

# A Methodological Approach to the Assessment of the Impact of Digital Technologies Development in Energy Industry on Electricity Price and Demand in a Region

Elena Galperova<sup>1\*</sup>, and Vasilij Galperov<sup>2</sup>

<sup>1</sup> ESI SB RAS, Department of Energy Security, 664033 130, Lermontov Str., Irkutsk, Russia

<sup>2</sup> ESI SB RAS, Department of Systems of Artificial Intelligence in Energy, 664033 130, Lermontov Str., Irkutsk, Russia

**Abstract.** The relevance of this study is due to the importance of assessing the prospective dynamics and structure of demand for energy carriers when developing and making strategic decisions in the field of energy and economic security of the country and its regions. The advance of digital technology redefines the properties of electric power supply systems, erases the boundary between electric power producers and consumers, and impacts the formation of electricity price and demand in the region. This study presents a method of electricity costing in the regional power system, which serves as an integral part of the approach to assessing the impact of intelligent systems development on the demand for electricity in the region. The approach is unique in that it simulates the behavior of electricity consumers and producers of various types as they pursue their own interests and assesses the impact of this behavior on the demand and price of electricity in the regional power system. Determining the cost of electricity in the system is based on the consistent alignment of the required amount of electricity consumption with the capabilities of producers seeking to achieve their best economic performance. Each producer is described as an optimization model, which is a standalone agent in a multi-agent power system model.

**Keywords.** Digital technology, smart grids, active consumer, optimization, agent-based approach, power demand, price.

## 1 Introduction

Studying and projecting the prospective dynamics of volumes and changes in the structure with respect to demand for fuel and energy resources (FER) is one of the most important tasks when developing and making strategic-level decisions in the area of energy and economic security of the country and its regions and the policy aimed at improving the quality of life. Furthermore, one should have an overall idea of the dynamics and structure of the demand for energy carriers when developing directions for efficient development of the energy sector of the country and its regions, ensuring reliability of energy supply to the individual geographical areas, and developing long-term programs of activities of energy companies, etc.

Difficulties in studying and projecting energy demand are due to the multiplicity and interplay of factors determining the levels and structure of demand for FER, along with their high variability and change over time. Attempts to overcome these difficulties have led to the development of quite a large number of approaches, methods and models for projecting estimates of demand for fuel and energy both in our country and abroad. These are heuristic methods (expert judgment, brainstorming, the Delphi method, etc.) based on the knowledge and experience of professionals active in this

field (see, e.g., [1, 2]), extrapolation methods, methods based on long-term trends and patterns in changes in energy consumption and basic macroeconomic indicators of development of different countries (see, e.g., [3-6]), and building of a variety of models (simulation, optimization, and input-output models) (see, for example, [7-10]). Such models are used both for solving standalone problems of projecting demand for fuel and energy resources and for serving as a part of model systems employed to determine directions of energy industry development [11-14].

Despite the availability of a significant number of the methods developed, they fail to account for, or do not take into account to the extent feasible, the changing conditions governing the shaping of prospective demand for energy carriers, in particular, the drastic development and widespread adoption of digital technologies. The emergence of active consumers capable of managing their own energy consumption as well as electricity storage and production increases the importance of projection studies that deal with demand dynamics at the regional level when determining the total demand at the country level and requires further development of methods of studying and projecting the prospective demand for FER.

\* Corresponding author: [galper@isem.irk.ru](mailto:galper@isem.irk.ru)

## **2 Digital technologies in energy production and consumption**

Digital technologies contribute to the emergence of new properties of energy supply systems. The key ones are: 1) smart demand management; 2) emergence of small distributed electricity resources, including those based on renewable energy sources; 3) adoption of smart charging for electric vehicles.

### **2.1. Demand response**

This is an arrangement that allows electricity consumers to respond to the system parameters to ensure reliable power supply at minimal cost. Digital metering, control, and communication technologies enable the consumer to continuously monitor the use of energy by their appliances and equipment, transfer this data to the electricity supplier and receive information from them to optimize their own demand in accordance with the supply available in the power system. During the hours when the power supply is limited or the grid is overloaded, connected devices such as smart electric heaters and air conditioners, industrial boilers, and smart home appliances can automatically shut down or operate at a lower load level, and do so without compromising the convenience for the consumer [15-18].

