Methodological Framework for Planning The Development of Mongolia's Electric Power Systems and Energy Industry

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***Abstract* — To successfully establish Mongolia's Unified Electric Power System (UEPS) and ensure its future participation in the global electricity market, it is crucial to create a scientifically supported methodology for the expansion planning and control of the country's electric power systems. The approach can and should be developed relying on the concepts provided for in the Mongolian Energy Development Policy Documents, with focus on the challenges of increase in the reliability, the growth of domestic electricity consumption, and the features of the external market. Modeling options and scenarios for the expansion planning of the UEPS of Mongolia are designed by means of systems analysis methods. This paper explores the research methodology utilized and presents a concise summary of its findings.**

***Index Terms* — unified power system, hierarchical level, expansion prospects, unified system model, system control, performance indicators.**

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I. Introduction

In light of the strategy and policy of Mongolia's electricity industry development, the stages of its historical development in accordance with the stages of socio-economic development of the country can be divided into two-time intervals: the first covers the period before 1990 and the second covers the period after 1990.

The former time interval coincides with the period of building socialism in the country, i.e., the years when the country was governed in line with the principles of a centrally planned economy. During this period, various sectors of the national economy began to develop intensively throughout the country according to the state five-year planning regulation of national economic development with the aid of Comecon member countries, including the direct assistance of the USSR. This time span saw Mongolia's transformation from a country with the economy based only on nomadic animal husbandry to a country with a developed multi-sectoral economy based on agriculture; processing and mining industries; construction; energy, transport, and communications infrastructures [1]. Consumption of electricity went beyond its usage predominantly for lighting purposes and came to be largely used in industry, agriculture, and other sectors of the economy. Statistical data indicate that in 1989, for example, electricity generation reached 3,568.3 million kWh and made it possible to cover 95.8% of demand for electricity by domestic sources. An important indicator of scientific and technological advances is the availability of electric power to the workforce in the national economy, which by that time was 19.2 thousand kWh/person, and electricity consumption per capita, which was 1,767.5 kWh/person and came close to the world average of electricity consumption at that time [2].

With the change in Mongolia's concept of development in the 1990s, when the country started transitioning to a market economy, there have been major changes in the electricity sector. Although there was some slowdown in the pace of the electric power industry development at the beginning of this period, the electricity sector gathered the necessary pace at the beginning of the 21st century owing to the introduction of new equipment and technology that complied with international standards. Over the past 20 years, electricity output has doubled, reaching 6,900.1 million kWh in 2019. However, 20% of the country's demand for electricity was still covered by electricity imports [3-5]. According to current data, electricity consumption per capita reaches 2,163.1 kWh/person, whereas the world average is 3,507.1 kWh/person. These data confirm the obvious growth of the domestic electric power industry.

Today's power industry is facing pressing issues, which include an increase in domestic consumption of electric power by boosting the availability of electric power to the workforce for the development of the processing industries, the creation of the unified electric power system (UEPS) of the country covering its entire area, the integration of the regional electric power industry, and the participation in the interstate electric power interconnection of North-East Asian (NEA) countries. These tasks need to be accomplished not only at the level of political and international relations. The optimal solutions require the development of a scientific and theoretical rationale and methodology reflecting the specific problems and unique features of the Mongolian context.

Mongolia has huge resources of renewable (solar, wind) and non-renewable (coal, oil shale) energy sources. However, due to the enormous territory, small population, and poor development of energy-intensive and continuous production, there are some specific features of electricity generation and supply to the population, and energy security.

Therefore, the specific methodologies applied in developed countries cannot be directly transferred or used for developing and defining the concept of the expansion of electric power systems in Mongolia. The unique features of the electric power system of Mongolia are generally due to such factors as low energy consumption in the country; no time zone differentiation, hence the impossibility of managing regional electric load curves; over 80% of electricity is produced by coal-fired combined heat and power plants (CHPPs); difficulties in controlling the

Fig. 1. Electric power systems of Mongolia and their electric ties with neighboring countries

operating states in the system due to heat and electricity co-generation and subsequent delivery to municipalities and industrial enterprises; and the lack of opportunities in this regard to incorporate large capacities of renewable energy sources (RES). In addition, energy policies of neighboring countries that lead the world in energy production and consumption generate the need to take them into account. At the very least, these factors constantly affect the development of Mongolia's energy policy as well.

Currently, Mongolia is connected with Russia and China via several power lines of different voltage levels, and these lines are designed for electricity imports alone (Fig. 1).

There is an opinion that one can meet all of their electricity needs through the self-generation. However, the above-mentioned specific features do not allow the creation of an independent power system with sufficient generating capacity, because, firstly, creating these capacities, given their necessary reserves, requires enormous unreasonable capital outlays, and secondly, keeping them partially or completely available also incurs massive operating costs. In [5], we investigate current operation of Mongolian electric power systems without regard to electricity imports. The findings indicate that, for example, the available power required for the Central electric power system alone necessitates 418 MW of new generating capacity to be commissioned in the areas of Erdenet and Sainshand towns. Meanwhile, the electric tie line with the Russian Federation not only provides the required available power but also serves as a power reserve and frequency regulator for the electric power system. Therefore, the choice of the best power supply option for the country should be approached in a way that would take into account the actual plausibility and reliability of power supply, and strengthen energy security and country's position in foreign markets. With the above factors in mind, in what follows, this paper presents the results of the research into the scenario of stand-alone expansion of the Mongolian energy system in the future without external interstate electric ties.

At different periods of electric power industry development, the goal was often put forward to create an independent power supply system by building several large power sources based on the country's energy resources, thus reducing electricity imports and subsequently switching from importing electricity to exporting it.

In fact, it is impossible to increase the level of energy security and reliability of the country's power supply without both appropriately limiting imported electricity and creating new generating capacities [6]. Therefore, it becomes crucial to develop a science-backed vision and to outline on its basis the most appropriate future lines of development for the electric power industry of the country, bearing in mind the above factors and the development of national fuel and energy resources [7].

The structure of the subsequent presentation of the material in this paper is as follows. Section 2 covers the main tenets of the methodology for the expansion planning of electric power systems in Mongolia. Section 3 presents the methods and findings of studies on the development of the electric power industry in Mongolia and an analysis of the findings obtained. The influencing factors are identified for different levels of the electric power system hierarchy. The mathematical modeling of the structure of the UEPS of Mongolia is carried out and the optimal option of backbone lines is selected. The formation of regional EPSs is substantiated and their performance indicators are analyzed. Section 4 discusses the directions and problems of smartization of Mongolia's electric power systems. The conclusion contains key takeaways from the research findings.

II. RESEARCH METHODOLOGY

The study aims to develop a model of Mongolian electric power system, which would reflect the above-mentioned influencing factors and which would make it possible to determine a rational technological structure and directions for the creation of the Unified electric power system with its unique characteristics to capture the specific features of the country's economic development. To accomplish the goals and objectives of the study, we have developed a methodology characterized by four alternative scenarios of energy system expansion: Scenario 1 - an independent closed/isolated system (i.e., without external tie lines), which meets all its electricity needs and is independent of imports at any time (I); Scenario 2 - a half-closed system that ensures energy consumption under emergency conditions by relying on imports (II); Scenario 3 - a powerful open system, which operates on the basis of sufficient development of its primary energy sources and exports electricity to foreign markets (Fig. 2)(III); and Scenario 4 - the actual, even optimal unified electric power

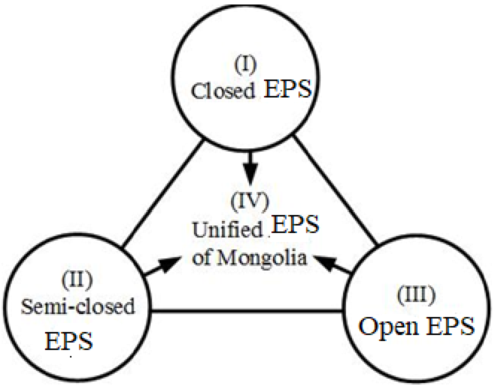

Fig. 2. Model for selecting an optimal scenario for EPS

system, which matches the specific features and scale of socio-economic development and the development of productive forces of the country, and operates in import-export modes as needed and possible (IV).

