Development of Mongolia’s Electric Power Industry and its Role in Shaping the Northeast Asian Super Grid

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***Abstract* — The paper presents the background of creation and development of Mongolia’s electric power industry and its current state. Despite considerable energy resources, the country suffers from electric power shortage that is covered by electricity supplied from Russia and China. The expected considerable power consumption growth can be met by doubling generating capacities, enhancing electrical networks and by interconnecting the five existing electric power systems (EPSs) into an Integrated Power System (NPS) of Mongolia as a future component of the Northeast Asian Super Grid. To accomplish these tasks, we propose a number of conceptual structural and technological models for the development of Mongolian electric power systems that can form a basis for the future Integrated Power System of Mongolia.**

***Index Terms* — Electric power generating industry, energy resources, electric power systems, power plants, transmission lines, forecasting, structural models of the system, electric power interconnection.**

I. Introduction

Until the early XX century, Mongolians remained nomads occupied largely with livestock breeding. Energy demand was reduced to heating by open fire of conventional household stoves; there was no idea of the energy supply in the most general sense. The first electric lighting was used in Ulaanbaatar, the capital of Mongolia, in 1912. The emergence and development of electric power industry within a little more than 100 years can be divided into four phases:

1. 1912-1940. The economy of Mongolia is mainly a livestock economy; industry is predominantly represented by small trades. This is the time when the first 2.5 MW cogeneration plant was put into operation in Ulaanbaatar.
2. 1940-1960. Manufacturing industry comes into being, the first large processing plants are constructed, and urban population grows. The need arises to establish electric power systems, and the groundwork for the accomplishment of this task is laid.
3. 1960-1990. A new economic policy is pursued to transform the country’s economy from agrarian-industrial to industrial-agrarian one. The implementation of this economic policy primarily required development of new heat and power generating facilities, and they were constructed. This is the period when four independent EPSs that covered almost the entire country were constructed and further developed.
4. 1990- until now. This period is characterized by technological advancements in the electric power industry, by its furnishing with modern machinery and equipment, development of new technologies, implementation of a number of advanced projects. Nevertheless, some urgent problems remain. They include expansion of generating capacities (including maneuverable ones); construction of transmission lines; establishment of an Integrated Power System (IPS) of Mongolia and its integration into the Northeast Asian Power Grid, International Power Pool in Northeast Asia, and others. All these challenges require

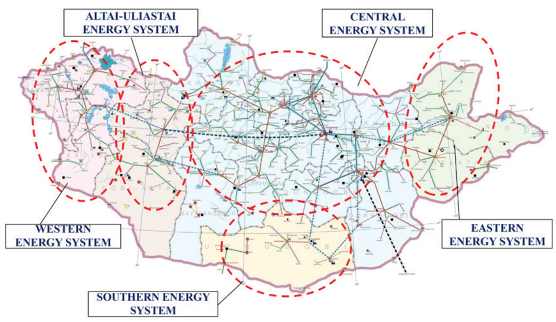

Fig. 1. Electric Power Systems of Mongolia.

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Table 1. Characteristics of electric power systems of Mongolia.

No.	EPS	Power plants		Length of transmission lines, km					Note
		Name	Installed capacity, MW	220	110	35	15	10-6	
1	CEPS	CHP-2	21.5 (1.99%)						CEPS supplies power for people in 13 aimags and covers 60 percent of Mongolian territory.
		CHP-3	198 (18.39%)						
		CHP-4	723 (67.14%)						
		NEEPS	50 (4.64%)						
		ECP	36 (3.34%)						
		DarCHP	48 (4.46%)						
		BUPVS	0.4 (0.04%)						
		Total	1076.9 (100%) (92.6%)	1434	3439	6197	1694	9619	
2	WEPS	Durgen HPP	12 (100%)						110kV transmission line 800 km long works in parallel with Krasnoyarsk EPS (the Russian Federation).
		Total	12 (100%) (1.03%)	-	779	951	960	1207	
3	SEPS	DCP	9 (33.3%)						Mining industry is rapidly developing in this province, including Oyu Tolgoi copper-molybdenum mine, and Tavan Tolgoi coal basin
		TTCPP	18 (66.7%)						
		Total	27 (100%) (2.32%)	-	-	431	161	236	
4	AUEPS	Taishir HPP	11 (100%)						It is connected to WEPS by a single-circuit 35kV TL and to CEPS by a single-circuit 110kV transmission line.
		Total	11 (100%) (0.95%)	-	253	929	533	525	
5	EEPS	DorCHP	36 (100%)						It is connected to CEPS by a single-circuit 110kV transmission line.
		Total	36 (100%) (3.1%)	-	849	990	292	722	
Total:			1162.9 (100%)	1434	5321	9498	3640	12309	

both technical implementation and development of an appropriate methodology for modeling and for feasibility studies on the complex development of rapidly growing electric power industry and EPSs of Mongolia.

II. The Current State of Mongolia's Electric Power Industry and Prospects for its Development

1. The Current State of Mongolia's Electric Power Industry

The area of Mongolia is 1.5 million square kilometers; its population is about 3 million people. The country is rich in different mineral resources, including coal and oil shale. In the foreseeable future they will remain the major fuels for the power industry. There are also some other prospective energy resources to be taken into account when making decisions on strategic development of the national EPSs [1].