### **2.2 Distributed generation**

The development of small-scale distributed generation helps to reduce power transmission and distribution losses, to respond more flexibly to changes in demand, and in many cases to improve the security of supply. Distributed (small-scale) energy sources include a set of technologies represented by small-scale or even micro-scale installations that allow generating energy near the place of its consumption, such as home solar photovoltaic systems [19-22]. Digital technologies enable consumers to have their own production and/or storage technology and to sell and/or buy electricity from both individual sellers and the power system.

### **2.3 Smart charging**

Smart charging for electric vehicles allows connected electric vehicles to be charged according to price and/or control signals in the power system. For example, they consume power when there is cheap electricity production available, or they stand by when the grid is overloaded. If two-way battery charging is possible, in addition to smart charging, electric vehicles can provide greater system flexibility by selling electricity to a grid operator or making use of it to meet the needs at their own home (Vehicle-to-grid). This two-way energy exchange provides a number of economic, environmental and operational advantages [23-26].

### **2.4 Blockchain**

Given a growing number of heterogeneous devices, owners, and operators in smart power systems, the distributed ledger technology (blockchain) can prove instrumental in solving the problem of their coordination as well as trade automation. A blockchain is a continuous chain of data blocks built in accordance with predefined rules so that each subsequent block is linked to the previous one through the set of records it contains and each block stores all the information in the chain starting from the very first block. All blocks of the network are in strict chronological order and are linked to each other by a cryptographic signature created using complex mathematical algorithms. The block is stored as a "chain" on distributed computers. Any blockchain member can read it or add new data [27-31].

The use of digital technologies in the energy industry contributes to the development of intelligent systems and networks, digitalization of systems of control, metering, and management of energy supply and transforms the network infrastructure into a new cyber-physical platform for flexible and efficient energy supply to various types of consumers. Taking account of the above features in the methods of projecting energy demand will enable us to improve the quality of projections and enhance the validity of prospective options for the energy sector development and strategic decisions in the field of energy and economic security of the country and its regions.

## **3 Proposed approach to estimate the cost of electricity in the region with the diffusion of digital technologies factored in**

This study continues the line of research and further develops the methodological approach to the assessment of the impact of intelligent systems development on the energy demand in the region, the key points of which were covered in [32, 33].

A distinctive feature of the approach is that it simulates the behavior of electricity consumers and producers as they pursue their own interests and assesses the impact of this behavior on the demand and price of electricity in the regional power system.

The key assumptions underpinning the approach are as follows: 1) the regional power system is made up of a centralized power grid with a number of consumers connected to it; 2) the centralized power grid consists of a set of major electricity producers (coal-fired, gas-fired, and nuclear power plants, etc.) with their technical and economic performance indicators (fuel consumption, cost price, etc.); 3) the composition of the power production (the share of individual power plants in the total volume) determines its price level in the grid. Three types of consumers are considered: (1) the stable (passive) consumer who cannot adjust their power consumption due to technological or other constraints, (2) the active consumer who is able to adjust (reduce) their power consumption, (3) the prosumer, who, in addition to being able to manage their demand, possesses

their own sources of electricity production and storage as well as the ability to supply it to the centralized grid.

The algorithm of assessing the influence of consumers' behavior on demand in the regional energy system is described in detail in [33] and it allows iteratively estimating the maximum possible reduction of demand for energy in the power system due to changes in the volumes of energy use by active consumers and prosumers in response to changes in its cost.

Below is described the method of electricity cost formation in the regional system as based on simulation of behavior of the individual producer. The method is based on optimizing the key economic performance indicators of an individual power plant. Depending on the actual situation in the system, the following can serve as optimization criteria: maximum profit, minimum cost price, maximum production volume, etc.

Determining the cost of electricity in the system is about the consistent alignment of the required amount of electricity consumption with the capabilities of producers kWh, as (1):

$$\sum_i N_i h_i = \sum_j V_j, kWh, \quad (1)$$

where  $N_i$  – installed capacity of power plant  $i$ , kW;  $h_i$  – the number of hours of utilizing installed capacity of power plant  $i$ , hours;  $V_j$  - demand for electricity by consumer  $j$ , kWh.