It is worth noting that at present, the commissioning of new generating capacities in Mongolia lags far behind the growing demand for electricity. Moreover, the problem is exacerbated by the significant aging of the main equipment at existing power sources. Incidentally, it can be pointed out that studies conducted to determine the energy security performance of Mongolia's power system show that with respect to some indicators it borders on a possible onset of a pre-crisis situation [6]. Moreover, the introduction of new wind and solar energy sources of relatively large capacity (50-100 MW) complicates the operating conditions of power plants. In order to enhance the reliability and operational efficiency of the country's power system and effectively implement the government's energy policy, it is imperative to develop well-founded and practical solutions and a robust model for the growth of the power sector. These solutions and model must align with the specific demands and conditions of the electricity market of Mongolia as well as the North-East Asia region [7].

The development of Scenario 4 involved the first three scenarios taken as indicators of limiting conditions. An attempt was also made to develop and apply a comprehensive analysis with an emphasis on a systems approach based on systems analysis. Based on the above methodology, the future acceptable state of the power system of Mongolia, corresponding to Scenario 4, can be defined as shown in Figure 2.

The EPS state corresponding to this scenario will not be a static point, as it will vary freely within the triangle depending on situational and temporal changes in the influential factors. From a research and methodological perspective, the entire power system can have four hierarchical levels of expansion, namely, Level 1: the currently existing EPSs; Level 2: Mongolia's UEPS; Level 3: a system operating in parallel with electric power systems of neighboring countries; Level 4: Mongolia's UEPS as part of the cross-border power interconnection being the "supergrid" of the North-East Asia countries.

Hence, there is a need to use methods of systems research with a hierarchical multilevel representation of power systems and the energy sector of Mongolia in general [8]. This study also aims to identify the indicators of energy

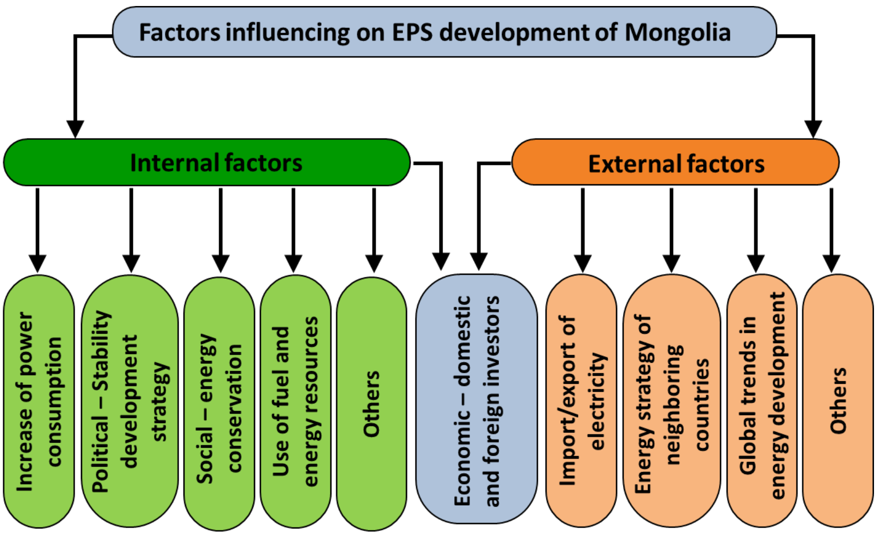

Fig. 3. Classification of factors influencing the development policy of Mongolia's electric power systems

development based on the analysis of influencing factors for each hierarchical level. One of the reasons that makes this objective more complicated and difficult to achieve is the uncertainty and inaccuracy of data on the influencing factors. When processing mathematically uncertain data, we had to search for a possible way to determine the numerical values of indicators of power industry development.

III. Research and analysis of findings

3.1. Factor analysis

The factors that affect the development of the energy sector and expansion of electric power systems of Mongolia can generally be divided into external and internal with respect to their origin.

The systems analysis of the factors shown in Figure 3 indicates that they can be classified into the following levels of hierarchy (Figure 4). This classification makes it possible to properly assess their impact and identify the prospects of energy development for Mongolia.

The Table marks the factors that have an influence at a specific level of the hierarchy with (+) symbol, and the factors that have no influence, i.e., have no value, with (-) symbol.

Mongolia, with its small population and vast territory, can have multiple competitive options (within the triangle in Figure 2) in the electricity sector. To choose the most feasible option among them, one should develop a mathematical model, which could calculate the optimal ratio of factors at each level of the hierarchy.

The main directions are:

a. The success of the energy business, which is characterized by relatively long payback periods, depends largely on a sustainable and prioritized state policy on electric power industry [9] with long-term and stable support from the government. In this regard, budgetary funding is needed to build power plants that ensure stability in the electric power system. In addition, the financial policy of the state with respect to regional energy sources of private sector investment is also required (indicators 3, 5 of Table 1).

b. Active participation in the energy integration of Northeast Asian regions, connection to the cross-border grid through power lines transmitting high power to the electric power systems of neighboring countries, establishment of a rational ratio between electricity imports and exports, and delivery of energy security (indicators 6, 7, 8, 9 of Table 1).

Table 2 shows the conditions reflecting the effect of the factors on each level of the hierarchy and the corresponding criteria.

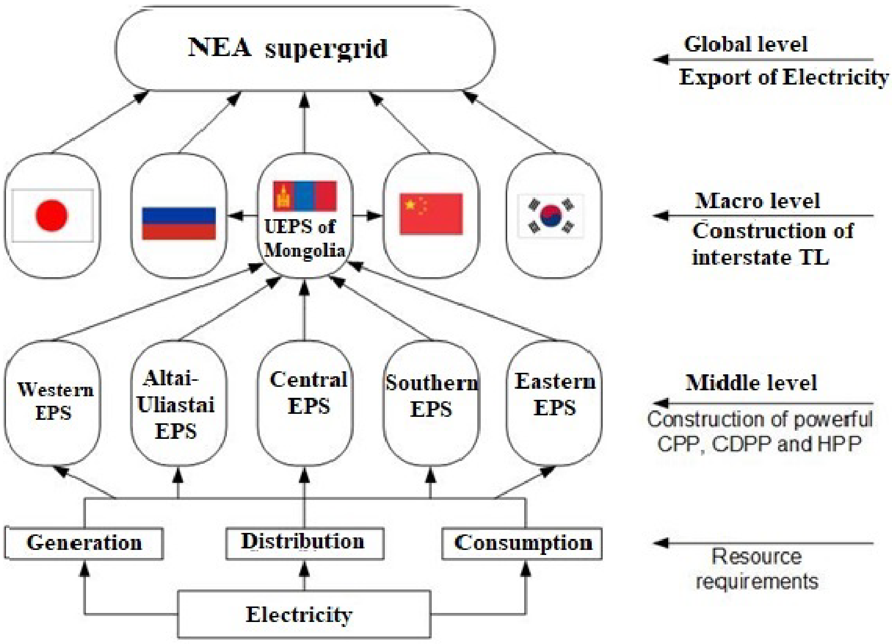

Fig. 4. Hierarchical diagram of energy development in Mongolia

Table 1. The matrix of factors to be considered at different levels of the EPS hierarchy

No.	Indicators of factors	Hierarchical level			
		I	II	III	IV
1	Growth - electricity consumption	+	+	-	-
2	Social indicator - energy conservation	+	+	-	-
3	Policy - stability of development policy	+	+	+	+
4	Fuel consumption - resources of energy sources	+	+	+	+
5	Economy - investment	+	+	+	+
6	Electricity imports	+	+	+	+
7	Electricity exports	-	+	+	+
8	Power industry strategies of neighboring countries	-	+	+	+
9	Global trends in the development of the power industry	+	+	+	-

Table 2. Interrelation of factors, hierarchical levels, and criteria

No	Factors	Hierarchical levels			
		I	II	III	IV
1	Growth: electricity consumption	Reliability of networks	Transmission of electric power over overhead lines	-	-
2	Social indicator: energy saving	Energy saving	Adoption of energy-saving technologies	-	-
3	Policy: stability of development policy	Unified development policy	Long-term development policy	Energy policy of neighboring countries	Policies of the NEA region
4	Fuel consumption: primary energy resources	Fuel and energy resources of a particular region	Location of sources	Balance of exports and imports	Resources of RES
5	Economy: investment	Recovery of capital outlays in a short run	Interests of domestic and foreign investors	Investment support	Economic feasibility
6	Electricity imports	Reduction in energy imports	Creation of an optimal ratio of exports to imports	Reduction in imports	Reduction in imports
7	Electricity exports	-		Increase in exports	Becoming an exporting country
8	Energy strategy of neighboring countries	-	Strategy of unified electric power system expansion	International / cross-border overhead power lines	
9	Global trends in energy development	Creation of distributed sources	Adoption of digital technologies	Infrastructure of digital technologies	Intelligent electric power system

3.2. Mathematical modeling of the structure of Mongolia's unified electric power system and selection of an optimal option for backbone lines

The proposed methodology utilizes a multi-nodal integrated structural diagram to determine the structure of the UEPS. This diagram effectively incorporates regional electric power systems and enables a comprehensive analysis. The calculation relies on the Soyuz model developed at the Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences (ESI SB RAS). The model has a modular structure and includes modules of power balances, balances of zones of daily load curves, flows through cross-nodal lines, as well as the modules describing the operation and expansion of various types of generating equipment [10].

