Chapter 2
Large Energy Systems

Complex buildings belong to large energy systems, which are continuously developing artificial systems with a hierarchical structure. The chief system in the hierarchy is the domestic energy system divided into five subsystems, four of which (solid fuels, liquid fuels, gaseous, and electro-energy systems) comprise the whole country and the fifth one—the thermal energy system—is a set of municipal, industrial-municipal, and industrial systems of feeding heat carriers (hot water and steam). The subsystem of transporting and transmission of primary and final energy carriers is the next stage in the hierarchical structure. Lower stages are centers of the supply of final energy carriers. A still lower stage comprises the consumers of final energy, among them complex buildings.

A characteristic feature of large energy systems is the inseparable inclusion of the consumers of fuels and energy in the structure of the systems. Large energy systems are, besides their internal connections, characterized by a complex system of external connections with other branches of the domestic economy and the environment. Particular attention ought to be paid to interconnections of large energy systems with the natural environment mostly causing negative ecological results.

A characteristic feature of large energy systems is their continuous development. Hence, there exist dynamically direct connections and back-connections. Information plays an important role, both in controlling large energy systems and in designing and programming their development. From the viewpoint of credibility, input information is divided into deterministic, probabilistic, probabilistic incomplete, and incomplete ones. The level of credibility of available input information determines the type of the mathematical model used to analyze the development of large energy systems.

Large energy systems are characterized by an uncertainty of solutions of their optimal development. This indefinability results from the impossibility of determining explicitly the future really optimal stage of the system, due to the incompleteness of input information. Large energy systems are also characterized by the

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economic stability of the solutions. Both these features involve the formulation of the domain of uncertainty of optimal solutions. The active share of humans in making decisions is for this reason indispensable.

The algorithm for controlling large energy systems cannot be described in a strictly mathematical way. The final solution for planning or designing can be obtained in the course of iterative balance calculations.

2.1 Characteristics of Large Energy Systems

Large energy systems are continuously developing artificial systems with a hierarchical structure in which people are organically connected with the controlling or controlled part of the system. It is therefore a system of the type "man-machines-environment". Large energy systems belong to that group of artificial open systems which determine the most important relations in the domestic economy.

Depending on the point of view of investigations, large energy systems may be considered to be technical systems of the cybernetic type or economic systems. Technical systems are characterized by the following features:

- connections between the elements are of a material (energy) character,
- the processes are continuous in time,
- the mathematical description of physical laws describing the fundamental phenomena and changes in the system is rather accurately known,
- humans play the role of the operator (controller) of the system,
- the controlled part of the system is machines.

Systems of the economic type are characterized by:

- the active role of humans in the controlling and controlled parts of the system and their interconnections,
- the lack of a precise mathematical description of the behavior of the system,
- a special role of social-economic impulses in the case of optimal control.

Depending on the aim of the analysis and the timing of its performance such a large system may be either a technical or an economic system [3, 4]. Thus, for instance, the domestic electro energy system considered from the operative-disposition point of view is a large technical system of the cybernetic type with a hierarchical structure. From the viewpoint of domestic economy, however, it is an economic system; the main aim of the control is the correct organization of the activities of groups of people who are responsible for the supply of electricity without breakdowns.

Large energy systems are characterized by the following specific features:

- the constitution of the entire energy system as a materially compact system due to interconnections of the power grids, pipelines, and internal connections resulting from the partial mutual substitution of final products,

- the existence of numerous external connections resulting from the universality and considerable importance of the final product (e.g., electricity) in the domestic economy,
- active influence on the development and localization of other branches of industry in spite of realizing the required services of the energy system for the domestic economy as a whole,
- inseparable inclusion of the consumers of fuels and energy in the structure of the systems,
- special role for automatic control of the operation of the systems and operative supply of fuels,
- impossibility of applying the classic transport model in energy systems, which assumes that consumers are assigned to the deliverer; such a model of control can play only an auxiliary role,
- particularly large dimensions and, as a result, a high degree of complexity.

2.2 Hierarchical Structure of Large Energy Systems

The hierarchical structure of large energy systems is based on both productive and territorial connections. Productive connections are vertical connections and territorial ones horizontal connections. Territorial connections are important because the mutual substitution of the production manufactured by large energy systems occurs directly on the territorial level.

