E3S Web of Conferences **114**, 06001 (2019) https://doi.org/10.1051/e3sconf/201911406001
Energy Systems Research 2019

Systemic aspects of the energy complex based on coal TPP

Natalia Fedorova[1,*]
[1]Platov South-Russian State Polytechnic University (NPI), Prosveshcheniya str. 132, Novocherkassk, Russia

Abstract. The paper is devoted to study of energy-technological complex (ETC) based on coal-powered TPP using methods of system analysis. The concept of the full-cycle ETC is presented. The zonal structure of ETC is considered. The place of ETC in the systematical classification is determined. The interpretation of system-wide principles is investigated applied to the TPP and ETC. The application of system analysis methods allows to predict the directions of ETC development.

1 Introduction

Thermal power plants (TPPs), especially those ones which work on solid fuel, as an industrial facility at the current stage of the society and technology development, cease to meet the requirements of an economic efficiency, an environmental safety and technical feasibility. Full-cycle energy-technological complexes (ETC) should replace the TPP as a producer of electric and thermal energy. Those ETCs should also utilize all by-products of energy production. ETC are complex technical systems. The forecast of the ETC development problems and the directions for solving these problems is possible using the concepts and methods of the theory of systems.

2The concept of an Energy-Technological Complex

The concept of an energy-technological complex should provide for:
1) The operation of a complex gives the solution of the double-purposed task: the energy production (including electric and thermal) and the production of material products (which source is the waste from the preparing process and the energy production itself);
2) As a result of the complex operation all the waste (including the existing and the newly generated waste) should be recycled; the production of the newly generated waste should be as low as possible (in the future there should be no such waste);
3) The complex itself should have a block structure, which allows to change its configuration according to changed working conditions;
4) At the stage of the forming of technical facility of the complex mass produced and certified in Russia equipment should be used;
5) The complex operation should not worsen the ecological equipment in the region;
6) The complex operation should be profitable;
7) che Complex operation should rely on the legislative framework;
8) The strategy of the ETC operation (the strategy includes the choose of resources, products, methods and ways of the recycling, the management of the waste movement) should be optimal; the choose of the strategy should take into account many criteria and it should rely on existing theoretical and practical methods of analysis.

3 The zone structure model of the ETC

The zone structure model of the ETC, which functions in conjunction with the external environment, is shown on the fig. 1. It includes:

- three levels of the ETC operation which include: the information and legislative environment (A), the external material and financial environment (B), the internal material and financial environment (C);
- six zones of the ETC connected with inputs and outputs (I–IV);
- zone inputs and outputs, outgoing material products (MP);
- objects and subjects of the internal material and financial environment (6-11), the external material and financial environment (2-5), the informational and legal environment (1), connected with the ETC via inputs and outputs.

The coal-powered TPP is the central technological part of the energy-industrial complex. Depending on the specific industrial, infrastructural, territorial, climatic and social conditions of the TPP placement, this complex include between 1 and 6 zones (with different features):
I – the thermal-energetic zone (6 – TPP);
II – the industrial separation zone (7 – group of enterprises for the primary preparation of TPP by-products for use and disposal);
III – the industrial recycling zone (8 – group of enterprises for deep processing and utilization of TPP by-products);
IV – the analysis zone (9 – laboratory);
V – the service zone (10 – intermediary, coordinator);
VI – the transport and logistics zone (11 – transport and logistics enterprise).

* fedorovanv61@rambler.ru

These zones form the internal material-financial environment (C) of the TPP operation. Any of these zones can be placed in the external material-financial environment (B), except the TPP itself as a coal consumer and a producer of main products (electric and thermal energy) and by-products (including ash and slag materials (ASM)). The TPP owner (the managing company (2)), coal and material resources suppliers (3) and consumers (4) of material products (produced in the ASM separation and recycling process) are placed in this external environment, as well as objects of the natural environment (5), natural resources involved in the technological process.

Every enterprise operates in the legislative equipment (information and legal environment A). State authorities and organizations (1) are responsible for this equipment.