The papers [7], [11], [12] present a detailed analysis of the structural diagram for calculation of the UEPS of Mongolia with 9 nodes (Fig. 5), which include the production and consumption of electricity of the corresponding economic and industrial areas, and the results of modeling energy and power flows along the

Fig. 5. Provisional calculation diagram of the electric power industry of Mongolia

backbone lines with imports factored out. The nodes include distribution networks for consumers (Level I of the hierarchy), and they are not explicitly captured in the calculation diagram. Possible surplus power and electrical energy that can be supplied to the external network or exported are marked in the diagram with corresponding values for specific nodes.

The mathematical modeling of the power flow in Mongolia's UEPS creates the need to exchange energy and power flows of the nodes of Level II of the hierarchy at the corresponding points with Levels I and III of the hierarchy. Designed for exports, the environmentally friendly thermal power plants built at large coal deposits will not only supply electricity to the foreign market but will also serve to increase the reliability of Mongolia's UEPS under emergency conditions, and to cover power shortages under peak loads of normal and off-design operating conditions of the system.

Therefore, further research was conducted based on the results of analysis of the previous option in terms of some unique features of the system, including such of them as excess power in some areas and shortage in other areas of the Central EPS, and with changes in the calculation diagram. For this purpose, 12 nodes were formed at Level II of the hierarchy on the basis of the former 9 nodes (Fig. 6). In doing so, the currently active overloaded nodes (e.g., 6 and 10) are not specified and are expressed indirectly. In order to effectively manage the system's peak load, a pumped-storage plant is located at node 3 in Ulaanbaatar**.** The formulas and expressions for the mathematical modeling are described in detail in [11].

As seen, this flow diagram somewhat differs from that in [7], i.e., the planned overhead line 1 (between nodes 8 and 9), overhead line 2 (between nodes 12 and 9), and overhead line 7 (between nodes 3 and 9) fail to meet the conditions imposed by the modeling process (i.e., they are not needed), and the optimization revealed the need to introduce new overhead lines to increase the transfer capability of existing overhead lines, and the number of their circuits. The calculation results also show that the overhead line that connects node 8 with other nodes and represents the electric connection of the Western EPS to other nodes of the electric power system is economically and technically unfeasible, unless large industrial enterprises, for example, powerful mining and other production, transport, and social sector facilities are put into operation.

In general, it is worth noting that the absence of electricity-intensive industries of the economy greatly affects the rational placement of generating capacity and the operating conditions of Mongolia's power systems. Therefore, a crucial requirement for establishing the UEPS in the country is a government commitment to a well-defined policy that focuses on developing and strategically locating domestic industrial and transportation infrastructure. This involves the creation of processing

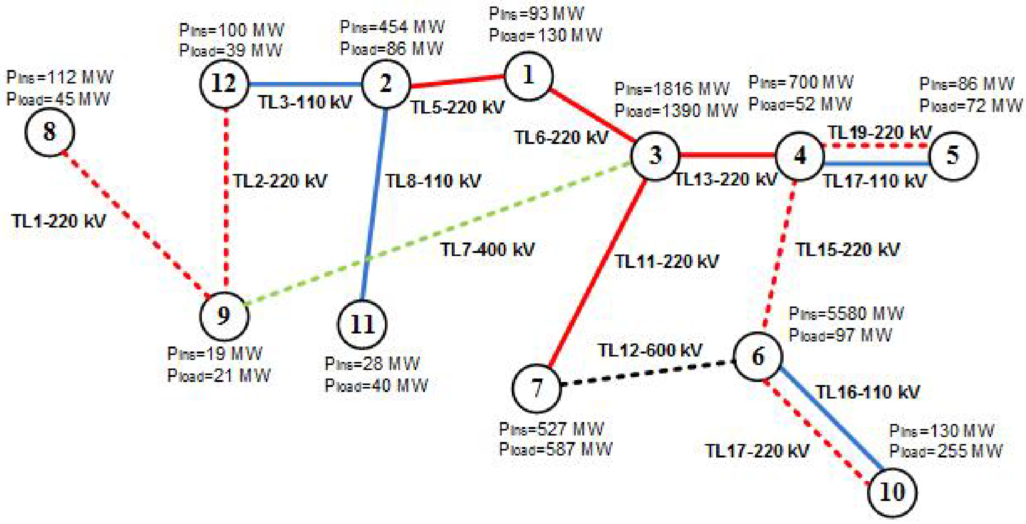

Fig. 6. The primary version of the structure of Level 2 of the UEPS hierarchy

1 - Darkhan, 2 - Erdenet, 3 - Ulaanbaatar, 4 - Baganur, 5 - Choibalsan, 6 - Choir, 7 - Tavantolgoi, 8 - Western, 9 - Altai, 10 - Sainshand, 11 - Bayanteeg, 12 - Khuvsgul (Mogoin Gol)

facilities for agricultural and mining resources, coal processing [13], as well as eco-friendly thermal power plants for the energy and agricultural sectors [14]. Additionally, the development of electrified railroads is an essential component of this effort [15].

3.3. A study on Mongolia's electric power industry development strategy without considering external cross-border electric tie lines

As previously mentioned, the possibility of developing Mongolia's electric power industry independently, without considering external cross-border electric tie lines is considered in this paper as one of the equally significant options, and in a way, as the reference case. Let us consider the main findings of scenario-based studies of this option using the SOYUZ optimization software [10]. The initial conditions for the studies were assumed to be identical to those used in section 3.2.

Given the geographical location of existing power facilities of the country and potential new energy capacities, the placement of existing consumers and the emergence of new ones in the future, an aggregate diagram of the backbone power grid of Mongolia was built for the

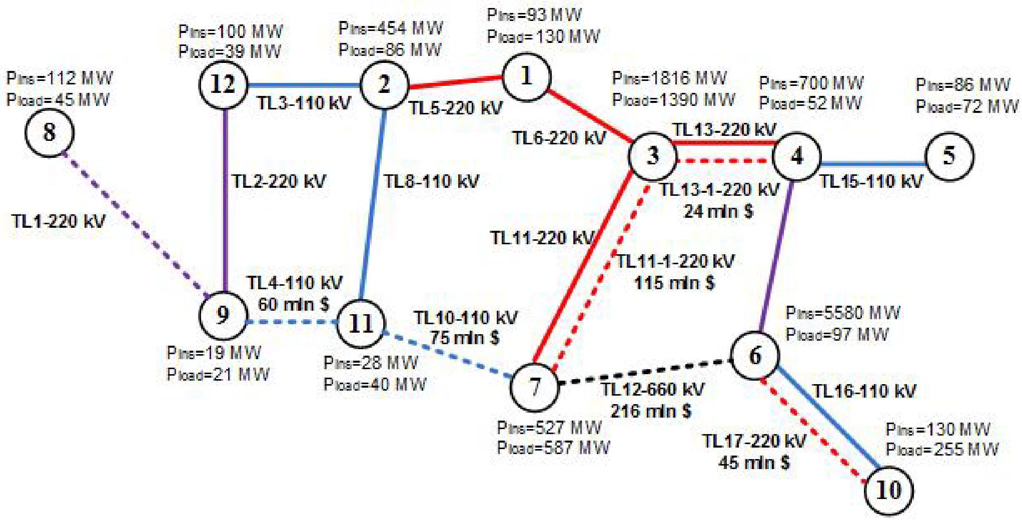

Fig. 7. Schematic diagram of the obtained solution (using the optimization model)

time horizon until 2030 (Fig. 6). Based on this diagram, a mathematical model of the expansion of Mongolia's electric power system was constructed, and the expansion scenarios for electric power systems (without external cross-border electric tie lines) were examined to analyze the internal needs and opportunities of the country in terms of development of the electric power industry and the expansion of electric power systems. The calculations considered one option of electricity consumption for 2030 corresponding to the directions of the State Energy Policy [9] and being twice the level of electricity consumption of the reporting year 2018 (Fig. 7). The main load nodes in these years are the same - Darkhan, Erdenet, and Ulaanbaatar. The share of these nodes in the total electricity consumption is about 90%.