Figure 2.1 presents a diagram of the hierarchical structure of large energy systems [3]. At the top of the hierarchy there are five subsystems constituting the domestic energy system. On a lower level there are productive subsystems of primary and final energy, as well as installations realizing the import, in many countries mainly of liquid fuels and high-methane natural gas. On this level, electro-energy and thermal-energy subsystems have common productive installations, viz., CHP plants realizing the production of heat and electricity in cogeneration. The next level consists of transporting subsystems for solid, liquid, and gaseous fuels, as well as electricity, which ranges all over the country.

The level of energy consumers, which in the presented hierarchical structure is conventionally the last level, is joined to the level of the centers supplying final energy carriers. These centers are considered to be sites of concentration of production, distribution, and consumption of final energy carriers. Such center may be an industrial plant, a town, an agricultural region, and also large complex buildings (e.g., airports, supermarkets, and recreation centers). On the level of energy-supplying centers we have the thermal-energy subsystem (e.g., district heating system), which due to the economic range of transporting steam and hot water is not considered to be on the level of the whole country. On this level we have distributed energy systems, realizing non-centralized delivery of heat and electricity, as well as local resources of natural gas with a large content of nitrogen, technological fuel

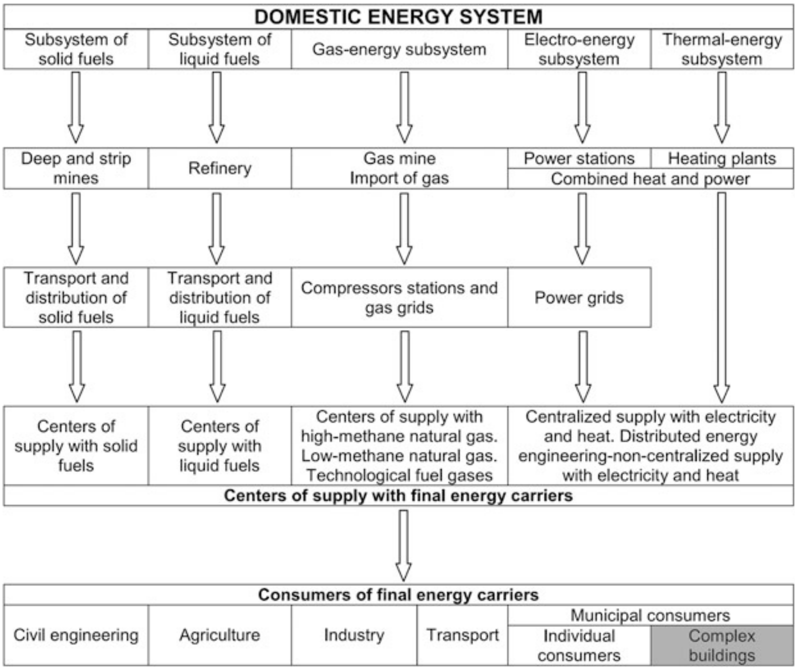

Fig. 2.1 Scheme of the hierarchical structure of large energy systems adapted from Mielentiev [3]

gasses, and waste liquid fuels (e.g., soft asphalt). The level of consumers comprises industrial plants, municipal and individual consumers including complex buildings, and transport.

2.3 External Connections

These are the connections of the given system with other hierarchically higher systems or systems on the same level. In investigating large energy systems, only those external connections, which influence its operation perceptibly are to be taken into account. Figure 2.2 presents a diagram of fundamental external connections with the domestic energy system [2]. To these belong the following groups:

- connections resulting from interbranch flows between the domestic energy economy and other branches of the domestic economy,
- restrictions concerning financial and material means, as well as the availability of human resources and sites; they should result from the optimization of the trends in the development of the domestic economy,
- connections resulting from the interdependence of the domestic energy economy and non-energy branches in the process of technical progress,