At present there are five independent EPSs in Mongolia:

1. Central Electric Power System (CEPS)
2. West Electric Power System (WEPS)
3. South Electric Power System (SEPS)
4. Altai-Uliastai Electric Power System (AUEPS)
5. East Electric Power System (EEPS)

Present-day structure of Mongolian EPSs is given in Fig. 1, while some quantitative characteristics of five independent EPSs are given in Table 1, where NEEPS is Northeast EPS, DarCHP is Darkhan CHP, ECP is Erdenet CHP, TTCPP is Tavan-Tolgoi CPP, DCP is diesel CHP, DorCHP is Dornod CHP.

The data given in Table 1 show that 92.6% of Mongolia's generating capacities are concentrated in CEPS that covers more than 60% of the country's territory. Almost all the power plants of CEPS (with the exception of 50 MW Salkhitiin wind mill and 0.4 MW Buyant-Uhaa photovoltaic system – BUPVS) are combined heat and power plants (CHPs) designed for heat and power cogeneration. In the structure of CEPS generating capacities, the cogeneration plants account for 92.15%; condensing power plants (Ukhaa-Khudag CPP) fired by brown coal make up 1.54%; wind mills - 4.3%; hydro power plants (HPP) - 1.97%, and solar power plants account for 0.04%. The share of renewable energy sources in the total power generation does not exceed 6.3%.

The presented structure of generating capacities does not take into account back-up diesel power plants of aimag and somon centers, and local hydropower plants. According to the data available, diesel power plants of aimag and somon centers in 2014 generated about 0.15% of the total electricity generated in the country.

Electricity demand of almost all the consumers distant from the centralized electricity system has been satisfied owing to the "100 000 Solar Ger Electrification" programme launched in the early 2000s. The Project implied the use of small-size power sources. This project has been successfully implemented and electricity demand of local households has been almost 100% met. Due to lack of reliable statistical data it is difficult to assess quantitative results of the "100 000 Solar Ger Electrification" programme. Nevertheless, assuming that power consumed by one herder family in the decentralized areas (provided they use energy-efficient domestic appliances) is approximately equal to 100 W, the power consumed by 180 000 nomadic families will make up 18 MW. Thus, electricity generation by solar power plants reaches 1.4% of the total power generation in the country.

At present 80% of consumed electricity is generated in Mongolia and 20% is imported from Russia and China. On the average, 14.4% of electric power generated by CHP are used for auxiliary needs; power losses in the system on the average are 13.7%. These figures are by 1.3-1.7 times higher than those for developed countries [2]. In the future, they should be made equal to the world indicators.

Electric power systems of Mongolia are composed of overhead transmission lines for the voltage levels of 110 kV, 220 kV, as well as of 0.4 kV, 6 kV, 10 kV, (15), and 35 kV. Transfer capability of a transmission line depends on the wire cross-section, the number of circuits and the distance the line covers [3].

Technical characteristics of the lines, including their transfer capability, and the largest power transmission distance are given by voltage level in Table 2 [3].

An analysis of a scheme of Mongolia's electric power systems (Fig. 1) and the data in Table 2 reveal that 220 kV transmission lines are within feasible limits in terms of transmitted power and extension, whereas the distance covered by 110 kV and 35 kV transmission lines exceeds the recommended values given in Table 2, which reduces transfer capability of the lines and disturbs their normal operating conditions. As an example, 110 kV transmission line Bulgan-Muren-Uliastai-Altai covers the distance of 1000 km. Excessive (above recommended size) length of this line has a negative impact on its operation, reduces its transfer capability and complicates its operation.

In Mongolia's electric power systems, the length of 220 kV transmission lines in CEPS alone is 1434 km, that of 110 kV lines is 5321 km, including 3439 km within CEPS. Due to poorly informed technological policy in the national electric power industry, the electric power systems of Mongolia have not been appropriately developed. Ultra-long low-voltage transmission lines built in the late 1990s were, on the one hand, of high social value as they supplied power to a large community but, on the other hand, they produced some negative effects. In particular, the quality of transmitted power deteriorated, the systems could not operate efficiently, and the dispatching and emergency control capabilities diminished.

According to the calculations of power flows of the ultra-long low-voltage transmission lines, it was necessary to install compensators at the terminal substations but due to a considerable increase in the total costs, this was not done. Improper decisions on the transmission line length, voltage, and technical implementation negatively affect the coordinated operation of relay protection and automatic

Table 2. Transfer capability of transmission lines.

Rated voltage, kV	Highest transmitted power per circuit, MW	Largest distance of transmission, km	Actual transmitted power, MW
35	5-15	30-60	3
110	25-50	50-150	30
220	100-200	150-250	120

Table 3. Mix and characteristics of the existing substations.

Voltage, kV	CEPS	WEPS	AUEPS	EEPS	SEPS	Total
220	6					6
110	56	9	4	13		82
35	207	18	12	17	15	269
15	94	39	21	34	11	199
6-10	3811	431	132	206	117	4697

devices, lead to the adverse changes in the functional properties and operation principles of earthing protection in the lines with insulated neutral. Moreover, the increasing length of the transmission lines makes it more difficult to detect faults; the error of their detection increases, and it takes more time to restore the lines.

The total length of transmission lines is given in Table 1. The number of substations in each individual system is given in Table 3. Quantitative characteristics of the country's electric power systems are assumed based on the data published by the Energy Control Committee of Mongolia in 2014 [4].

Eighty eight 110 kV (and above) substations are currently in operation in five EPSs of Mongolia, of which 18 substations are major substations, and the remaining 70 are intermediate and terminal substations. Long distances between substations have a negative impact on power flows. Thus, it becomes necessary to construct additional major substations and power plants. Raising the transmission line voltage can be an alternative to construction of substations and power plants and a way to tackle the pressing problems.