Four scenarios of the Mongolian electric power system expansion to 2030 were calculated. The calculations optimized the expansion of condensing power plants (CPPs) and power plants running on renewable energy sources: wind power plants (WPPs) and solar power plants (SPPs). The HPP and CHPP capacities to be added were determined based on expert assessment according to the National Energy Strategy: Taishir HPP is under construction; the commissioning of Egiin HPP is due to the need for flexible capacity; CHPPs are tied to the thermal loads at the respective nodes.

The baseline scenario (No. 1) assumes the expansion of the main power grid to be fixed. The results of the calculation are presented in Table 3.

The baseline scenario suggests that covering the power and energy balances of Mongolia’s electric power system requires about 1.5 million kW of capacity to be commissioned at power plants, including 200 MW at HPPs and 434 MW at CHPPs. According to this scenario, it is also necessary to add coal-fired capacities in Tavantolgoi (92 MW) and Baganuur (254 MW); wind capacity in Gobitek (460 MW) and Choir (55 MW); and SPPs with a total capacity of 38 MW. The installed capacity of Mongolia's power plants will increase by more than 1.5 times and will be 2.7 million kW by 2030. In this scenario, the electrical loads of all nodes are fully covered taking account of the daily and seasonal irregularity of their electricity consumption.

The main power flows go from the peripheral nodes of the electric power system to the central nodes - Ulaanbaatar, Darkhan, Erdenet, which account for 86% of total electricity consumption. The Choibolsan and Western nodes have weak links with the power system and are virtually self-sufficient.

The construction of the Egiin hydropower plant in Erdenet may lead to serious and as yet poorly studied consequences for the environmental situation in the Lake Baikal area. With this in mind, three more scenarios of the expansion of Mongolia's EPSs were considered (Scenarios

Table 3. Calculation results for generating capacities at nodes for baseline scenario

Indicators	Installed capacity, 2018						Capacity additions, 2018-2030						Installed capacity, 2030					
Nodes	HPP	CPP	CHPP	WPP	SPP	**Total**	HPP	CPP	CHPP	WPP	SPP	**Total**	HPP	CPP	CHPP	WPP	SPP	**Total**
Darkhan			48		10	**58**			35		3	**38**			83		13	**96**
Erdenet			65			**65**	120		47			**167**	120		112			**232**
Ulaanbaatar			881	50	10	**941**			202		10	**212**			1083	50	20	**1153**
Baganuur								254				**254**		254				**254**
Choibalsan			36			**36**			100			**100**			136			**136**
Choir										55	25	**80**				55	25	**80**
Tavantolgoi			24	50		**74**		92				**92**		92	24	50		**166**
Western	22					**22**	80		50			**130**	102		50			**152**
Gobitek										460		**460**				460		**460**
Total	**22**	**0**	**1054**	**100**	**20**	**1196**	**200**	**346**	**434**	**515**	**38**	**1533**	**222**	**346**	**1488**	**615**	**58**	**2729**

Table 4. Generating capacity additions in Mongolia's EPSs for different scenarios to 2030, MW

Nodes	Scenario 2						Scenario 3						Scenario 4					
	HPP	CPP	CHPP	WPP	SPP	Total	HPP	CPP	CHPP	WPP	SPP	Total	HPP	CPP	CHPP	WPP	SPP	Total
Darkhan			40		2	**42**			35		2	**37**			35		3	**38**
Erdenet		141	47			**188**		300	47			**347**			47			**47**
Ulaanbaatar			202		10	**212**			202		11	**213**			202		11	**213**
Baganuur		256				**256**		160				**160**		480				**480**
Choibalsan			100			**100**			100			**100**			100			**100**
Choir				55	16	**71**				55	28	**83**				55	27	**82**
Tavantolgoi		77				**77**						**0**						**0**
Western	80		50			**130**	80		50			**130**	80		50			**130**
Gobitek				466		**466**				425		**425**				440		**440**
Total	**80**	**474**	**439**	**521**	**28**	**1542**	**80**	**460**	**434**	**480**	**41**	**1495**	**80**	**480**	**434**	**495**	**41**	**1530**

2, 3, 4). The main findings of the study on these scenarios are shown in Table 4.

Given the above, in Scenario 2, the construction of the Egiin hydropower plant is not considered. In this case, the power and electric energy balances in the electric power system are not covered. The transfer capability of power transmission lines is insufficient to transmit electricity from new sources to the Central EPS of Mongolia, which leads to a power shortage of about 140 MW at the Erdenet node. The Choir - Baganuur - Ulaanbaatar line is loaded to the maximum and cannot be used to mitigate the shortage. Therefore, it is necessary to commission a new coal-fired power plant in Erdenet or at other nodes with the corresponding strengthening of cross-nodal connections.

Scenario 3 considers the commissioning of a 300 MW coal-fired power plant in Erdenet instead of the Egiin HPP without additional reinforcement of the power grid. This scenario will mitigate the power shortage in the power system and reduce the need for new capacity at the Baganuur and Tavantolgoi nodes by about 90 MW at each node.

Scenario 4 proposes an alternative to the coal-fired power plant in Erdenet. This alternative suggests enhancing the transfer capability of the line along the Gobitek - Choir - Baganuur - Ulaanbaatar - Erdenet route, in order to transmit electricity from new CPPs, WPPs, and SPPs to the nodes of Central EPS (see Table 4).

Thus, the studies on the expansion scenarios of Mongolia's EPSs to 2030, without external cross-border electric tie lines, attest to the need for significant expansion of generating capacity and the main power grid.

3.4. Principles of control of the Mongolian UEPS

The construction of an optimal model for the UEPS of Mongolia involved a calculation using the model (considering unified supervisory control) based on the determination of minimum costs. Violations of the UEPS operating conditions have serious socio-economic implications. On the one hand, the UEPS is subject to operational supervisory control that regulates power generation and active power flows between interconnected electric power systems. On the other hand, the UEPS determines the boundaries of individual electric power systems (interface points) in terms of the structure of electrical networks based on the location of generating capacities, on the geographical location of consumers and their economic performance, and based on the location of administrative units.

The power balance of the i-th EPS, which is part of the UEPS, is determined by the following equation:

$$S_{Ci} + S_{LdHi} + S_{Li} + S_{Oi} = 0\,, \qquad (1)$$

where: S_{Ci} - total power of all power plants of the i-th system; S_{Ldi} -total load of the i-th system; S_{Li} - total electricity transmission losses of the i-th system; S_{Oi}- generated and/or received power of the i-th system, which is transmitted through cross-system transmission lines (Fig. 8).

The energy balance for the UEPS is expressed by the following system of equations:

$$\left.\begin{aligned} S_{C1} + S_{Ld1} + S_{L1} + S_{O1} = 0; \\ S_{Ci} + S_{Ldi} + S_{Li} + S_{Oi} = 0; \\ S_{Cn} + S_{Ldn} + S_{Ln} + S_{On} = 0. \end{aligned}\right\} \quad (2)$$

The power balance of the UEPS (Fig. 9) is expressed by the equation of interrelation of the electric power systems included in it:

$$S_{01} + S_{02} + \cdots + S_{0i} + \cdots + S_{0n} = 0 \quad (3)$$

In order to control and regulate the output of the UEPS capacity, it is first of all necessary to determine the minimum value of the electricity generation costs within the system. One way to assess the performance of the UEPS is to describe it by the function of the basic production costs (C_{bas}) and determine its minimum value $(C_{bas})_{min}$ as the objective function that determines the performance of the system:

$$C_{bas} = \mathrm{g}\left(\sum_{i=1}^{n} S_{Capi}\right) = C_1 + C_2 \ldots + C_i + \cdots + C_n\,, \quad (4)$$

where: $g -$ constant cost factor; $\sum_{i=1}^{n} S_{Capi} -$ total capacity of the UEPS; C_i - components of current operating costs of the i-th power system (in practice, the fuel component of costs accounts for 60-70%).

Thus, in order to control the UEPS with the minimum economic fuel costs and the greatest economic effect, the optimized control of the UEPS can be expressed as follows:

$$\lim_{u_i} C_{bas} \to min\,, \quad (5)$$

where: u_i - control signal of the supervisory control center of the upper level.