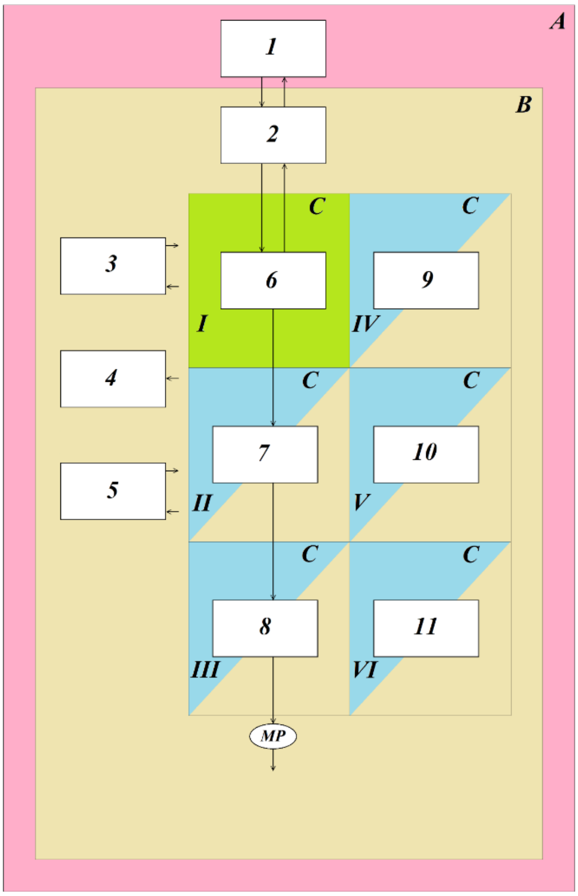

Fig. 1. Scheme of the full-cycle energy technological complex on the basis of (coal) TPP (zonal): A – informational and legal environment; B – external material and financial environment; C – internal material and financial environment; I-VI – ETC zones; 1-11 – objects and subjects involved in the production process; MP – material product.

The TPP owner (or the decision maker (DM)) makes decisions on the complex making up and the choose of specific separation schemes and ways to utilize ASM. This subject carries out actions on the implementation of chosen schemes and ways. So, it takes extra powers and becomes the owner of the energy-industrial complex. According to the information coming from the energy-industrial complex and the legislative environment, the owner is able to make management decisions up to changing the separation scheme and the structure of the energy-industrial complex.

When proper conditions exist, the complete package of the complex on the fig. 1 is the most rational from the technological, economical and ecological point of view. The presence of the analysis zone allows one to take samples of the coal, ASM and separation and final products, to carry out the physical research and chemical analysis of samples and promptly make decisions on adjusting the conditions of technological processes, up to adjusting the ASM separation and disposal scheme. The ASM separation company, including other solid materials which are present or being produced in the TPP technological cycle, allows to obtain enriched concentrates with increased fraction of various components (the so-called industrial product). That is the first stage of the ASM transformation.

The company producing ASM-containing products produces final commercial products using enriched concentrates, which are produced from ASM, and the separation waste. At the same time, deep processing of concentrates is carried out, taking into account the requirements of consumers to the quality and commercial forms of the final product. That is the second stage (level) of the ASM transformation. ASM and other TPP materials are separated and deeply recycled for the use in final material products. Both final material products, concentrates (industrial products) and the non-recycled ash and slag could be the commercial product for other companies.

The transport and logistics zone allows one to enhance the mobility of the technological cycle and to decrease transportation and storing financial expenses across all the resources and products. The agent (coordinator) manages material flows, harmonizes legal and financial issues between producers and consumers of resources and products. Foreign experience shows the efficiency of the complex for the implementation and recycling of the main and by-products of separation and processing of ash and slag materials, uniting the intermediary, laboratory and transport and logistics company into a single production facility.

Regardless of tasks and the structure of the energy-industrial complex, it functions in the state information and legal environment. Laws, standards, methods of work are determined at the level of state institutions. However, in the process of work, it may be necessary to change the informational legal environment, to adjust standards, to refine or change methods in connection with the development of technologies, to improve laws and to adjust them in accordance with the realities of life. Thus, there is a feedback, a request from the external material and financial environment, in particular, from the owner of the TPP, for lawmaking, for the modernization of the information and legal environment. According to the information on the energy industrial complex activities the state bodies and services control the legality of his activities from a legal and financial standpoint, environmental safety, and also monitor the need for adjustment of laws.