Due to a rapid urbanization process, 70% of population is concentrated in the cities of Ulaanbaatar, Erdenet, and Darkhan. These are central provinces where power consumption grows and power flows increase causing overload of transmission lines and substations, which reduces the reliability of CEPS as a whole [4]. Lack of sufficient generating and backup capacities results in electric power shortage, which diminishes energy security of Mongolia.

Table 4. Forecast of per capita power consumption.

Years	Forecast of per capita power consumption, kWh		
	Low	Medium	High
2012	1.739	1.739	1.739
2015	2.269	2.269	2.269
2020	3.914	4.232	5.015
2025	4.994	5.408	6.425
2030	6.172	6.692	7.959

2. Power consumption forecast

As Mongolia's industry develops, the power consumption grows annually by approximately 10%. According to estimations, electricity demand in 2030 will be as high as 3.5 GW, whereas total present-day generating capacity is 1GW. The expected demand for electricity and power in terms of reliability and security cannot be met by imported electricity alone, therefore, construction of new power plants, substations and transmission lines is required.

The development of electric power systems was stipulated in the "State Energy Policy for 2015-2030" approved by the Decree of Great Khural No. 63 of June 19, 2015 [6]. Objective of the Policy is to establish an Integrated Power System of Mongolia. Paragraph 1.2 of the Decree indicates that "Governmental energy policy pursues the objective to provide continuous and reliable power supply in the country and to convert Mongolia into an electricity-exporting country". Implementation of this policy will require construction of new power plants, electric networks, and substations.

All the five above-mentioned operating electric power systems should be interconnected into an Integrated power system of Mongolia. Reliable operation of each individual power system should be provided to ensure reliability of the entire Integrated power system. A feasibility study of optimal sites and required capacities of new power plants and substations should be conducted, given the increase in electricity demand. Based on the note to Table 1, we can suppose that some of the five existing power systems are interconnected but more careful consideration makes it obvious that for efficient operation of this interconnection certain technical requirements should be met to provide their joint operation.

Three most probable scenarios of per capita power consumption growth are given in Table 4. The annual growth, depending on scenario, is on the average 15-20% and during the period under review, it will increase by 3.5-4.6 times.

The estimated growth of power consumption requires

Table 5. Projected power facilities, expansion of existing facilities.

No.	Power plants	Location	Installed capacity, MW	Date of commissioning
1	CHP-3	Ulaanbaatar	250	2019-2020
2	Darkhan CHP	City of Darkhan	35	2019
3	Erdenet CHP	City of Erdenet	50	2019-2020
4	CHP-5	Ulaanbaatar	450	2019-2021
5	Tavan-Tolgoi CHP	South-Gobi aimag	450	2019-2021
6	Baganuur CHP	City of Baganuur	700	2019-2021
7	Telmen CPP	Zavkhan aimag	100	2019-2021
8	Choibalsan CHP	City of Choibalsan	100	2019-2021
9	Nuurst-Khotgor CPP	City of Ulan-Gom	100-600	2019-2021
10	Eg HPP	Selenge aimag	325	2019-2022
11	Chandgana CPP	Khentii aimag	600	2019-2022

Table 6. Projected transmission lines and substations.

No.	Names of substations (SS) and transmission lines (TL)	Voltage, kV	TL length, km	Note
1	CHP-5-Songino 2-circuit TL and SS	220		FS and FEED
2	Baganuur-Choir 2-circuit TL and SS	220	178	FS and FEED
3	Choir-Saynshand-Zamyn-Uud 2-circuit TL and SS	220	406	FS and FEED
4	Baganuur-Underkhan-Choibalsan 2-circuit TL and SS	220	519	FS
5	Oyu-Tolgoi-Tsagaan-Suvarga 3-circuit TL and SS	220	160	FEED
6	Nariinsukhait TL and SS	220	270	
7	Ulaanbaatar-Mandalgovi TL and SS	330	260	FS and FEED
8	Baganuur-Ulaanbaatar 2-circuit TL and SS	500 minimum	157	
9	“Baganuur-Choir” TL and SS	500 minimum	190	

Note: FS - Feasibility Study; FEED - Front End Engineering and Design; SS - substation

construction of new power plants, given their technical characteristics and geographical location of consumers.

3. Prospects for Mongolia’s Integrated Power System Development

To meet the rising power demand of the economy and social sphere and to provide the required technical and technological reliability of power supply it is necessary to concurrently put into operation new generating capacities, transmission lines and substations. A presumable mix of new power plants, transmission lines and substations for the years to come is given in Tables 5 and 6. All these measures were developed in different years, for different conditions and very often were not interrelated, therefore, additional comprehensive studies are necessary to justify the investment and motivate investors.

An analysis of operating electric networks within EPSs shows that transfer capability of some existing transmission lines does not match the output capacities of power plants. This fact indicates the necessity of raising the voltage levels and increasing the number of circuits in transmission lines. According to the calculations, new 330kV and 500kV overhead power lines need to be constructed. These voltage levels are new for Mongolia. However, they have been scientifically grounded and tested in other countries, and have all the prerequisites for being implemented.