The minimum value of expression (5) is determined subject to conditions (1) - (3). For this purpose, control of the UEPS subsystems should be carried out from a single Control center or it should be based on the principle of multi-stage (multi-level) control (Fig. 9). Meanwhile, each EPS, as a subsystem of the UEPS, should be controlled by its Control center.

Acceptable supervisory control, management, protection relays, and a modern integrated automation system will ensure reliable and stable operation of the UEPS. In this regard, the objective is set to establish an intelligent power system, where the application of digital technology for measuring, processing, and transmitting information is

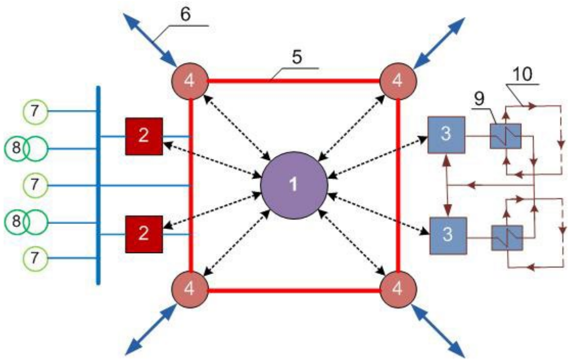

Fig. 8. Control diagram of the electric power system: *1 - central control room; 2 - electric power plants (CPP, HPP, SPP, etc.); 3 - combined heat and power plants (CHPPs); 4 - distribution substations; 5 - ring power lines; 6 - lines connecting adjacent systems; 7 - distribution networks; 8 - electricity consumers; 9 - heat consumers; 10 - heat network.*

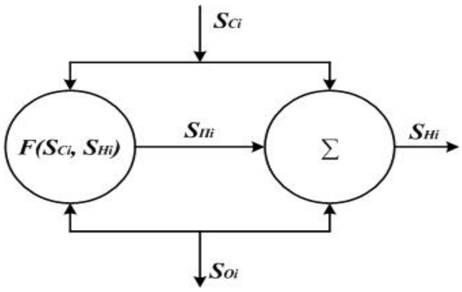

Fig. 9. Diagram of power balance in the electric power system

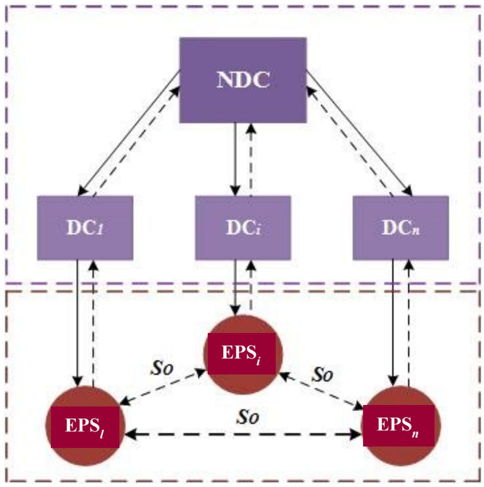

Fig. 10. Schematic diagram of the UEPS multistage control structure

essential.

In other words, the SCADA systems or automated process control systems based on digital technology, as well as information systems and automated information management systems such as WAMS, WAMPAC adapted to local conditions for operational supervisory control, are the basis for developing an intelligent UEPS (Fig.10). The prospects and problems of making Mongolia's EPSs intelligent are discussed in detail below in subsection 3.6.

3.5. Rationale for establishing regional electric power systems and analysis of their indicators

Regional electric power system is part of the regional energy sector, which in the traditional sense is characterized by the following indicators: sufficient fuel resources; generating capacity ensuring flexibility; ability to be governed by supervisory control in the optimal operating state of the UEPS; several cross-system tie lines allowing the exchange of power and energy flows with adjacent systems under emergency and off-design conditions.

In the context at issue, the adequate fuel resources of the regional power system mean the availability of coal enterprises that can fully meet the demand for fuel of all thermal power plants and other consumers of the considered region for a sufficiently long time, for example, for a year. At the same time, it is necessary to take into account the increasing output of electricity from renewable energy sources (WPP, SPP, and HPP). In this case, the research should factor in the share of the increase in renewable electricity generation, which was 20% in 2020 and will be 30% in 2030 [9]. Therefore, to take into account this circumstance in (6), we introduced the per-unit quantity β, which factors in the reduction in the amount of electricity produced at the TPP and, in principle, at other fuel sources. Thus, we can determine the annual electricity output at coal-fired thermal power plants using expression (6).

$$E_{el}^{CHPP} = E_{el}^{reg}(1-\beta) + E_{el}^{loss}, \quad (6)$$

where: E_{el}^{reg} - annual electric load of consumers in the region, kWh/year; E_{el}^{loss} - electricity losses in the system networks, kWh/year;

The remaining types of the region's coal consumption (B_{fuel}^{ind}) are calculated on the basis of the regional annual coal balance:

$$B_{fuel}^{ind} = \sum_{j=1}^{J} B_{fuel,j}^{ind}. \quad (7)$$

Then the annual coal consumption of the region is calculated as follows:

$$B_{fuel} = E_{el}^{CHPP} \cdot b_{c.e.}^{el} + B_{fuel}^{ind} + \Delta B_{fuel}^{loss}, \quad (8)$$

where: E_{el}^{CHPP} - electricity production by thermal power plants in the region, kWh/year; $b_{c.e.}^{el}$ - specific coal consumption for electricity generation (as converted to tce), tce/kWh; $B_{fuel,j}^{ind}$ - coal consumption by other industries, tce/year; J - number of socio-economic industries included in the coal balance and in the unified energy balance; ΔB_{fuel}^{loss} - coal transportation losses, tce/year.

The annual coal production is determined as the sum of productions of all $(k = 1, \ldots, K)$ coal enterprises in the region:

$$B_{fuel} = \sum_{k=1}^{K} B_{mines,k}^{coal}. \quad (9)$$

In this regard, the condition for the creation and operation of power system as part of the regional energy sector is the presence of sufficient reserves and the actual production of primary energy resources (coal), which can be written as follows:

$$B_{fuel,i} > K_{res} B_{fuel}\,. \quad (10)$$

Here, the fuel reserve factor (K_{res}) takes into account the standardized reserves, which should be available at the TPP operating under the standard conditions, and the emergency reserves. The substitute fuels of the region can also be considered in (9).

One of the main indicators of the power system performance is the quantity of electricity losses E_{el}^{loss}, which is included in (6) and depends on the parameters of electricity transmission through transmission lines, for example, on the voltage level and the total length of the lines.

When analyzing the expansion of EPS at the level of the regional energy sector, the following parameters can be used as indicators of the fuel and energy supply:

The ratio ($\alpha_{ins.cap}$) of the total available capacity of power plants (P_{av}) to the maximum electric load capacity within the region (P_{max}).

$$\alpha_{ins.cap} = \frac{P_{av}}{P_{max}}\,. \quad (11)$$

The ratio ($\alpha_{int.tl}$) of the sum of the power available and transmitted through the intersystem tie-line at the maximum load of consumers ($P_{int.tl}^{max}$) to the maximum load power of a given region (P_{max}):

$$\alpha_{int.tl} = \frac{P_{av}+P_{int.tl}^{max}}{P_{max}}. \quad (12)$$

3. The transfer capability of backbone high-voltage transmission lines (110 and 220 kV) of the intersystem tie-line:

$$P_{int.tl} = \sum_{i=1}^{N} P_{int.tl.i}\,, \quad (13)$$

where N is the number of intersystem tie-lines.

The possibility of supplying primary fuel and energy resources (FER) at the expense of local resources is expressed by the following formula:

$$\alpha_{fuel} = \frac{\sum R_{fuel,i}}{\sum B_{fuel,i}} 100\%\,, \quad (14)$$

where: $R_{fuel,i}$ and $B_{fuel,i}$ are production and consumption of the i-th primary fuel and energy resource respectively.