The scheme (on the fig. 1) show different levels of influences on the technological process.

The zone modelling of the ETC allows: to change the ETC configuration to take out some functions to external material and financial environment or, vice versa, to include them into the internal material and financial environment; to localize the zone that caused the trouble and that needs priority changes more than others, if any trouble in the ETC operation happens; to change the internal configuration of each zone independently without changing other zones, so that inputs and outputs are the same; to determine zones that need the modernization, if inputs or outputs are changed; to control and adjust ETC operational problems at the level of inputs and outputs connecting the internal and external material and financial environment.

The ETC is a system, the research of which using system analysis methods allows one to determine ways of the ETC development based on system-wide rules and principles, to localize possible problems and to predict solutions of these problems.

4 The place of the ETC in the system classification

From the system theory point of view, ETC as an object is a:
1) Complicated system [1] that consists of a lot of interacting parts (subsystems), so the complicated system gains extra features, that doesn't exist on the subsystem level and that can't be reduces to properties of subsystem level, i.e. properties and functions of individual blocks;
2) Open system [2] that exists in the interaction with the external material-financial and information-legislative environment; it gets input material and non-material flows from external environments, generates and produces material and non-material flows to external environments;
3) Dynamic system [3] influenced by economical, legislative, technical and technological, ecological, social, organizational, risky and other factors, which changes its state under its influence;
4) Technical system [4]: an artificial system which is intended to meet the people needs in the electric and thermal energy;
5) Organized system [5]: a material and energetic system existing as a system on account of the use of technical, legislative, financial and other information.

5 The operation and development of ETC in light of system-wide principles

1) Mono-centrism principle [6]. A sustainable system «described as having one center; if it is complex or chained, then it has one top, uniform center». In the case of poly-centrical systems, their coordination processes disfunction, they are disorganized, destabilized and so on. If we consider the ETC as an object inscribed in external environments, then undoubtedly the guarantor of the sustainable state is the adequate state and the impact from the information and legal environment, the primary state and international laws. If, on the other hand, the ETC is not considered to be connected with external environments, then the decision maker is such center, the subject that assumes all responsibility for choosing a modernization strategy and ansuring the implementation of this strategy For that subject the profit maximizing with the expenses cut has the highest priority, within the law if possible But this approach could be non-compatible with ecological requirements or could cause material losses in the future. There is a contradiction: a biological subject with its set of qualities is the guarantor of the stability of a complex technical system inscribed in the material, financial, information and legal environment. Therefore, it is important to DM to be widely informed about the consequences of made decisions. Also, is important to decrease the influence of subjectivity in decision making.
2) Organizational continuity principle [6]. On the one hand, «between each two complexes in the universe, with the proper research, intermediate links are introduced, which make them single chain of ingression», so we can consider that with the operative purposeful regulation, the ETC tasks and problems can be solved. On the other hand, according to that principle each possible system is fundamentally disconnected relative to its internal composition and open to element-wise and complex modification. Solving the problems of choosing a modernization strategy [7-8] of TPP subsystems and the ETC as a whole indicates the direction of such a modification. The detailed strategy in the IDEF0 format [9-10] reveals the mechanism of modification [11-15].
3) Limiting factor principle [16]. «Total sustainability of the system is determined by its least sustainable part». In present coal-powered energy production the accumulation of negative impact of TPP on the environment is that part. Three problems exist that interfere the maintenance of a sustainable state and the development of coal-fired TPPs: the need of burning of deteriorated coal, the accumulation of ash and slag dumps, the wear and tear of equipment. If we don't solve these problems, environmental state in the region of TPP would worsen. The plant wouldn't be able to operatively provide customers with the electric and thermal energy with existing quality metrics, there would be problems with increasing the energetic power.
4) Ontology continuity principle [17]. A system represents the state and the dynamics of the environment. At the same time, «the system change is simultaneously the change of its environment, and the change causes could be in system changes or changes of its environment». So, present problems of energy production (such as burning a poor-quality coal, the accumulation of waste in ash and slag dumps, the wear and tear of equipment) are the consequence of operational problems in the present society, ExtILE imperfection and poor maneuverability of ExtMFE. But if we do not make efforts to solve energy problems, this can affect the external environment, negative ecological and social consequences will accumulate and go into irreversible form, which can cause a crisis (catastrophe).
5) Necessary variety principle [18]. The ETC configuration should be complex enough for the optimal solution of relied problems. At the same time, if individual