4. Structural Models of Prospective Integrated Power System in Mongolia

In 2013, the Asian Bank for Reconstruction and Development proposed a Master Plan for development of

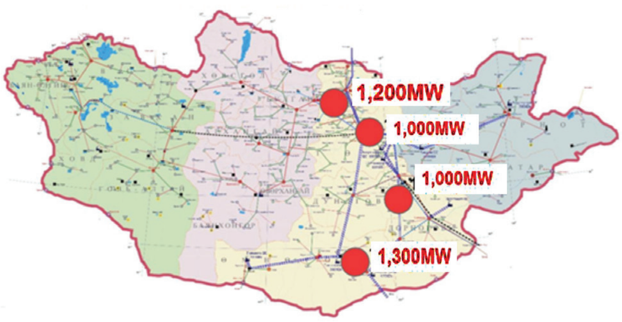

Fig. 2. Prospective industrial zones of Mongolia.

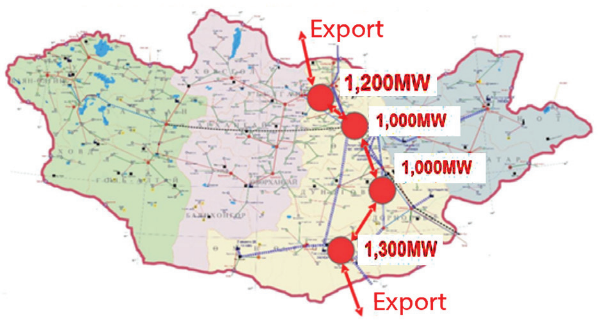

Fig. 3. Export-oriented model (vertical).

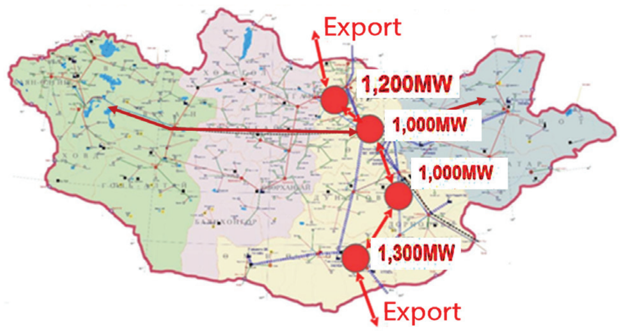

Fig. 4. Time-zone model (horizontal).

Mongolia's electric power industry. In the long term, this Plan suggests creation of four industrial zones with power consumption of about 1000 MW each (Fig. 2). One zone is proposed to be located in the neighborhood of Ulaanbaatar; the so-called "northern industrial zone" is proposed to be located in Darkhan-Erdenet; the "central industrial zone" is proposed to be located in Sainshand or Choir, and the "southern industrial zone" - in Tavan Tolgoi.

To meet energy demand of the future industrial zones it is advisable to have several conceptual models of EPS development and to select the most optimal one. There can be three options of initial conceptual models.

Export Model (power export-oriented) suggests construction of an interconnected power system connecting four developing industrial zones through high-voltage (400 kW minimum) transmission lines and cross-border lines to Russia and China. It has exporting and importing transmission lines spatially oriented along the vertical axis of Mongolian territory (Fig. 3).

Time-zone model suggests construction of EPSs around the HV (400 kV minimum) transmission line extending along the horizontal axis of Mongolian territory (Fig. 4). This model takes into account time differences between western and eastern provinces of the country. This and the previous model ensure the participation of Mongolia in the energy cooperation with NEA countries, primarily with China and Russia.

Radial model, the so-called "pitchfork", represents a mixed system integrating the above-considered models (Fig. 5). This model is the most advantageous but requires the highest investment.

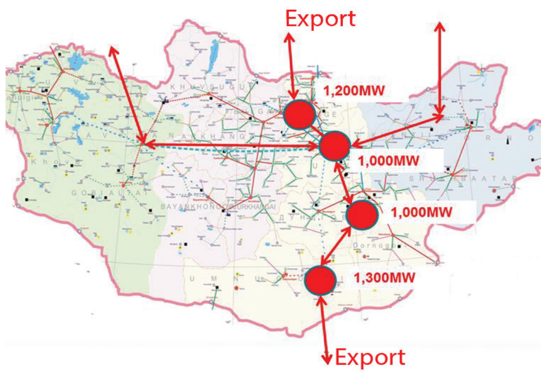

Fig. 5. Radial model, a "pitchfork".

Apart from the largely available technical capabilities of the EPSs development and establishment of Mongolia's integrated power system, it is necessary to prepare the scientific and methodological grounds to make it part of the Northeast Asian energy infrastructure.

Relevant scientific and methodological procedures should be developed to determine optimal location of generating capacities, select their type and size, and determine location of transmission lines and substations.

III. Mongolia's Potential for Interstate Energy Cooperation

1. Characteristic of the Potential

Against the background of different levels of development of the world countries, availability of renewable (wind, solar, and hydro) and conventional energy sources, power import and export have become an indispensable part of the energy policy in many countries. In this context, the energy market expands, as a rule, to the neighboring countries. Energy market expansion is primarily based on the construction and development of International Power Pools (IPPs) [7].

Creation of an IPP as an integrated engineering system will benefit electricity trade, provide sustainable power supply to the regions, enhance the efficiency of installed capacities, boost technological advancement of the energy infrastructure, contribute to the development of environmentally friendly power generation, help to solve environmental problems, and encourage joint construction of power generating facilities in the countries within the power pool.

An analysis of international experience shows that international power pools are, as a rule, established on a bounded territory covering two or more states, or in the off-shore zones [8]. Studies on creation and expansion of interstate power pools focus on large capacities based on renewable energy sources (solar, wind, hydro). This is done, on the one hand, to compensate for the shortage of generating capacities of conventional power sources and, on the other hand, to ensure the sustainable environment. For example, China deploys solar and wind facilities, Mongolia studies possibilities for constructing similar facilities in the Gobi Desert [8,9] with a view to their future integration into the Northeast Asian Super Grid (Fig. 6) [10].