The calculation of reliability indices of the fuel and energy supply to the region's energy sector should factor in first of all the ability to provide fuel and energy resources under normal conditions and in the event of extreme conditions, i.e., under a steep increase in fuel demand due to unforeseen conditions, for example, due to cold weather not taken into account in the analysis of thermal loads, and others. The following three indices will be considered here: the share of fuel resources ($\alpha_{pr.fuel}$) prevailing in the total consumption of fuel and energy resources in the region; the share of the most powerful power plant in the electric power sources of the region ($\alpha_{large\ PP}$), the amount of backup fuel resources necessary to cover consumption in the event of an emergency, such as the ability to supply a 10% increase in fuel consumption ($\alpha_{b.fuel}$). They are expressed as follows:

$$\alpha_{fuel} = \frac{max(\sum B_{fuel,i})}{\sum B_{fuel,i}} 100\%\,; \quad (15)$$

$$\alpha_{large.PP} = \frac{P_{large.PP}}{P_{\Sigma ins.cap}} 100\%\,. \quad (16)$$

The indices of backup fuel resources under extreme conditions are determined as per the following formula:

$$\alpha_{b.fuel} = \frac{R_{fuel\ ext.}}{B_{ext.}} 100\%\,, \quad (17)$$

where $R_{fuel\ ext.}$ - the maximum possible primary fuel resources supply for the region's needs, mln tce; $B_{ext.}$- the maximum (with a 10% increase) region's fuel consumption under extreme conditions, mln tce.

Here R_{heat} is expressed by the following formula.

$$R_{heat} = \sum min(P_{heat,i}\,, P_{HN,i})\,, \quad (18)$$

where: $P_{heat.i}$ is the total power of the normal operating state of the i-th district heating source of the given region, Gcal/h; $P_{HN,i}$ is also heat delivered to consumers of the i-th heat network, Gcal/h.

Determination of R_{heat} is the subject of a separate

Fig. 11. Location and lines connecting electric power systems of Mongolia's regions (with 12 nodes of the model considered)

independent optimization study of the heat and power economy of the region. Here we took the value of this index as a given input value.

Initially, a study on the selection of a rational structure of the UEPS was conducted for the parameters (indicators) of currently operating five electric power systems of regional importance within the areas they serve in accordance with the medium-term development program of the electric power industry of Mongolia until 2030. The analysis has indicated that it is advisable to transform them into three power systems as shown in Fig. 11. Then the newly formed power systems meet the requirements for the fuel resources, capacity to ensure their flexibility, and controllability under the optimal operating conditions of the Unified EPS given the existing and proposed several intersystem lines, which ensure to an adequate extent the exchange of power and energy flows with neighboring systems under emergency conditions.

To calculate the indicators of annual coal consumption and reliability indices of fuel and energy supply on a regional scale, we used coal balance data for 2019 from the unified database of the National Statistical Committee. This database shows that in 2019, Mongolia extracted 55.9 million tons of coal and consumed 9.8 million tons, of which 7.7 million tons of coal were consumed by thermal power plants. The remaining 2.1 million tons of coal were consumed for the household needs of the population, mainly for heating. Transportation and storage losses amount to 661.4 thousand tons [3]. Table 5 shows the general characteristics of the three electric power systems.

When determining the indicators of fuel and energy supply, optimization using expression (10) (with 2019 as the baseline year) reveals that currently all three systems have $\alpha_{ins.cap} < 1$ (Table 6), which confirms the demand for new sources. In 2050, however, by the end of the period of the long-term policy document "Long-Term Vision - 2050" [16], the same indicator for the Western and Central EPSs is projected to be $\alpha_{ins.cap} > 3$. The sources of Southeastern EPS, however, prove inadequate by this time, although, the Southeastern EPS is supposed to have reliable connection to the Central EPS through five overhead transmission lines and, in this case, the system will operate properly. In addition, the reliability of the Central EPS sources will be ensured and the system will work for the external market, i.e., electricity exports will be provided.

Table 5. General characteristics of Mongolia's regional electric power systems (1)

No	Regional power systems	Territory area, km^2	Population, thousand	Electricity consumption, million kWh/year	Share of RES, %	Fuel consumption, thousand tons			Fuel losses, thousand tons
						TPP*	Others	Total	
1	Western EPS	415.2	408.9	858.69	55	0.97	0.27	1.24	83.5
2	Central EPS	583.1	2,473.2	5,193.72	20	5.88	1.60	7.48	505.1
3	Southeastern EPS	561.1	356.4	748.44	30	0.85	0.23	1.08	72.8
	Total	1,559.4	3,238.5	6,800.85		7.70	2.10	9.80	661.4

* This factors in a 100 MW coal-fired power plant to be commissioned in the western region.

Table 6. General characteristics of Mongolia's regional power systems (2)

No	Regional power systems	Installed capacity, $P_{ins\,cap}$[MW]		Maximum load, P_{max}[MW]		Power of the tie line**, P_{tl} [MW]		Indicators of fuel and energy resources supply			
								α_{ins}		α_{tl}	
		2019	2050	2019	2050	2019	2050	2019	2050	2019	2050
1	Western EPS	31.1	331	58	105	16	48.2	0.54	3.15	0.81	3.61
2	Central EPS	1,223	8,801	1,153	1,745	-	-	1.06	5.04	-	-
3	Southeastern EPS	243	743	208	884	23.4	395.7	1.17	0.84	1.28	1.29
	Total	1,497	9,875	1,419	2,734	39.4	443.9	1.05	3.61	1.08	3.77

** The 2019 value is determined by the maximum power transmitted through the existing transmission line in 2019, and the 2050 value is obtained by calculations (see [11]).

3.6. Problems of power supply to off-grid consumers in Mongolia

The above-discussed principles and directions for the development of the electric power industry and electric power systems of Mongolia concerned the expansion of large generation capacities, high and ultra-high voltage of backbone electrical network; and the establishment on this basis of the country's Unified electric power system, in particular, for Mongolia to participate in the creation of an interstate power grid of North-East Asia.

Meanwhile, in recent years, small-scale power generation in Mongolia has developed significantly. In 2019, there were 13 mini- and micro hydropower plants, 17 mini- and micro- solar power plants, 3 mini wind power plants, and 7 hybrid microgrids (photovoltaic panels and wind turbines with or without electricity storage). Mongolia successfully implemented an impressive national project "The 100,000 Solar Gers" program to electrify individual gers of nomads, which is of great social significance [17]. The program was funded by the Governments of Japan and China, and by the World Bank [18]. The program was launched in 2000 and continued until 2012. As a result, 70% of the nomads (about 500,000 inhabitants) were supplied with electricity. The total power of PV panels per ger is 3-4 kW. In addition, there are backup PV panels and electricity storage units. These microgrids run on direct current.

A typical set of electrical appliances in a ger now includes at least the following units: lighting, electric stove, refrigerator, electric heater, digital TV, and PC. In the not-too-distant future, there will be additional electrical loads, in particular, an automatic washing machine, and other domestic appliances. The total number of electrical loads in a ger, as follows from international experience [19], can be much more than ten.

This will increase the total electricity consumption and the total maximum load of the individual consumer, as well as the irregularity and uncertainty of their daily load curve. It is crucial that the random nature of the operation of some electrical loads (for example, the timing of switching on and off the washing machine), if their number goes up, will lead to an increase in the random component of the daily load curve of the consumer.

Many modern domestic appliances operate on a digital basis and therefore have higher requirements for power supply reliability and power quality. At the same time, the power generation by the photovoltaic panels is stochastic in nature, and these random fluctuations in power generation must be smoothed out by the electricity storage unit. The efficiency of the "PV panel - storage" system is ensured by the control system.

Important non-trivial tasks arise when considering a local mini system consisting of microgrids for a large family residing in several adjacent gers. Another unique, fundamentally new situation will occur when nomads have electric cars, which are already widely used in cities.

In general, the development of a comprehensive methodology, models, and methods is required to justify the expansion of such microgrids and small local systems consisting of several microgrids for power supply to isolated individual consumers and the control of their operation. It seems obvious to maintain the off-grid operation of the considered mini- and microgrids of individual consumers due to their remoteness from the centralized power supply areas.

3.7. Environmental issues of Mongolia's energy sector

In light of the current requirements of the 21st Century Sustainable Development Concept and the UN Paris Agreement on Climate Change, both on the scale of a single country and on a global scale there are requirements to reduce emissions of triatomic gases, which produce the so-called "greenhouse effect," from energy sources (TPPs, boiler-and-furnace systems) and transport vehicles. Today, the majority of power and heat sources in Mongolia run on coal and emit carbon gases which make up 15.7 million tons of CO2 equivalent (as estimated in [20]), 84.5 thousand tons of nitrogen oxides, and 107.3 thousand tons of sulfur dioxide (2020) [21]. Coal-fired sources generate more than 90% of electricity and all thermal energy. Other facilities that produce a large share of air pollutants are cars.