problems could be effectively solved at specialized companies (such as sorting and recycling of ASM), they should be taken out to the ExtMFE. Made decision on the configuration of the ETC should be substantiated by system and optimization studies.

6) Feedback principle [18]. In complicated dynamic systems the sustainability is achieved by making feedback loops. For the sustainable development of the energetic-technological complex (ETC) the following requests from the internal material and financial environment (IntMFE) are needed: to the external material and financial environment (ExtMFE) on material and financial flows and the feedback in the form of emitting those flows in the amount that is needed for the ETC operation (taking into account environmental changes); to the external information and legal environment (ExtILE) on getting the required information about recent achievements in technics and technologies, market requests, social requests, ecological problems and so on, on adjusting the organizational and financial legislation and the feedback in the form of providing the required information and changing laws.

7) Compatibility principle [19]. It is stated that «the presence of the relative compatibility property of objects and the qualitative and organizational uniform is the condition of interacting between them». There are approaches to solving the tasks and problems of the ETC that are not sufficiently supported at the technical and technological side; there are no sufficiently developed technologies for the utilization of carbon dioxide; the equipment of the appropriate capacity for generating oxygen or coal enriching (which can be used for modernization of existing TPPs) is not adequately represented on the market of special equipment, i.e. it is incompatible with the existing technological cycle of energy production. The present legislative base in the Russian Federation is not also compatible enough with the solving of the problem of ASM recycling and the complex modernization of a TPP into an ETC.

8) Functions actualization principle [20]. «An object acts as an organized one only if properties of its parts (elements) show up as functions of preserving and development of that object». A system exists, is preserved and is developed if functions of its elements are continuously developed (actualized). When transforming a TPP into an ETC functions are expanded: to the function of energy production is appended by the function of material production (production of material products from the energy production waste). For implementing new functions it is important to include new elements in the system structure, because its existing structural elements would not be able to do their functions at the required capacity and quality.

9) Progressing segregation principle [21]. When differentiating the structure and functions of a system, elements progressively lose the interaction between them. Applying to the situation with TPPs and ETCs this process happens in two ways. First, autonomous interaction between system elements is lost, because some functions are taken to the higher level of management: the staff of a TPP is considered only as the minimum required for the equipment operation, engineering and technical administration could not control financial and material flows (i.e. control the benefit, independently buy the equipment and fuel, plan the equipment repair and modernization and so on), all mentioned bullets are in the control of the owner (or DM) that can have its own point of view on the problems and perspectives of ETCs. Second, the interaction between TPP (as a system) and external environments is not adequately developed, especially at the feedback: laws are not adequately developed, laws are outdated, not enough funds are received, repair and replacement periods are not followed, fuel is low quality. But according to the system theory, each differentiation comes along with the local integration. We believe, that in the future, the optimal balance between centralization and decentralization, differentiation and integration would be achieved.

10) Progressively spreading mechanization principle [21]. While a system develops, «its parts become fixed relative to specific mechanisms». Primary regulation of elements «is caused by dynamic interaction inside single open system, that restores its adjusting stability. Secondary mechanisms of regulation are applied over primary one as a result of progressive mechanization». A. Bogdanov calls that process «a degression»: during system development, specific «degression complexes» are formed, they fix processes from the connected with them elements that reduce variety and mutability of states and processes, including internal and external ones. Applying to TPP modernization, we could talk about conservatism, reluctance of changing habitual, well tried technologies. In the tasks of choosing a modernization strategy [13-15], a «zero option» is usually taken for comparison: modernization without modernization – replacement of outdated equipment by the new one with the same old technological scheme. As a rule, that variant commonly becomes cheaper than others, it is supported by legislative side, by the organizational side, by the technical side, by the staff support side. So, when choosing a modernization strategy of a technical object it is recommended to consider another project as well (that is nearest to the «zero option» in the terms of indicators). If its cost and introduction efforts (from the standpoint of DM) are not higher than allowed, should be preferred to modernization.