2. Prerequisites for Mongolia's Participation in the Energy Cooperation in Northeast Asia

For participation in the Northeast Asian Super Grid, Mongolia can offer construction of large-scale power plants by making use of rich renewable energy potential in the Gobi Desert, and construction of high-voltage AC and DC transmission lines to ensure sustainable development of the electric power industry in the region. It is worth noting that Russia, China, Japan and South Korea are interested in this project, and comprehensive studies on the prospects for the development of the region are currently under way [10, 11]. Some of these countries border one another; they have a multi-year experience of mutually beneficial trade and have sufficient financial potential for investing into construction of large-scale power plants of different types. Russia together with China and Japan, and China together with Democratic People's Republic of Korea have launched some joint large-scale energy projects [12, 15] that can form a basis for the future Northeast Asian Super Grid. Mongolia's potential for participation in the Asian Super Grid Project [16, 17] requires a scientifically grounded assessment of capacities and sites for new power plants considering spatial distribution of energy resources throughout the country, and an analysis of energy markets.

In the recent years investors very often refused to finance construction of coal-fired power plants as they pollute the environment. After large accidents at nuclear power plants (NPPs) followed by negative consequences, public in many countries of the world is against NPP construction and operation. These circumstances require revision of the energy policy in many countries and its switch to renewable energy sources. Similar tendencies are observed in Mongolia as well, as along with considerable amount of conventional fuels the country has rich potential of renewable energy sources. The forecast coal reserves in the country are estimated at 175 billion t, oil reserves make up 205 million t, and those of uranium - 68 million t [18, 19]. According to the estimates of the US National Laboratory on Renewables, Mongolia has high wind resource potential, its forecast capacity equals 1100 GW (only as little as 10% of Mongolian territory has specific power of above 600 W/h) [9]. According to the Report of the Energy Charter Treaty issued in 2014, the forecast solar-based capacity can amount to 2500 GW [9, 16, 17]. This potential is graphically presented in Fig. 7.

The country has considerable energy resources, both

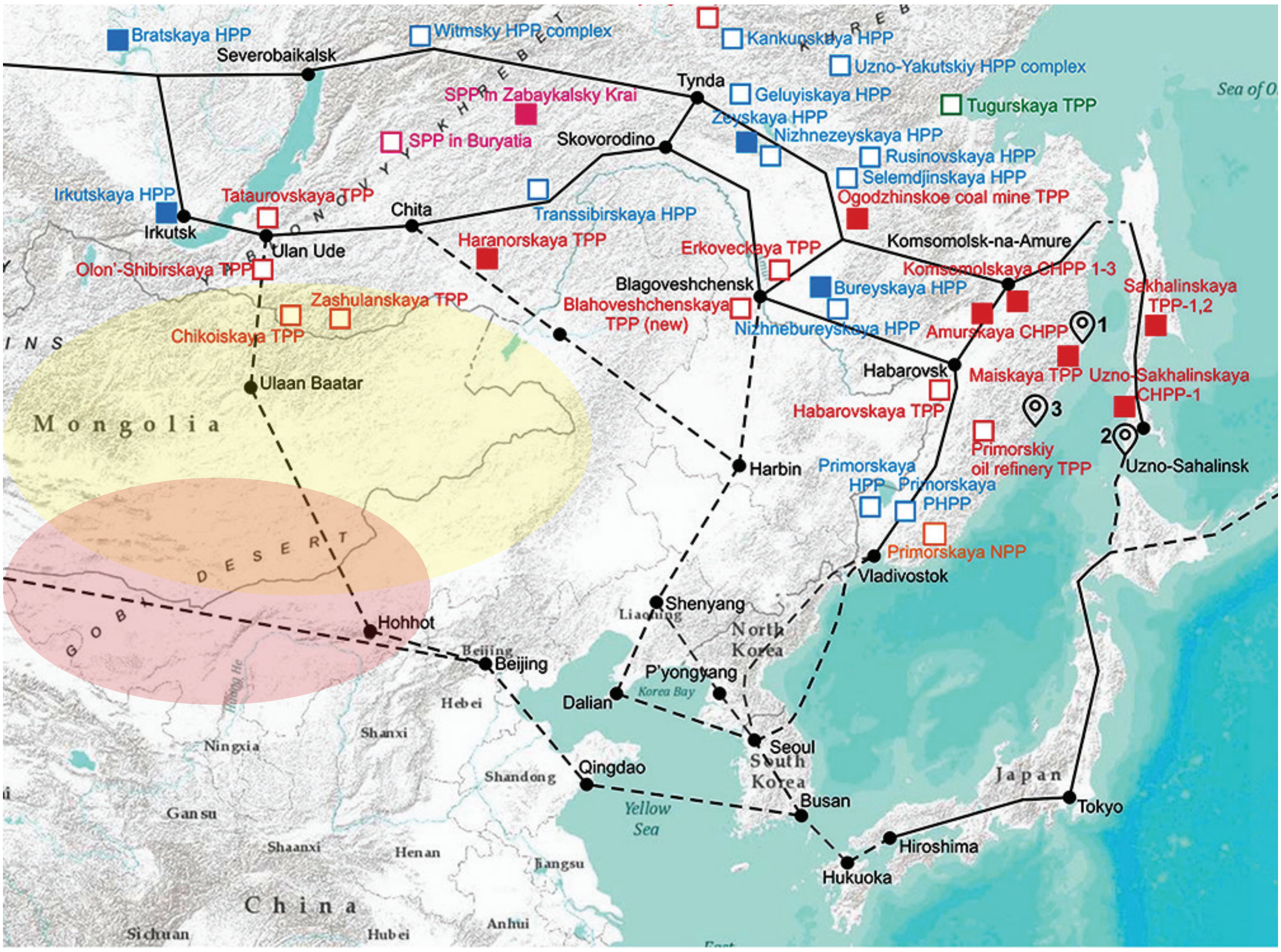

Fig. 6. General scheme of the projected Northeast Asian Super Grid. Map source: Skolkovo Institute of Science and Technology.