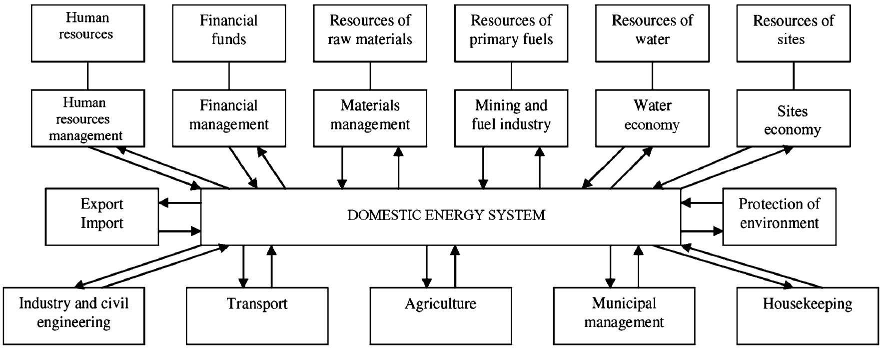

Fig. 2.2 Scheme of external relations of the domestic energy system adapted from Mejro [2]

- social-economic connections between the energy economy within the domestic economy and the environment,
- connections resulting from international commerce.

External connections are characterized by their inertia. This means that additional demands of the energy systems for machines, installations, and equipment cannot be satisfied at once, and neither can the demands of the domestic economy for additional amounts of energy carriers. This inertia must be taken into account in investigations concerning energy systems together with the existing system of interbranch connections in the domestic economy.

Particular attention ought to be paid to interconnections of the domestic energy system with the natural environment mostly bringing about negative ecological results. Figure 2.3 presents a diagram of energy-ecological interconnections [4]. The domestic energy system derives primary energy carriers, water, and air from nature. An undesirable effect of the energy systems is carrying away of harmful gaseous emissions, solid and liquid waste, heat from cooling systems, and radioactive waste into the environment.

Power stations, CHP plants, and heating plants fired with fuels, particularly coal, emit considerable amounts of sulfur and nitrogen oxides and flue dusts into the environment. These are mainly local effects. The emission of CO_2 and other greenhouse gasses influences the global changes in the climate. Installations that desulfurize flue gasses may radically reduce the emissions of sulfur oxides. This, however, involves a 15–20 % increase in capital expenditures and a decrease in the efficiency of producing electricity (the power rating of desulfurizing installations amounts to 3–4 % of the power rating of the energy unit). Another problem is the emission of NO_x the noxious effects of which exceeds that of SO_x by six to ten times. The emission of dust can be reduced by a higher efficiency of dust collection plants, the development of district heating systems, by supplying individual consumers with fuel of a better quality, and improvement in the state of exploitation and control of combustion processes. The application of fluidized beds in the boilers is connected with a decrease of sulfur and nitrogen oxides.

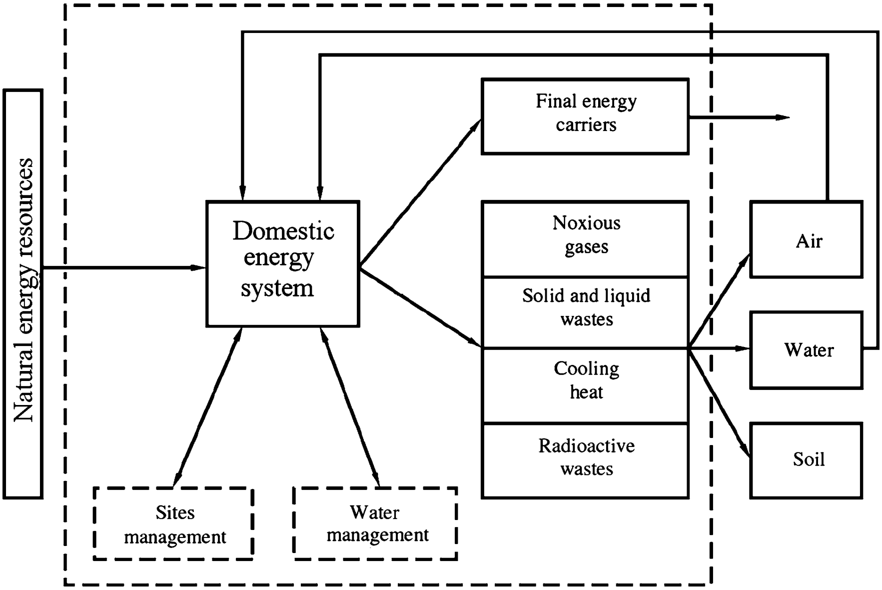

Fig. 2.3 Scheme of energy and ecological relations adapted from Mielentiev [4]

The cooling heat in power stations is carried away to the environment by applying open or closed water cycles. The passing of heat with the cooling water to lakes or rivers in open cycles may negatively affect the biological realm. Large irreclaimable losses of cooling water in cooling towers with closed cycles increase the deficiency of water in any given region. Cooling towers also involve a deterioration of the local climate near the power station, particularly in winter [6].

