such as wind generators, solar systems, the generators working on biofuel etc. The prominent feature of such sources is their rather small capacity and instability of parameters. It is obvious, that for parameters stabilization of such sources and their automatic synchronization with a network «intellectual device» is necessary.

The traditional electric network has treelike structure (Figure 1): electric energy is passed from the centralized generating sources by the main and radial lines to consumers. In most cases modern electric networks consist of radial lines with a unilateral energy flow. Only in some cases electric networks are girdled. According to Smart Grid concept the future network will not have any more treelike structure. The future network will have the interconnected structure with the set of connection points (Figure 2) where the consumer of electric energy can be also a generator. The power flows on such network will not be strictly determined. It is obvious, that such difficult nonstructured network should have the powerful operating system coordinating all network components. For this purpose all network components should «communicate» with each other and with operating centre by special communication channels.

The intellectual network development will allow raising reliability of consumers' supply, to reduce electric power losses and power resources cost, to lower costs for transmission lines and substations construction, to create conditions for wide application of renewable energy sources. Besides, the intellectual network will promote the resources economy, reduction of harmful emissions to atmosphere and to decrease negative climate influence.

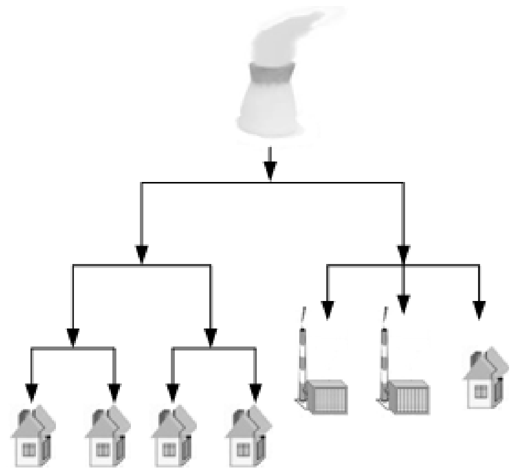

Figure 1. Tree like structure of modern electric network

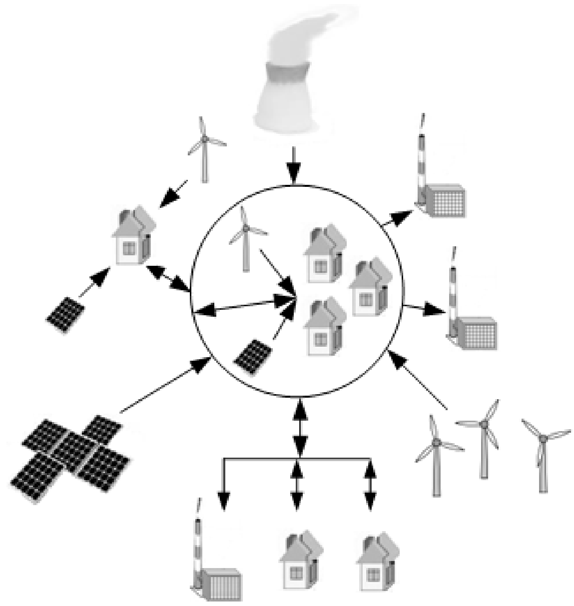

Figure 2. The interconnected structure of intellectual network

As directions of Smart Grid basically following three key parts are considered: metering systems; distribution automation; control and management systems [8]. Let's consider them in more details.

- *Advanced Metering Systems (AMS)*: Basically this part concern microprocessor electric power meters. Almost all Smart Grid projects begin with so-called Smart Metering.
- *Distribution Automation (DA)*: Speaking about Smart Grid concept, it is a question first of all of power distribution. The distances of such networks, number of consumers connected to them etc. It includes the actual power equipment, such as switches, capacitor banks, breakers etc.
- *Distribution Management Systems (DMS)*: Data management refers to all aspects of collecting, analyzing, storing, and providing data to users and applications. Application requirements are becoming more sophisticated to solve increasingly complex problems, are demanding ever more accurate and timely data, and must deliver results more quickly and accurately.

III. INTELLECTUAL REACTIVE POWER AND VOLTAGE CONTROL

At present with the application of Smart Grid technologies the problem of reactive power and voltage control has obtained new meaning. This problem traditionally is carried out by fixed and switched capacitor banks, substation transformers with load tap changers operated by independent controllers. The controller use local measurements of voltage and current to determine the appropriate control actions for the associated device. Thus voltage and reactive power control is carried out independently from each other.

Intellectual reactive power and voltage control gathers the information about the electric parameters at any point of distribution system. All information about these parameters are delivered to the special program complex which is software designed to determine the optimum set of control actions to achieve optimal required conditions. Figure 3 shows the basic principles of considered intellectual voltage and reactive power control.

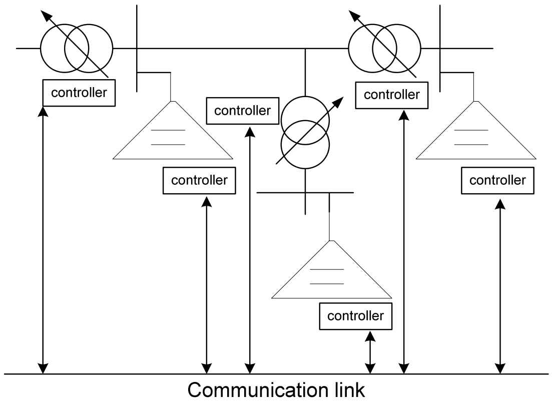

Figure 3. Intellectual reactive power and voltage control

Intellectual reactive power and voltage control defines the best set of control actions for all devices regulating reactive power and voltage to provide the following objectives:
- to minimize electric power losses;
- to improve electric power quality (voltage level);
- weighted combination of the above.