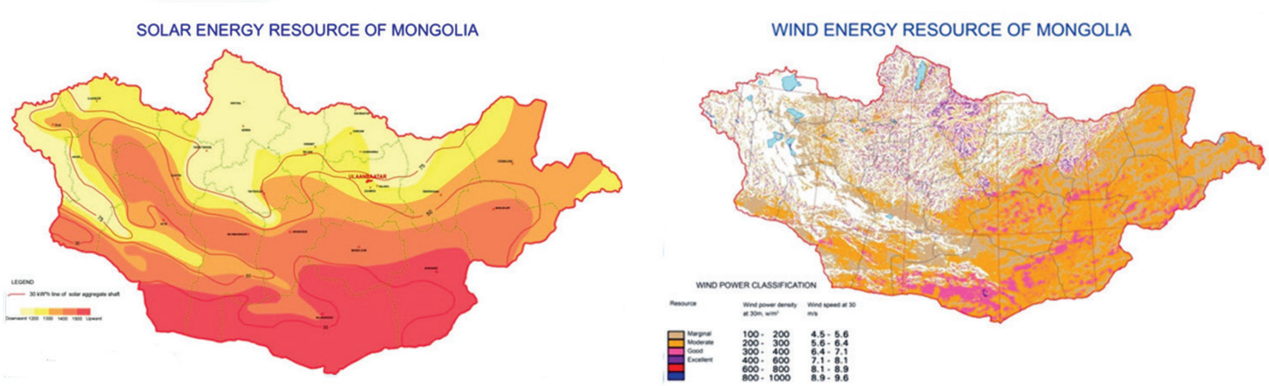

Fig. 7. Average annual solar and wind potential in the projected solar-wind Gobitec system. Source: http://eeam.energy.mn/

Table 7. General characteristics of electric power industry of Mongolia and Northeast Asia countries.

Indicator	PRC (2013)	Russia		Republic of Korea (2013)	Japan (2012)	Mongolia (2012)	DPRK (2012)
		Siberia* (2013)	Russian Far East* (2013)				
Area, m sq. km	9598	5115	6169	99	373	1565	121
Population, m people	1357.4	19.3	6.3	50.0	127.6	2.8	24.8
Electricity consumption, TWh	5322.3	205.3	31.61	474.9	991.6	5.2	1.2
Per capita consumption, kWh	3921	10637	5017	9498	7771	1857	734
Power generation, TWh	5347.4	197.4	35.2	517.1	1094.0	5.2	21.5
Installed capacity of power plants, GW	1247.4	49.3	9.1	91.0	287.3	1.02	7.22
Including thermal power plants:	796.4	25.0	5.7	56.3	188.9	0.97	2.96
On coal	758.1	24.2	5.2	24.5	50.9	0.88	2.76
On gas and fuel oil	38.3	0.8	0.5	31.8	138.0	0.09	0.2
HPP	280.0	24.3	3.3	6.5	48.9	0.03	4.26
NPP	14.6	-	-	20.7	46.1	-	-
Renewable energy sources	86.8	-	-	3.5	3.4	0.01	-

*Power production and consumption, and installed capacities are given for Interconnected Power Systems of Siberia and the Russian Far East, respectively

conventional and renewable, and at the same time it suffers from electric power shortage that keeps growing against the background of continuous power consumption increase (from 7% to 10% annually) [20]. Unfortunately, appropriate measures to bridge this gap have not been taken. For instance, power import from neighboring countries in 2017 reached 1420 million kWh, its major share being the power flow through the Mongolia-Russia cross-border transmission line. The existing energy cooperation with the neighboring countries is as a rule limited to power import. It is obvious that this principle of cooperation is inefficient in the context of cooperation between electric power systems of neighboring countries, to say nothing about cooperation in creation and development of the Northeast Asian Super Grid.

3. Specific aspects of Northeast Asian Super Grid and Prospects for Mongolia

Currently, there are several 110-220 kV cross-border transmission lines operating in the Northeast Asia with a transfer capability of 100-150 MW. Existing transmission lines between Russia and Mongolia, Russia and China, China and Democratic People's Republic of Korea (DPRK), and China and Mongolia can also be referred to such cross-border transmission lines [13 - 15]. An export

500 kV cross-border transmission line connecting Amur (RF) and Heihe (China) substations was put into operation in 2011; its transfer capability is 750 MW and it has a DC link [21, 22].

Studies on creation of interstate electric power systems are carried out by research institutions from Russia, the Republic of Korea, the People's Republic of China (PRC), Japan, Mongolia and from some other countries, as well as by Asian-Pacific Energy Research Center (APERC) in Tokyo (Japan). General characteristics of electric power industry of potential participants in the Asian Super Grid Project are given in Table 7.