The development of the energy system is connected with the economy of sites and often also negatively influences the state of the soil. Thus, for instance, the construction of a strip mine of lignite leads to the formation of a depression crater and consequently to a lowering of the underground water level, which negatively affects the agricultural production. In power station, with four GW, which covers a site of 200 $\div$ 300 ha, not counting the dumping ground for ashes and the water reservoir, in the course of ten years of exploitation, the ash dumping ground increases each area up to 8 km^2 [2].

Of fundamental importance for the environment is the problem of the localization of radioactive cemeteries. A nuclear power station with a power rate of 1,300 MW produces every year about 200 m^3 of solidified wastes, of which 80 % being low-active, 15 % are medium-active and 5 % high-active [1]. Up to now the storing of low- and medium-active wastes, this problem may be considered to be solved. In the case of high-active wastes, intensive investigations are actually underway. Similarly as in the case of solidified medium-active nuclear wastes, also the best localization of solidified high-active wastes is a stable geological formation (deposits of rock-salt and clay, as well as rock mass).

According to the assessment of experts capital expenditures for the reduction of harmful effects on the environment resulting from the development of energy systems may usually amount to five to ten per cent of the entire expenditure for the development of the energy systems.

2.4 Characteristics of Dynamic Connections and Back-connections in Large Energy Systems

A characteristic feature of large energy systems is their continuous development, i.e., quantitative growth connected with simultaneous structural changes. Hence, there exist dynamical connections, divided into direct and back-connections. The former are characterized by the influence of previous stages upon later ones. The latter are characterized by the effects of later conditions in the development of the systems on earlier stages. Such strong connections necessarily lead to the optimization of the system from the end of the time horizon to the initial state.

The intensity of the occurrence of dynamic connections in the system is higher as the time horizon is longer. The longer the time horizon, the more the results of the choice of elements must be taken into account, but on the other hand the error of input information increases with time. Practically, it is assumed that the maximum time for planning amounts to 15 years, while the maximum time for predicting is 25–30 years.

If the dynamic connections are very strong and the horizon of optimization is stable, the problem arises as to how to divide this time into shorter periods mostly comprising 5 years. In order to optimize a gas-energy and electro-energy system it is indispensable to investigate the conditions of operation of these systems in various seasons of the year (at least in summer and winter).

During the development of a large energy system turning points may occur (e.g., the commissioning of nuclear power plants) which require particularly accurate researches. These turning points introduce discontinuity in the usually continuous process of the development of large energy systems.

The dynamic features of large energy systems have been manifested for many years, not only in the programming of their development, but also in their actual functioning. Thus, for instance, the chief aim of controlling an electro-energy system is the optimal distribution of the production over 24 h between the particular power stations, taking into account starting losses and the chosen filling and emptying conditions of water reservoirs in hydro-electric power stations, as well as other factors with essential dynamic features. These are not static and determined problems but rather dynamic, usually probabilistic ones. The connections in other domestic energy subsystem (gas- and thermal-energy ones) have a similar dynamic character.

Mathematical models concerning an energy system with dynamic connections ought to apply dynamic programming, although this, radically increases the dimensions of the problem. Therefore, while solving dynamic problems it is recommended that either a specific method of constructing nonlinear dynamic models or wider constructed and generalized linear models are applied. In this case, linear block programming is applied [3].

2.5 Information about Investigations of Large Energy Systems

Information plays an important role in planning and programming the development and designing large energy systems and their control. Information has the following function [3]:

- it is a form of presentation of the internal and external connections of energy systems,
- it permits the selection of the most adequate variants in the development of the systems,
- it affects changes of the parameters of the structure and functioning of the systems.