It is also possible to minimize the number of operations for specified load tap changers, regulators or capacitor banks. So, it is possible to formulate the basic requirements for intellectual reactive power and voltage control [9]:
- to provide the optimal voltage level at all points of distribution system under any loading conditions;
- to provide the optimal power factor to minimize electric power losses under any loading conditions;
- to combine reactive power control and voltage control to provide coordinated optimal control actions;
- to provide self monitoring because it is able to report to the distribution system operator when equipment failure is detected;
- to provide the distribution system operator to override the standard control actions if necessary, for example at system failures;
- to adapt automatically to power distribution system reconfiguration.
- to properly apply Smart Grid devices (metering systems, distributed generation etc.) as a part of the reactive power and voltage control.

IV. INTELLECTUAL METHODS

So, as it has been specified above, for optimal control in electric networks with Smart Grid elements it is effectively to apply a special program complex or decision-making support system. In this article the intellectual approach for such reactive power and voltage control is considered.

The mathematical formulation of the problem is the following:

Objective function: $F(Q_k) = C_{Q_k} + C_{\Delta P} \rightarrow \min$ (1)

Subject to inequality constraints

Capacitor banks limits: $Q_{k\_\min} \le Q_k \le Q_{k\_\max}$ (2)

Bus voltages limits: $U_{\min} \le U \le U_{\max}$ (3)

The components of the objective function

$$C_{Q_k} = EKQ_k \quad (4)$$

$$C_{\Delta P} = C\left(\begin{array}{l} \dfrac{(Q-Q_k^2)}{U_f^2} R_{line}\tau_{\max} + \\ +\Delta P_{fe} 8760 + \Delta P_{cop} \dfrac{(Q-Q_k^2)}{S^2}\tau_{\max} \end{array}\right) \quad (5)$$

where Q_k is capacitor banks reactive power; E is norm of discount; C is cost of the active power losses; τ_{max} is number of maximum losses hours; K is cost of high-voltage capacitor banks; Q is reactive power loading of the substation; R_{line} is active resistance of transmission lines; U_f is voltage on feeding substation; ΔP_{cop} is copper losses of transformer; ΔP_{fe} is iron core losses of transformer and S is transformer rated power.

The voltage is defined as follows:

$$U = \frac{U_f - \dfrac{(Q-Q_k)(X_{line}+X_{tr})}{U_f}}{\left(1+\dfrac{nD}{100}\right)K_{tr}} \quad (6)$$

where X_{line}, X_{tr} are reactive resistance of transmission lines and the transformer; K_{tr} is rated tap setting; D is magnitude of the additional voltage per tap step and n is actual tap setting.

For the problem decision, it is proposed to apply the methods of artificial intelligence: genetic algorithms (for optimal reactive power of capacitor banks) and artificial neural networks (for regulation reactive power and voltage level according to a daily substation loading). In this paper the neural network is employed to regulate the reactive power of capacitor bank and voltage depending on substation loading. Artificial neural network used in this paper includes three layers: the input layer, the output layer and one hidden layer. The neurons in the input layer receive the initial information - value of substation reactive power loading. The neurons in the output layer give out the resultant value of capacitor bank reactive power and tap setting.

For training data set and also as the algorithm for minimization of the training error the genetic algorithm is applied. The application of the genetic algorithm is caused mainly by the discrete character of variables (regulation step of capacitor bank and tap setting of the transformer tap changer). The optimal structure of the neural network for all cases is multilayer perceptron. After the neural network has been trained and checked up, it can be applied to reactive power and voltage control.

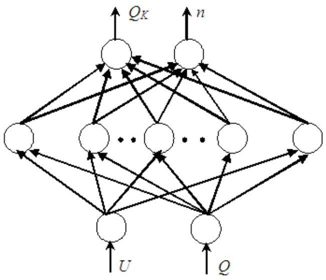

Figure 4. The structure of artificial neural network

The basic feature of this approach consists on its sufficient simplicity and efficiency. The artificial neural networks are universal and effective means for the different control problems. The application of the genetic algorithm for optimization problem and also for neural networks training is based on discrete character of the optimized variables. The combined use of such methods of the artificial intelligence allows solving the reactive power and voltage control problem with higher level of its reliability and quality [10].

V. CONCLUSIONS

At present, in many countries more attention is paid to the intellectual technologies. As the example of such approach it is possible to define the intellectual reactive power and voltage control. The main purpose of the reactive power and voltage control problem is to increase the electric network effectiveness. It allows to reduce the electric power losses, substation loading and to improve the electric power quality. So intellectual control will play an essential role in the electric utility of Smart Grid.

In this paper the main principles of such control is considered on the basis of the Smart devices and parallel application of artificial intelligence methods: neural network and genetic algorithm. So the combined use of artificial intelligence methods and Smart Grid technologies allows solving the reactive power and voltage control problem with higher level of its reliability and quality. This paper has review nature and considers general approach and models to solve the reactive power and voltage control problem more effectively. In the future the testing of these models is supposed.

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