Energy Systems Research: Conceptual and Historical Aspects

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Abstract

General conceptual points and brief historical overview of system ideology are presented. Main objective reasons for generalization and development of the methodology of system studies in energy by L.A. Melentiev are explained. Fundamental principles for an approach to such energy systems research are described. A short example of energy systems research application is discussed.

Keywords: System methodology, system analysis, conceptual aspects, history of system approach, energy systems research, fundamental principles.

1. Introduction

Energy Systems Research, or System Studies in Energy, is a system methodology addressing all the aspects of energy systems (electric, gas, oil, heat, and others), including their sustainable development, reliable and effective operation, smart control and management, integration and interaction in a complex physical, technical, economic and social environment. System methodology is also used for study of complex energy problems. Generally, energy systems research methodology is based on a system approach considering complex energy objects (power, heat, gas, oil, etc., integrated energy systems) as systems with complicated, usually inhomogeneous, structure and external ties. It is important that a system acquires the properties, which are not found in its components. Such a methodology uses the methods and technologies of system analysis as the techniques for solving system problems in energy.

These basic principles of the methodology for energy systems research are intuitively obvious for the experts thoroughly investigating the sophisticated modern energy systems which are the most complex artificial objects humanity has ever created.

Meanwhile, even the Ancient Greek Philosophers had the initial understanding of the system structure of the environment. According to the figurative definition by B.S.Fleishman [1], this was a naïve systemology. In the Middle Ages, in the epoch of physicalism being the philosophy of cognition, the system views of the Ancient Greeks were completely forgotten. An objective reason for the renaissance of the systemology, intensified use and expansion of the system views in various domains of knowledge was complication of technical objects generated by the technical revolution of the 20th century, their stronger interaction and mutual influence, as well as their impact on the environment and human health, and an increasing role of man as a link of control of these complex objects.

A.A. Bogdanov [2] and L. von Bertalanffy [3] made a considerable contribution to the revival and development of the methodology for system studies. The research by R.L. Ackoff [4], W.R. Ashby [5], J.Klir [6], M. Mesarovic [7], I.V. Blauberg and E.G. Yudin [8], V.V. Druzhinin and D.S. Kontorov [9], N.N. Moiseyev [10], B.S. Fleishman [1], to name but a few, shaped modern ideas about the methodology of system studies, and developed the methods and technologies for system analysis. Peak of the research into the development of the system philosophy and methods for system analysis in a general theoretical context and for specific system problems in different areas was observed in the 1960s-1980s. At the same period, the International Institute for Applied System Analysis was founded in Wien, Austria. The goal of the Institute was to conduct system studies on urgent global problems by international groups. In the 1990s-2000s, the intensity of elaboration of general theoretical fundamentals for the system methodology somewhat decreased, however its successful application, adaptation and extension to specific areas of research continued. The latter is objectively conditioned, because at a general theoretical level the methods and approaches are normally very abstract and have to inevitably be specified in terms of concrete applications, which by no means diminishes the methodological and theoretical significance of such a specification.

2. Energy Systems Research: History and Reasons

An important area of application and expansion of the system philosophy is energy represented by an aggregate of interrelated energy systems that constitute energy sector, and integrated energy systems. In the USSR, this trend was associated with the name of G.M. Krzhizhanovsky who headed the State Commission for Electrification of Russia (GOELRO) in the 1920s. In actuality, the electrification plan developed by this Commission was a program for the national economic development based on the electric power industry [11]. To develop the GOELRO plan, G.M. Krzhizhanovsky applied the so called comprehensive method rooted in the system philosophy. In the 1930s, researchers in the USA devised a method for integrated energy resources planning that was also based on the methodology of system approach, and further intensively applied in the energy system expansion planning [12 et al].

In the 1970s, L.A. Melentiev generalized and developed the comprehensive method of G.M. Krzhizhanovsky in the form of a methodology for system studies in energy, or energy systems research [13]. There were several objective reasons that encouraged the development of this methodology. Firstly, in the 1950s-1970s the USSR saw intensive energy development: the unique unified electric power, gas and oil supply systems of the country were established, and the nuclear energy and coal industries were built up. There was a need for a methodology for planning the expansion and control of these complex energy objects. Secondly, this period was characterized by the emergence of rather powerful computers that were used to devise effective mathematical models for modeling, optimization and planning of the expansion and control of complex systems, including energy systems. Thirdly, developing the methodology of system research in energy, L.A. Melentiev actively used general methodological trends in the system philosophy and system analysis for the research into the complex systems and problems.