Direct greenhouse gas emissions from these sources can be reduced by taking the following measures: 1) substitute conventional technologies and means of coal combustion at energy sources for new technologies that significantly reduce the aforementioned gas emissions, of which the most harmful are nitrogen oxides and sulfur dioxide; 2) reduce the share of coal and other conventional fossil fuels by substituting them for renewable and other environmentally friendly energy resources (hydraulic, solar, wind and geothermal energy, hydrogen and fuels of advanced processing of natural feedstocks); 3) use all kinds of electric cars, underground railroads, and other advanced types of vehicles in cities.

The Mongolian government is currently taking a variety of measures to support new innovative technologies in the energy sector. Since 2007, under the Law on Renewable Energy, there have been incentivizing tariffs for RES-based electricity generation for power generating sources of electric power systems and the heat power economy [23].

The widespread adoption of the entirety of these measures for the energy sector can be referred to as the greening of energy sources. Here we consider aspects of greening in the field of electric and thermal power.

The policy document of energy development "The Long-Term Vision - 2050" [16] sets the goal to increase the share of renewable energy sources in the power generation sources to 20% in 2020, to 30% in 2030, and to 40% in 2050. In 2020, in the Mongolian energy sector, the capacity of SPPs, WPPs, and small HPPs combined reached 271.2 MW, which is 18.3%. We can say that the goal set at this stage is almost fulfilled. However, because of the operating conditions of electric power systems, which are due to the lack of large basic condensing and hydraulic capacities, and the nature of electrical load curves, the annual output from these environmentally friendly sources is around 9.1% of the total annual production [22]. The use of renewable energy, such as solar energy [24], on a large scale can also cover the demand for heat of individual consumers and maintain the operation of local power grids in remote areas.

To provide a methodological framework for the adoption of "green technology" in the energy sector, over the past more than 20 years, we have conducted a large amount of basic scientific research on the combustion of coal particles [25], experimental studies on the combustion of domestic coals in the fluidized bed and circulating fluidized bed. The studies were also carried out on vortex technology, which serves as a basis for the creation of large steam generators for export-oriented environmentally friendly TPPs in the electric power systems [26], [27]. These works have led to the development of boilers with fluidized bed technology and their implementation in several municipal heat sources. In recent years, circulating fluidized bed boilers of various unit capacities (7 to 116 MW) have been introduced at thermal power plants in Mongolia. In the future, it is planned to install such boilers of large capacity at CPPs to be built at coalmines. Therefore, detailed studies of the mechanical and thermal engineering properties of Mongolian coals are required to draw up design specifications for circulating fluidized bed (CFB) boilers. In addition, it is necessary to investigate the combustion of these coals in the CFB conditions, the yield of nitrogen oxides and sulfur dioxide, and ways to reduce the latter.

The comparative studies of the standards on coal specifications indicate that Mongolian lignite of grades X1, X2, and X3 correspond to coal grades B1, B2, and B3 respectively according to the standards set in the Russian Federation. Coal of grade X3 corresponds to ligB and ligA as per American rankings and to Chinese grades HM1 and HB2. Domestic coals X1, X2 correspond to American sublignites (subB and subC) and Chinese semi-hard CY grade coal. Mongolian coal of Ch12 grade corresponds to the Russian marking of long-flame coal D, American sublignite of sub and subA grades, and to Chinese semi-hard coal of CY grade. All coals of grades Ch11-Ch2 correspond to Russian coking coals, American bituminous coals, and Chinese hard coals of grades QM-FM [26]. Thus, individual coal grades in the standards of different countries overlap with each other and there are some differences in coal grading in different countries, which complicates the choice of design specifications of furnaces and heating surfaces and generates the need to conduct detailed experimental studies of domestic coals as applied to specific boilers produced abroad. This strand also underlies the methodological framework for the adoption of clean coal technology in the energy sector.

Ultimately, the gradual implementation of these new lines in the energy sector provides the greening of Mongolia's fuel and energy balance, which also includes energy and water use of watercourses of inland and transboundary rivers.

3.8. Prospects and challenges of the transition to intelligent electric power systems in Mongolia

In the context of current global trends, the Mongolian Ministry of Energy declared 2019 as the "Year of Smart Energy" and proposed the national program "Smart Energy System" developed to improve the reliability and efficiency of Mongolia's electric power system and its energy security.

To implement this program, it was planned to carry out a set of studies in the following areas:

Ensuring reliable and stable operation of electric power systems under various conditions.

Improving the economy and efficiency of the country's electric power industry as a whole.

Implementing intelligent systems, primarily in the distribution grids and at the level of electricity consumption.

Analysis of the package of studies proposed in the adopted program with respect to the three areas noted above raises the following overriding concerns:

a) Establishment of an intelligent electric power system (IEPS) is a systemic transformation of the electric power industry, which, according to the experience of other countries [[20] – [22], etc.], requires the development of conceptual principles and a rationale behind the IEPS creation priorities. Meanwhile, as a basis for the transition to intelligent electric power system of Mongolia, the program provides for the development of documentation for the IEPS infrastructure (standards, regulations, etc.). Without detracting from the importance of regulatory documents, we emphasize that they should be based on the vision of the IEPS creation [23].

b) Future mass use of wind and solar power generation plants will radically alter the properties of Mongolia's electric power system. This will reduce its controllability and flexibility and will cause the system instability in emergency operating states due to random fluctuations in the power output of the WPP and SPP and insufficient maneuverability of the TPP.

c) Issues of the transition to intelligent microgrids for power supply to the off-grid consumers are not touched at all. Despite the relatively small scale of this area, it has extremely important social significance. Furthermore, it is clear that the implemented 100,000 Solar Gers Program does not address all problems.

d) Implementation of the program aimed at intelligentization of Mongolia's power system requires training a new generation of professionals [24]. The program fails to reflect this extremely important task.

The transition to the intelligent power system is a complex integrated engineering, economic, scientific, and organizational task, which includes a large-scale revamping of the electric power equipment fleet on an innovative basis and the transition to a next generation of process control and market operations management systems at all levels of management. The process of changing the methods and tools for managing the expansion and operation of power systems in Mongolia involves research consisting of three important stages:

Improving automation that ensures greater responsiveness of technical devices and control systems not only during emergencies but also during normal transients with extensive use of emergency control devices to limit voltage and frequency decrease and increase, prevent loss of stability, etc.

Increasing informatization to enable a new level of observability and monitoring of the power system, controllability of operating states of facilities and the system as a whole, with extensive use of digital phasor measurements of state variables.

Adopting intelligent technologies at all levels of power system control to ensure not only "a response related to the actual state," but also "a prediction-driven response," based on probable changes in the operating parameters of individual facilities, systems, and consumers.

Thus, the transition to a new type of electric power industry should harmonize all directions of innovative modernization of power systems, naturally expand the boundaries of the usual production process and take it beyond the conventional extensive scenario of power system development, which is characterized by a simple quantitative increase in production capacity and its saturation with innovative technologies. At the same time, compared to centralized power system, intelligent microgrids possess a higher level of readiness for implementation when it comes to supplying power to the off-grid consumer. This is because they have newer equipment and are much less complex and smaller in scale.

The transition to an intelligent power system represents a significant step forward in the evolution of the electric power industry. This transformation brings about a change in functionality, altering existing properties and giving rise to new ones in various structural components as well as in the power system as a whole.

IV. Conclusion

1. There are currently five electric power systems of regional importance in Mongolia. They cannot fully meet the demand for electricity by their sources and do not comply with the classical definition of the power system in terms of structure and principles of monitoring and control.

2. Based on the study on the factors that influence the development of the electric power industry in Mongolia,

the paper identifies and details the conditions and actions to determine specific indicators for each level of the hierarchy of Mongolia’s electric power industry development.

3. A mathematical model of establishing the UEPS of Mongolia was developed, numeric values of some quantitative indicators of fuel and energy supply to consumers were determined, and the findings of the analysis were summarized.

4. The developed model of Mongolia’s UEPS meets the fuel resources and power requirements necessary for its maneuverability. It also ensures controllability in the optimal operating state of the UEPS and provides the capacity to regulate power flows from the adjacent systems through several cross-system tie lines. Under emergency conditions, the Mongolian UEPS is connected to Russia along three routes and to China along one route. This connection provides the basis for Level 4 of the UEPS hierarchy.

5. This study examined the existing regional electric power systems and energy consumption levels within the respective areas they serve. To meet the growing need for electricity and align with Mongolia's long-term economic development program, we will continue to research and implement measures to ensure a reliable power supply, optimize power transmission lines, and build new sources of electricity. The study suggests creating three large regional power systems having reliable cross-system tie lines, meeting the requirements of the UEPS, and fitting into the overall configuration of the country's energy sector.