Mongolia can become an important player in the energy space of Northeast Asia and increase its role in shaping and developing Northeast Asian Super Gird, provided the country has a comprehensive target-oriented energy policy and a scientifically grounded energy development concept. The implementation of this concept will open up the following opportunities for Mongolia:

1. Power from Mongolia will be supplied to the Northeast Asia regions that have a high demand for electricity due scarce energy resources;
2. The intermittency of renewable power generation will reduce and the efficiency of renewable energy sources will increase.
3. The nature of weakly developing Mongolia's electricity export and import will change qualitatively, as it will become an exporting-importing country rather than an importing country.

Technical and technological issues related to interconnection of regions by cross-border EHV (500 kV, 750 kV) and UHV (1150 kV) AC overhead transmission and cable lines, and DC ±400 kV, ±600 kV, ±800 kV transmission lines come to the forefront.

4. Formation of an Interstate Electricity Market

The above facts and level of the country development necessitate working out the national concept of Mongolia's participation in the large-scale project of the Northeast Asian Super Grid. For maintaining and expanding its electricity market and for entering the interstate electricity market in the near future, Mongolia needs to accomplish the following tasks:

1. Create incentives for foreign and domestic investors.
2. Develop and implement the projects on construction of new generating sources and transmission lines in cooperation with interested parties on the basis of Mongolia's energy development strategy.
3. Deploy solar and wind power plants with a capacity above 4000 MW, and new cross-border transmission lines in the sparsely populated areas of the desert.
4. Cooperate with the countries of Northeast Asia in the field of electric power industry. Enhance the efficiency of such cooperation by considering seasonal variations in loads in each country, time differences, and climatic features.

The creation of the Super Grid infrastructure primarily requires commitment and support of the neighboring countries and feasibility studies on power export-import.

According to [9, 11], the cross-border 220 kV transmission lines are currently operating in Mongolia for connection with the EPSs of Russia and China, which allows gaining the required experience of operating such lines. In the event that the existing interstate relations are developed and huge renewable energy resources of the Gobi Desert and coal reserves are involved, Mongolia can play a significant role in the formation and further development of interstate interconnections within the Northeast Asian Super Grid.

Table 8. World power production and consumption.

	Country	Generation, GWh	Population, thousand people	Per capita consumption kWh/capita
1	China	5649500	1376622	4103.89
2	USA	4297300	323394	13288.13
3	India	1208400	1288306	937.98
4	Russia	1064100	146545	7261.25
5	Japan	1061200	126980	8357.22
6	Germany	614000	81174	7564.00
7	Canada	615400	34850	17658.54
8	Brazil	582600	205738	2831.76
9	France	555700	64513	8613.77
10	Republic of Korea	517800	51431	10067.86
119	Mongolia	5541.7	3000	1847.23
215	NIUE	3	14	214.29
	World, total	23536500	7300000	3224.18

Japan comes second in the region after China in electric power generation and consumption and ranks first in Northeast Asia in nuclear power development. Due to limited domestic energy resources and import-oriented power supply, the electric power industry of the country has two objectives: to reduce the dependence on energy import and mitigate negative impact of thermal power plants on the environment. In this context, the interstate electric ties between neighboring countries and import of environmentally clean electric power from Russia and China could considerably improve the environmental situation in the country. Different projects of cross-border transmission lines between Japan and neighboring countries are proposed. They need feasibility studies for construction of overhead transmission and submarine cable lines.

The Republic of Korea has a highly developed electric power industry. This country is a leader among other Northeast Asia countries in per capita electric power production (Table 8). Structure of generating capacities in South Korea is similar to that in Japan. The country is highly interested in import of environmentally clean electricity from Russia and China.

Table 8 presents indicators of power production and consumption in the countries of Northeast Asia and the world versus similar figures for Mongolia. Of interest are the figures on specific per capita power consumption that are widely dispersed as regards the average level. Per capita power consumption is the highest in Canada, the USA, and South Korea. This indicator for Mongolia is below the mid-level. At the same time, it has a potential for enhancing this indicator owing to rich resources of conventional and renewable energy. Moreover, the country can enter the electricity market as an exporter.

5. Prospects for the Northeast Asian Super Grid

The studies [7, 10 – 15 et al.] show that the prospects for cooperation in the electric power sector in Northeast Asia largely depend on the projects of interstate electric ties and large-scale projects for the construction of the Northeast Asian Super Grid. There can be various forms of the cooperation: cross-border trade; electricity export; interconnection of national and local EPSs of neighboring countries for joint (or parallel) operation. There can also be different structures of generating capacities (ratio between power sources of different types), and engineering and technological solutions for the cross-border transmission lines (Table 9)

Power transmission from the wind-solar system in the Gobi Desert is another interesting option of interstate electrical ties in Northeast Asia (Table 9).

Russia offers options of constructing large-scale hydro power plants intended for long-distance electric power transmission. One of them is a 9050 MW HPP proposed to be constructed on the Lena River. The average multi-year

Table 9. Prospective interstate electrical ties between Northeast Asian countries.