It is worth noting that the comprehensive method by G.M. Krzhizhanovsky, the methodology of system studies in energy by L.A. Melentiev and the method of integrated energy resources planning largely originated from the plan-based approach to the expansion and operation control of energy systems and energy sector as a whole. In the last decades of the last century, due to restructuring and reforming of energy industries on a market basis, many countries faced the need to revise and develop the system methodology by rationally combining market mechanisms and state regulation in the energy sector. A so-called holistic approach was proposed as an updated method for the integrated energy resource planning [14, 15, et al]. It was also necessary to specify and develop the methodology of system studies in energy, which was related to the need to consider the increased uncertainty of external conditions; a great number of stakeholders involved in the process of expansion planning and control of energy systems, and their different, often contradictory, interests; considerably increased consumer requirements for reliability and resources delivered to consumers [16, et al.], efficiency of energy supply, and quality of energy

3. Fundamental Principles of System Studies in Energy

In today’s interpretation, the methodology of system studies in energy includes the following fundamental principles:

- Studying the nature of the investigated energy systems, including an analysis of factors shaping the main objective trends in the evolution of these systems and extent to which they manifest themselves; and research into the main energy systems properties that are transformed as these systems develop. This principle is of paramount importance since the success of future investigations depends totally on the insight into the essence of the studied object, i.e. an individual energy system or their aggregate within energy sector, or integrated energy system, as well as external conditions for the expansion and operation of the investigated system.
- Developing and updating the models and methods for the research into the energy systems and planning their rational expansion and effective operation. The models of energy systems should be updated and improved regularly to adequately consider changing properties and trends in the development of these systems, to take into account the external conditions for their development and operation, the impact of market mechanisms and state regulation, etc.

The methods for the study of energy systems and planning of their expansion and operation should consider not only the specificity of the models but also the expansion planning conditions, i.e. a great number of criteria and constraints, a contradictory nature of interests of different stakeholders involved in the expansion and operation of energy systems, etc.

- Solving acute expansion and operation problems that face individual and integrated energy systems, and energy sector, including: the development of state concepts, strategies and programs for energy development and investment programs for the development of energy companies; the study of national and regional energy security; the estimation of reliability, survivability and controllability of individual and integrated energy systems; the determination of control actions to ensure the required levels of reliability, survivability and controllability; the investigation on the issues of evolution and operation of interstate energy interconnections and energy markets; and many other important issues.

4. An Example of Energy Systems Research Application

Typical examples of complex energy systems that require the use of a system methodology of research to plan their expansion and control their operating conditions are electric power systems and their interconnections. Current national and international power pools embrace thousands of large-scale power plants, tens of thousands of high and super high voltage transmission lines that deliver electricity to tens of thousands of large-scale supply substations in local territories, cities and companies and other groups of consumers. The examples of such power pools are Unified Energy System of Russia, electric power interconnection of continental Western and Central Europe, power pool of North America and others.

Electric power systems are characterized by such system properties as stability and survivability, the latter is typical of bulk power systems. The components of the power systems however do not have such properties. The fundamental property of electric power system is inhomogeneity of their electrical network structure. Generally, the inhomogeneity of structure is characteristic of any, especially complex, systems. The inhomogeneous structure of electric power systems manifests itself through the presence of weak tie lines connecting strongly coupled subsystems with one another. The weak ties limit power exchange between the subsystems and, consequently, the possibilities of mutual assistance in backup generation for the subsystems in case of emergency. Weak ties are one of the primary causes of stability problems in electric power systems. Therefore, the control actions aimed at providing stability and survivability of a system should be first of all performed in the weak ties. Furthermore, such ties should be considered in measures on power system expansion planning, etc. [17, 18].

It is worthwhile mentioning that innovative technologies and means have a great effect on the structure and properties of electric power systems, particularly the technology of smart grid, which is recognized as a technological platform for electric power industry of the future in most countries. This technology, as the studies prove, can dramatically change the image of the future power industry and properties of electric power systems, including the fundamental property of the electric network structure, i.e. inhomogeneity [19].

Given the principal importance of the inhomogeneity as a property of the electrical network structure, it is obviously necessary to develop the methods to quantify the magnitude and place of manifestation of this property in a certain system. The knowledge of the quantitative indices makes it possible to usefully employ the inhomogeneity of electric network structure in the process of building and simplifying mathematical models of a complex system to plan its expansion [16], analyze its conditions [17,18], study the power system stability and choose control actions to ensure it [17,20]. Thus, we can considerably enhance the efficiency of the applied mathematical models in terms of adequacy of power system modeling, minimization of requirements for computers, etc. This, in turn, enables more effective implementation of rational methods for solving the relevant problems.

The indicated positive effects of improving the efficiency of power system modeling and methods for solving the problems favorably affect the soundness of the obtained estimates and generated recommendations on power systems expansion and control, and the increase in decision maker confidence in them.

5. Conclusion

The sophistication of modern energy systems, their interconnections, and integrated energy systems objectively requires a system methodology to investigate such complex objects, substantiate their expansion and control of operation. New properties to be gained in the course of the energy system expansion and operation determine the need to study and adequately account for them in modeling the systems and adapting the methods of solving relevant systems problems. Considerably increased consumer requirements for reliability of energy supply and quality of delivered energy resources make us search for new innovative means and solutions enabling these requirements to be met. Consequently, the internal trends of the developing energy systems together with the stringent consumer requirements and varying external conditions generate the need to use a system methodology to address complex crucial problems of expansion and operation of energy systems. Moreover, it becomes necessary to constantly develop approaches and technologies for system studies in the field of energy to take account of new factors and conditions.

The long-term experience demonstrates, that the methodology of system studies in the energy sector is a flexible tool for solving complex energy problems, and it is capable to methodically ensure the adaptation of the energy sector to permanently changing external challenges.

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