6. The unique features of Mongolia stem from the presence of remote and isolated consumers, which prompted the implementation of the national program "100,000 Solar Gers." To effectively analyze the features and operational conditions of microgrids, as well as their potential for expansion, it is essential to develop a comprehensive methodology, robust models, and effective methods for solving specific challenges. This paper discusses some of them.

7. In order to establish an intelligent power system in Mongolia, it is crucial to develop a scientifically-supported framework for transitioning to a self-aware and self-healing system. This framework should include integrated control functions across all hierarchical levels, catering to both the overall Unified Energy Power System of the country and the microgrids of individual isolated consumers. The implementation of the Intelligent Power System is essential for the successful achievement of Mongolia's Energy Strategy targets, as it plays a crucial role in transforming the energy sector industries. The country's intelligent UPS should be aimed at the quantitative and qualitative economic growth of Mongolia. Innovative technological solutions should be implemented to harness intelligent microgrids, which will effectively address the social problems faced by the nomadic population in the country.

8. The studies conducted had the purpose of enhancing the environmental efficiency of power boilers by implementing new and innovative technologies for burning Mongolian coals. We have identified the key strategies for making conventional energy sources more environmentally friendly. Moreover, replacing conventional coal-fired sources with renewable energy sources on a large scale promotes a significant shift towards a greener energy sector.

REFERENCES

[1] History of Mongolia in 5 volumes. Vol. 5 (The 20th century)/ed. by Acad. Zh. Boldbaatar, Academy of Sciences of Mongolia, Institute of History, 2003. Available at: https://www.academia.edu/28327644/pdf (accessed 23.06.2022)

[2] Socio-economic development of the Mongolian People's Republic in 1989. Statistical reference book. National Statistics Committee. Ulaanbaatar, 1990, 153 p.

[3] National Statistics Committee. Statistical reference book. 2019. Ulaanbaatar, 2000, 823 p.

[4] Batmunkh S., Bat-Erdene B., Voropai N.I. Development of the energy industry in Mongolia: I. Review, policy, research, modeling issues. *Energy & Engineering,* 2020, No. 7 (197), pp. 6-16 (in Mongolian).

[5] Bat-Erdene B., Voropai N., Lyankhtsetseg S., Batmunkh S. Expansion planning of the power energy system of Mongolia. *Energy Policy*, 2021, No. 11(165), pp. 66-81 (in Russian).

[6] Sodnomdorzh D., Bat-Erdene B., Tovuudorzh P. Analysis of energy security performance of Mongolia, *Energy & Engineering,* 2020, No. 8 (198), pp. 6-12 (in Mongolian).

[7] Bat-Erdene B., Batmunkh S., Voropai N.I., Khanaev V.V., Drachev P.S. Development of the Energy Industry of Mongolia: II. Modeling the PES and the issues of optimizing its structure, *Energy & Engineering* 2021, No. 2 (204), pp. 21-32 (in Mongolian).

[8] Melentiev L.A. *Optimization of development and control of large energy systems.* Moscow, Vysshaya Shkola, 1982, 356 p. (in Russian).

[9] State Energy Policy for 2015-2030. Resolution of the State Great Khural No. 63 of June 19, 2015. Ulaanbaatar, 2015. Available at: https://www.legalinfo.mn/law/details/15406 (in Mongolian).

[10] Voropai N.I., Trufanov V.V. Mathematical modeling of electric power systems expansion planning in today's context // *Elektrichestvo*. 2000. No. 5. (in Russian) *Elektrichestvo*, 2000, No. 10, pp. 6-13 (in Russian).

[11] Batmunkh S., Bat-Erdene B., Voropai N.I. Development of the energy industry in Mongolia: III. Methodological basis for the vision of the optimal structure of power supply in the regions of Mongolia, *Energy & Engineering,* 2021, No. 5 (207), pp. 20-30 (in Mongolian).

[12] Bat-Erdene B., Batmunkh S., Voropai N.I., Selifanov V.V., Trufanov V.V. Analysis of Mongolia's electric power industry development strategy without regard to external cross-border electricity interconnections, *Energetik,*2020, No. 11, pp. 55-59 (in Russian).

[13] Ochirbat P. *Development strategy of the mineral resources sector of Mongolia*. Moscow, Gornaya Kniga, 2007, 210 p. (in Russian).

[14] Batmunkh S., Salomatov V.V., Stennikov V.A., Enkhzhargal Kh. *The environmentally friendly coal-fired thermal power plant in the concept of the multi-complex with the integration into the power energy system of Mongolia.* Novosibirsk, *Geo* Publ., 2019, 253 p. (in Russian).

[15] State policy in railway transport. Resolution of the State Great Khural No. 32 of June 24, 2010. Ulaanbaatar, 2010. (In Mongolian).

[16] The Long-Term Development Concept of Mongolia "Alsyn Kharaa-2050" (Long-Term Vision-2050), adopted by Resolution No. 52 of the State Great Khural on May 13, 2020. (in Mongolian).

[17] Voropai N.I., Bat-Undral B., Enkhsaikhan E. Directions and problems of expansion planning of micro power supply systems of isolated consumers in Mongolia. *Izvestiya RAN. Energetika,* 2019, No. 6, pp. 43 – 50 (in Russian)

[18] Batbayar Ch. Development of renewable energy in Mongolia / Report. Ministry of Energy of Mongolia, 2013, 26 p. (in Mongolian).

[19] *Microgrids: Architectures and Control /* Edited by N. Hatziargyriou, New York, IEEE Press-Wiley, 2014, 319 p.

[20] Nationally Determined Contributions (NDCs) of Mongolia. Mongolian Government, Ulaanbaatar, 2020, 124 pp.

[21] Namkhainyam B., Tseyen-Oidov Zh. Scientific report on the work on the methodology and results of calculating the volume of greenhouse gas yield from energy sources in Mongolia. Commissioned by the Energy Coordinating Committee. Ulaanbaatar, Ulaanbaatar, 2021.

[22] Statistical energy indicators 2020. Energy Coordinating Committee. Ulaanbaatar, 2021, 86 p. Available at: http://admin.erc.gov.mn/uploads/files/statistic/erchim-huch_suuliinh_04-10_final.pdf

[23] Mongolian Law: Renewable Energy Law (adopted in 2007 and amended in 2015 and 2019). Available at: https://www.legalinfo.mn/law/details/465

[24] *Saneev B.G., Ivanova I.Yu., Khalgaeva N.A., Batmunkh S., Purevdorzh G., Onormaa C.* Resource and energy-economic prerequisites for the use of renewable energy sources in the transboundary area "Baikal-Khuvsgul" //*Region: Economics and Sociology*. 2020. No. 2 (106). pp. 259–280.

[25] Batmunkh S. Environmentally friendly coal-fired thermal power plant in the concept of the multi-complex with integration into the power system of Mongolia. Research monograph / S.Batmunkh, V.V. Salomatov, V.A. Stennikov, H. Enkhzhargal: ed. by V.A. Stennikov; SB RAS; Novosibirsk. Geo Publ., 2019. -253 p. (in Russian)

[26] Zhargalsaikhan B. Research on improving the environmental performance of the furnace of power boilers by applying a combustion technology that takes into account the quality of coal. Ph.D. thesis. Ulaanbaatar, 2015, 154 p.

[27] Batmunkh S., Tseyen-Oidov J. Technology of coal combustion in a fluidized bed. Research monograph. Ulaanbaatar, 2019, 228 p.

[28] Grid 2030: A national version for electricity's second 100 years. Office of Electric Transmission and Distribution. United States Department of Energy. July 2003, 89 p.

[29] European smart grid technology platform: Vision and strategy for Europe`s electricity networks of the future. European Commission, 2006, 38 p.

[30] Berdnikov R.N., Bushuev V.V., Vasiliev S.N., Veselov F.V., Voropai N.I., et al. *The concept of the intelligent electric power system of Russia with an active and adaptive grid.* Moscow, Federal Grid Company of Unified Energy System, 2012, 214 p. (in Russian).

[31] Bat-Erdene B., Batmunkh S., Voropai N.I., Munkhtulga D., Enkhtur E. The current state and prospects of the development of intelligent energy in Mongolia. *Bulletin of MPEI,* 2020, No. 3, pp. 11-16 (in Russian).

[32] Batmunkh S., Tserendolgor D., Ulam-Orgil C., Bat-Erdene B. Revision of Master's degree program in Energy Studies. *Energy & Engineering,* 2020, No. 12 (202), pp.16-20 (in Mongolian).

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