Each production facility (power plant) is described as an optimization model, the input data for which are as follows:

- installed capacity of the plant;
- specific capital expenditures;
- the number of hours of the utilization of the installed capacity;
- depreciation rate;
- consumption by auxiliaries of the power plant;
- specific fuel consumption for electricity production;
- fuel cost;
- the ratio of the number of plant personnel per unit of installed capacity;
- the average salary of the personnel.

Each plant can operate in different modes and, accordingly, with different electricity production cost values. Unit cost of electricity production at the condenser-type thermal power plant (CPS), is determined as (2) [34]:

$$C = Z / E (1 - \alpha_{aux}), \text{ rub./kWh} \quad (2)$$

where  $E$  – electricity production, kWh,  $\alpha_{aux}$  – the coefficient of electricity consumption by auxiliaries, %,  $Z$  – total electricity production cost, is determined as (3):

$$Z = P_f (b / Q_i^w) N_y h_y + (1 + k_m) [(n_d + \beta_r) K + n_a N_y F], \text{ rub} \quad (3)$$

where  $P_f$  – the price of 1 ton of the natural fuel, rub/t;  $b$  – specific consumption of the fuel for electricity production, g of fuel in coal equivalent/kWh;  $Q_i^w$  – combustion value of the natural fuel, kcal/kg;  $N_y$  –

installed plant capacity, kW;  $h_y$  – the number of hours of use of the installed capacity, h;  $k_m$  – the coefficient of expenses for miscellaneous needs, usually taken to be 0,2÷0,3 (the greater value is applicable to the CPS of small capacity);  $K$  – capital expenditures of the CPS, rub.,  $n_d$  - weighted average depreciation deductions (in the case of the CPS given the straight line depreciation method adopted for allocating depreciation is taken to be 0.035);  $\beta_r$  – the coefficient that captures the share of costs for repairs as a share of capital expenditures, taken to be 0.04-0.05;  $F$  – the average annual gross payroll per employee (with deductions factored in), rub./person;  $n_a$  – specific headcount, person/kW.

The profit of the power plant  $q$ , is determined as (4):

$$q = ET - Z, \text{ rub} \quad (4)$$

where  $T$  – the weighted average price of electricity in the power grid.

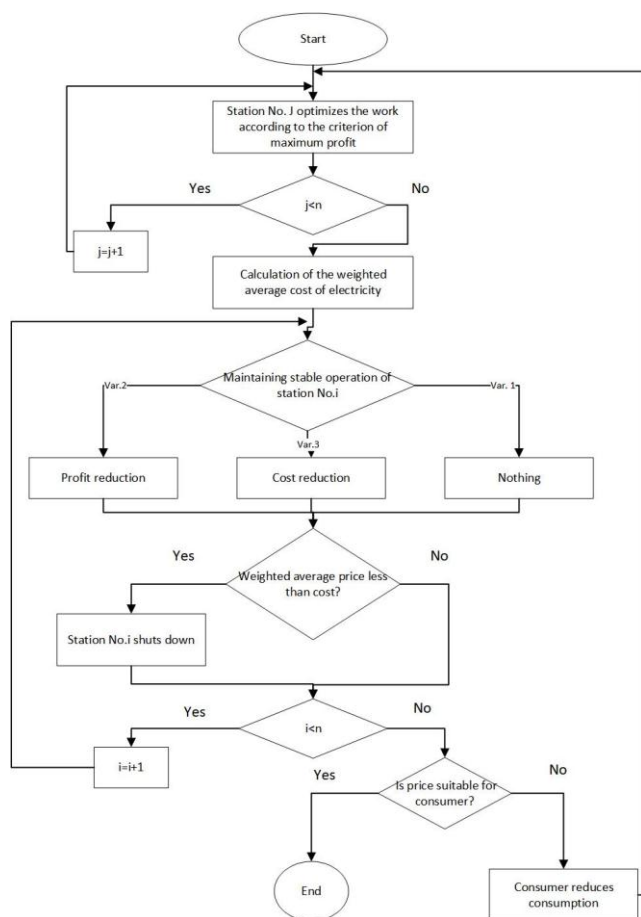
A two-level optimization scheme is provided, i.e. the operation of each power plant and the system as a whole is optimized. Individual power plants can optimize their operation with respect to the criteria they require, while the system is optimized with respect to minimum weighted average cost per 1 kWh.