6 Conclusion

The TPP-based energy-technological complex is a complex system, that is formed and developed according to common principles of the system theory. Application of methods of system analysis at the stage of conception forming, choosing a modernization strategy, designing and operation of ETC allows to take into account requirements and restrictions both directly to the energy and production facility itself and system-wide requirements and restrictions, to predict and minimize possible risks.

References

1. N.P. Buslenko, N.N. Kalashnikov, I.N. Kovalenko, *Lectures on the theory of complex systems* (Soviet Radio, Moscow, 1973)
2. V.N. Chernyshov, A.V. Chernyshov, *Theory of Systems and Systems Analysis: Textbook* (Publishing house of Tamb. state. tech. University, Tambov, 2008)
3. A.B. Katok, B. Hasselblatt, *Introduction to the modern theory of dynamical systems* (Factorial, Moscow, 1999)
4. V. Khubka, V. *The theory of technical systems* (Mir, Moscow, 1987)
5. O.A. Melnikov, A short essay on the theory of evolution of organized systems. 1986-1995 URL: http://masterint-21h.webzone.ru/publik/evolutn.htm
6. A.A. Bogdanov, *Tectology: General Organizational Science. In 2 books* (Economics, Moscow, 1989)
7. T. Saaty, K. Cairns, *Analytical Planning. Organization of systems* (Radio and Communication, Moscow, 1991)
8. T. Saaty, *Making Decisions. Analytic Hierarchy Process* (Radio and Communication, Moscow, 1993)
9. ICAM architecture Part II - Volume IV - Function modeling manual (IDEF0), AFWAL-TR-81-4023. Ohio 45433: Air Force Systems Command, Wright-Patterson Air Force Base (Air Force Wright Aeronautical Laboratories, USA, 1981)
10. P50.1.028-2001. Methodology of functional modeling (Gosstandart of Russia, Moscow, 2000).
11. N.V. Fedorova, V.A. Mokhov, A.Yu. Babushkin, Ecology of industrial production, **3(91)**, 2 (Moscow, 2015)
12. N.V. Fedorova, V.A. Mokhov, E.A. Krivobok, Biosciences Biotechnology Research Asia, 12(3) (2015) URL: http://www.biotech-asia.org/vol12no3/functional-simulation-of-the-method-for-the-coal-preparation-for-combustion-in-the-thermal-power-plant/
13. N.V. Fedorova, N.N. Efimov, Y.V. Fedorov, Safety and Reliability of Power Industry, **11(1)**, 54 (Moscow, 2018)
14. N.V. Fedorova, D.A. Shaforost, V.A. Mokhov, Yu.V. Fedorov, Ecology of industrial production, **3(103)**, 43 (Moscow, 2018)
15. N.V. Fedorova, D.A. Shaforost, V.N. Baltyan, A.M. Kolomiytseva // Proceedings of the higher educational institutions. North Caucasus region. Series: Engineering, **3(199)**, 61 (Rostov-on-Don, 2018)
16. A.L. Takhtadzhyan, System Studies. Yearbook, 245 (Science, Moscow, 1971)
17. V.A. Vinogradov, E.L. Ginzburg, System Research. Yearbook (Science, Moscow, 1971)
18. U.R. Ashby, *Introduction to cybernetics* (Foreign Literature, Moscow, 1959)
19. M.I. Setrov, *General principles of organization of systems and their methodological significance* (Science, Leningrad, 1971)
20. M.I. Setrov, System Research. Yearbook, 159 (Science, Moscow, 1969)
21. L. von Bertalanffy, The British Journal for the Philosophy of Science, **1,2**, 134 (1950)