In energy systems, which are open systems, information is divided into external and internal information. The former comprises mainly information about:

- geophysical conditions and geological discoveries,
- trends and rate of development of the domestic economy,
- technical progress in energy engineering and those branches of industry which are connected with energy,
- changes in the economic proportions in industrial branches influencing essentially the economic proportions in large energy systems,
- structure and level of the prices of fuels and raw materials,
- restrictions in capital expenditures, material, and human resources.

Internal information comprises, among other data, information about:

- the structure of the energy systems,
- conditions and structure of the supply of energy carriers,
- energy characteristics of machines and installations,
- degree of reliability of energy installations,
- mutual replaceability of energy carriers,
- degree of waste energy recovery.

The significance of information depends on its substantiality, sufficiency, actuality, and credibility. Of essential importance is information (or some part of it) which decisively influences the achievement of the aim of the analysis. Scarcity of information, as well as its excessiveness hamper analysis and decrease its effects. Delayed information may prove to be without any value.

As far as the degree of credibility is concerned, input information is divided into [5]:

- deterministic information,
- probabilistic information,
- probabilistically incomplete (insufficiently determined) information,
- incomplete information (insufficiently determined).

If exact values of the considered quantities are known, information has a deterministic character. This kind of information belongs to some discrete quantities, for instance the types of construction of machines and installations, the shape of the thermal diagram, and the number of energy devices. This group also comprises so-called conventional deterministic information [3]. In practical calculations due to only small changes in some parameters of the system depending on its conditions of operation, changeability in time, and measurement errors, information concerning them may be assumed to be deterministic [5].

The probabilistic form of presenting input information concerns random variables with accurately known statistical distributions (distribution function or density of probability). Data of a probabilistic character include, among other data, geophysical information (e.g., duration curve of the ambient temperature). Probabilistic characteristics are most often obtained based on statistical information concerning the past, assuming probabilistic stability. If the available statistical data cannot be considered as representative due to differences between past and future conditions, we have a probabilistic instability. In this case, probabilistic characteristics of the past cannot be extrapolated for the future. Then investigations concerning trends are inevitable.

In the case of incomplete probabilistic information the statistical distributions are not accurately known. Information about a given quantity is presented by a series of statistical distributions or by the range of values which the analyzed quantity may take.

Incomplete information does not display features of statistical stability and is based on variants of possible values without determining the degree of probability with which the given quantity may be expressed by the respective values.

In the two latter groups we may include information about technological indices and predicted costs of energy installations, the regime of their exploitation, and the strength of new kinds of applied materials.

In investigations concerning large energy systems only a small part of input information is deterministic or probabilistic form. Most input data are incomplete (insufficiently determined) information involving an uncertainty of input data.

Among the indices belonging to input information we can discern a group of indices whose mean values are explicitly defined in which the uncertainty is the result of incidental deviations from the average value. These indices may be considered as random values of the expected value. For some indices in this group, the function of statistical distribution can be defined accurately, considering the information to be a probabilistic. In most cases, however, based on assessments of experts, several possible distribution functions are accepted. This leads to an incomplete probabilistic quantitative description of input information.

In the case of processes and installations to be introduced in future the input data (technical-economical characteristics and characteristics of new materials) are preset as variants. The quantitative assessment of the variability of this group of indices is an assessment of the inaccuracy of each variant of data and of the probability of realizing the given variant. Otherwise the assessment must be expressed by experts.

Taking into account incomplete input information, the problem of optimization is much more extensive. Therefore, a selection of input information, and rejection of unessential information that does not affect the results, are very important. Experience indicates that about two thirds of information which theoretically might influence the solution, has practically no meaning [3].

The occurrence of incomplete or probabilistic incomplete information in the set of input data leads to uncertainty in the results of the problem to be solved. This uncertainty is also due to simplifications resulting from mathematical modeling, and the aggregation of input data, as well as errors in measurements and numerical calculations.

One of the fundamental means of preventing the harmful influence of incomplete information on the development of the system is secure optimal reserves of possible capacities, raw materials and final products, and to prepare for other variants in the development of energy systems.