The maximum cost of electricity in the grid is determined first. For this purpose, all plants optimize their operation with respect to maximum profit. The weighted average cost of electric power is calculated, which is the initial cost for estimating the influence of consumers' behavior on demand (see [33] for more details). If this cost of electricity does not suit active consumers and prosumers, they reduce their electricity consumption and the next stage of calculations is performed given the new demand value. In order to maintain stable operation, plants may reduce profits or reduce costs to maintain profits, some plants may fail to be profitable under certain conditions. Algorithm for formation of electricity price in regional power system is shown on fig.1, and algorithm to study the impact of consumer behavior on electricity demand on fig.2.

An agent-based approach is employed in the system to model forward and backward links of facilities. The model of each power plant is a separate agent that solves its individual problems under the conditions of the power system. The agent-based approach allows to provide any level of detail and abstraction [35, 36].

## 4 Conclusion

The drastically decreased adoption costs and the diffusion of digital technologies through energy production (primarily driven by renewable energy sources), the emergence of intelligent systems in the management of energy facilities, the changing role and place of consumers in power systems all fundamentally alter the organizational and technological structure of the energy industry along with the relationships between producers and consumers of electricity and exert an impact on demand and prices on regional energy markets.



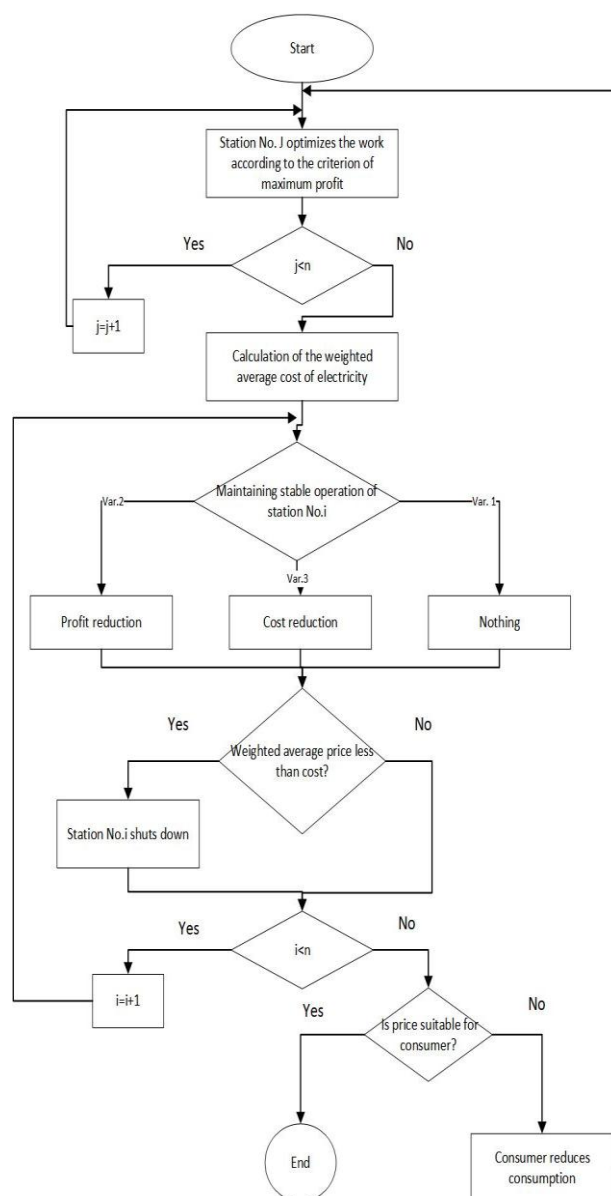
**Fig. 1.** Algorithm for formation of electricity price in regional power system

Taking account of the above new factors and interrelationships in the methods of projecting energy demand will enable us to improve the quality of projections and enhance the validity of prospective options for the energy sector development and strategic decisions in the field of energy and economic security of the country and its regions.

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**Fig. 2.** Algorithm to study the impact of consumer behavior on electricity demand in a regional power system

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