Interstate electrical ties	Length, km	Voltage, kV	Transmission capacity, GW	Transmitted power, TWh/year	Tentative cost, bn USD
Russia-China					
Bratsk - Ulaanbaatar - Beijing	2250	±600	5-6	18	1.8
Bureya HPP - Harbin	700	±400	1.0	3	2.2
Large-scale electric power export projects	3400*	±600	10*	60*	18*
Erkovetskaya TPP – Shenyang	1300	±600	3.6	20	8.8
DC transmission line Ust-Ilimsk - Khabarovsk	5000	±750	10.0	40	16.5
Russia - Korean peninsula					
Vladivostok - Chongjin	370	±500	0.5	3	0.13
Vladivostok - Pyongyang - Seoul	1150	±500	4.0	7	4.8
South-Yakutia HPP - Shenyang - Seoul	2400	±750	5.0	20	10.5
Russia – Japan					
Sakhalin - Hokkaido - Honshu	1850/1400**	±600	4.3	24	9.6
Sakhalin - Hokkaido	500/50**	±500/±400	4.0	24	6.7
Asian Super Grid					
Gobitec - Mongolia, Russia, China, Korea, Japan	7300	±800	100	200	56.7

*Generalized indicators of the project

** Total length is in the numerator, submarine cable length is in the denominator power generation is 7.8 TWh, cost of HPP construction is about USD 3.6 billion. There are plans to construct Mokskaya HPP on the Vitim River in Buryat Republic; its power will be transmitted to the power-deficient areas in the Russian Far East, Mongolia and China. The Bureya and Zeya HPPs operating within the Amur EPS can be referred to the export-oriented plants. Implementation of those proposals will ensure power supply to consumers in Siberia and the Russian Far East. Moreover, the above plants will certainly enable the maneuverable operation of cross-border transmission lines, and enhance the efficiency of the cross-border electric power systems.

Connection of the Mongolian EPS to the future Bratsk-Ulaanbaatar-Beijing project for export of surplus power from the Siberian interconnection will increase the efficiency of this project, and create good conditions for power export to the neighboring countries. A contract on mutually beneficial energy cooperation between RAO EES of Russia and State-Owned Network Corporation of China was concluded in 2005. According to this Contract, Russia was to export 60 trillion kWh annually to China [20]. Phase I of this project was completed by connecting the Russian Far East interconnection to Heihe network (Northeast province of China), which at present enables an annual supply of up to 3.5 billion kWh from the Russian Far East interconnection to the Northeast provinces of China.

Connection of the Russian Far East Interconnected System to the EPS of the Republic of Korea through the cross-border transmission line Vladivostok - Pyongyang-Seoul, 1150 km long, is expected to be the most cost-effective project among the projects named. The expected economic effect due to the interconnection of capacities and use of time zones will be USD 6-7 billion [7].

The Sakhalin - Hokkaido - Honshu project, the so-called "power bridge" whose idea emerged in the 1990s, is another interesting project of cross-border power transmission. Export-oriented thermal power plants (4 GW Solntsevskaya coal-fired power plant at Phase I and Vakhrushevskaya steam-gas power plant at Phase II) and a ±400 kV DC transmission line Sakhalin - Sapporo – Tokyo, covering the distance of 1600 km with two submarine cable lines across La Peruza Strait (50 km) and Tsugaru Strait (40 km), are planned to be constructed within this Project.

For participation in the creation of the Northeast Asian Super Grid, Mongolia should conduct a feasibility study on the project for construction of a wind-solar system in the Gobi Desert (Gobitec) with a view to exporting cheap electric power to China, the Republic of Korea, Japan, Russia, and take part in its implementation. This generates the need to construct DC (±600 kV) and AC (500 kV) transmission lines.

The use of the 100 GW wind-solar system in the Gobi Desert (Gobitec) will give an impetus to the formation of the Northeast Asian Super Grid, particularly, to some of its components: the Mongolian Ring: Gobitec-Mugden-Harbin-Kharanuur; the Sea-of-Japan Ring: Seoul-Pyongyang-Hokkaido-Honshu; the Big Ring: Bratsk-Urgalsk-Sakhalin-Tokyo-Shanghai-Beijing-Ulaanbaatar-Irkutsk. It is obvious that it will take a very long time to implement this super-project, but its effect will be enormous. For example, fuel saving alone will be USD 10.0 trillion a year.

IV. Conclusion

There are four stages in the creation and development of Mongolia's electric power industry, each with its specific features conditioned by the level of development and needs of the economy. Five electric power systems are currently in operation in Mongolia. They are interconnected but have no technical and technological prerequisites for operation within the Integrated Power System of Mongolia. With intensive development of industry, including mining industry and production of mineral resources, the power demand in the country grows dramatically. For meeting the growing power demand, Mongolia imports electric power from Russia and China. The imported electric power currently accounts for about 20% of its annual consumption.

An analysis of the current state of Mongolia's electric power industry shows that it faces some problems to be solved. These are incompletely used transfer capability of transmission lines due to lack of appropriate network equipment; comparatively high (up to 30%) power transmission losses; rather low efficiency of power plants (25-30%), etc. In order to increase the efficiency of EPSs, enhance their performances, and identify prospective innovative development of the electric power industry, it is necessary to undertake great research effort to study the unit commitment, structure of the systems, potentials for their technological advancement, feasibility of their interconnection into the Integrated power system, and substantiate the principles of its integration into the Northeast Asia energy space. This paper proposes conceptual models of restructuring Mongolia's electric power industry to meet the needs of its rapidly developing economy and allow the country to enter the electricity market of Northeast Asia.

Creation of an interstate power pool starts with construction of cross-border electrical lines ensuring joint operation of national or local EPSs. Normally, such lines are reverse, which makes it possible to gain many benefits constituting the synergy effect. For active participation of Mongolia in the creation and development of the Northeast Asian Super Grid, the future Shivee-Ovoo power plant should be considered as a candidate for integration into the interstate grid covering the Russian Far East, North and Northeast of China, Mongolia, South Korea and North Korea.

Mongolia is interested in active participation in the multilateral studies on the prospects for the development of the Northeast Asian Super Grid.

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