2.6 Indefinability of Optimal Solutions and their Economic Stability

Large energy systems are characterized by an uncertainty of solutions of their optimal development due to the overlapping of incidental phenomena and processes with their development. This indefinability results from the impossibility of explicitly determining the future really optimal state of the system, due to the incompleteness of input information concerning the development of large energy systems in the future. Input information always includes some element of uncertainty and even for this reason alone the solution cannot be explicit. Large energy systems are also characterized by an economic stability of the solutions. This means that a certain number of structurally different variants in the development of the system corresponds practically to the same capital expenditure. Near the extrema the objective function is comparatively flat.

The inaccuracy (incompleteness) of input data together with the economic stability of solutions involves formulations of "areas of uncertainty of optimal solutions", each of which may be treated as an optimal one in various actual possible conditions (combination of input data). This feature of a large energy system results from its definition as a developing set of elements, a typical feature of which is the incomplete cognizability of its quantitative characteristics; hence the impossibility of realizing an optimal control by means only of a formalized method. The active role of humans in making decisions is indispensable [4].

The reason for the economic stability of solutions in the development of large energy systems is that only 12–15 % of the capital expenditures are connected with the optimized set of installations. The remaining expenditures are assigned to already existing installation or new undertakings whose profitability is certain [3].

The feature of economic stability of large energy systems permits some simplifications to be introduced into optimizing calculations without any risk of "losing" the most economic solution. On the other hand, however, this feature complicates the calculations because, near the optimum, solutions frequently differ greatly in their technical parameters.

2.7 Control in Large Energy Systems

The control of large energy systems requires the formation of automatic control systems on the respective levels of the hierarchy of the domestic energy system. The aim of automatic control systems is to collect, process, and analyze information which is indispensable for those who have to choose the best solutions for the domestic economy and realize them. The complexity of automatic control systems consists in the following interconnected elements:

- controlled plant (system or hierarchical complex of actual systems),
- control elements,
- information subsystem warranting the archivization and monitoring of data,
- a set of mathematical models,
- computer center for data processing and optimizing calculations.

The advantages of applying automatic control systems are the attainment of more accurate solutions in planning and design, a better use of the data base, and higher organizational efficiency in the management of energy systems. In order to achieve effective operation of automatic control systems on the respective levels in the hierarchy of the energy systems, informational, methodological, technical, organizational, and mathematical uniformity is indispensable.

The algorithm for controlling large energy systems cannot be described in a strictly mathematical way. The mathematical model is merely an approximated image of a real system. An attempt should, therefore, be made in the control process to attain a cooperation of the formal (mathematical) method of attaining an optimal solution and the experience (intuition) of experts. Mathematical models, particularly in economic systems, are merely "advisers of man" when making decisions. In the case of automatic control systems on the respective levels in the hierarchy of the domestic energy system rational proportions must be kept between formal calculations and human heuristic activity. The control algorithm ought to be adapted in order to be applied to control actual incomplete input data. Taking into account the uncertainty of input data leads to the indefinability of optimal solutions concerning the future state of the energy system. The choice of the final solution depends to a large extent on human decision.

The algorithm for controlling large energy systems is an iterative algorithm. The initially accepted solutions for a higher level of the hierarchy of the automatic control system are transmitted for the purpose of exact calculations to the lower level, and after the return transmission to the higher level the obtained results are used to state precisely the preliminary solutions.

In the control of large energy systems four main time horizons are to be distinguished:

- long-term strategy (mostly 15 years),
- medium-term strategy (5 years),
- short-term strategy (detailed annual plan),
- current control throughout the year.

The tasks of the system of balance calculations concerning the domestic energy system are:

- to determine the fundamental optimal proportion of the development of the domestic energy management, balancing the development of other branches of the domestic economy,
- to determine annual and current plans for supplying the country with fuels, electricity, and heat,
- to control the current realization and prospective plans for developing the domestic energy management and their correction.

In the case of large energy systems planning is an iterative process. The final solution is obtained in the course of iterative balance calculations concerning the domestic energy system and its respective branches together with systems of balance calculations concerning other domains (e.g., transport, metallurgy etc.). The first stage of planning is the calculation of rational levels of the consumption of various energy carriers all over the country. The aim of the second stage is to calculate the optimal and mutually balanced production and distribution of energy carriers. The third stage deals with external connections and consists in matching the plan of the development of the domestic energy system and its branches with the environment (domestic economy).

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