POWER GRID INTERCONNECTION IN NORTHEAST ASIA: PERSPECTIVES FROM EAST RUSSIA

Sergei Podkovalnikov
Energy Systems Institute, Russian Academy of Sciences, Siberian Branch
130, Lermontov St., Irkutsk, 664033, Russia
Tel.: +7 3952 464930, Fax: +7 3952 462796, E-mail: spodkovalnikov@isem.sei.irk.ru

I. INTRODUCTION

Interconnection of electric power systems (EPSs) of countries and regions has been developing in the world. There exist interstate electric ties (ISETs) in Europe and North America. ISETs are being developed in South America and Southeast Asia. The feasibility of creating ISETs in Africa and Middle East is being studied. The problem of forming ISETs and interconnecting EPSs of countries and regions in Northeast Asia (NEA), including East Russia, China, the Republic of Korea (ROK), the Korean People's Democratic Republic (KPDR), Mongolia, and Japan, has attracted ever-greater attention in recent years. Some studies have been done by South Korean, Japanese, and Russian scientists and power engineers in this field [1-4].

Russian interconnected EPSs (IEPSs), having been developed as a part of the USSR Unified electric power system, have extensive electric ties with adjacent EPSs of both European and Asian former Soviet Republics, including Estonia, Latvia, Byelorussia, Ukraine, Georgia, Azerbaijan, and Kazakhstan. Russian IEPSs are also interconnected with the Finnish power system through a DC back-to-back link and Norway. There are a few weak and short 110-220 kV transmissions connecting Russia and neighboring Mongolia and China and some other Northeast Asian countries. Meanwhile, interconnection of Russian IEPSs with the power systems of adjacent NEA countries and among other countries of the region may bring about substantial energy, economic, and environmental effects for all participants involved in power interconnection.

Further considered in the paper are a) current state and perspectives of the East Russian power industry; b) major potential effects of EPS interconnection in the NEA region and ways of their realization; c) major ISETs of Russia with NEA countries and their effects being attained in total and in particular for the Russian side; d) barriers to power grid interconnection and ways to overcome them; e) ways and stages of power grid interconnection in NEA; f) elements of methodology for studying ISETs in the region.

II. CURRENT STATE OF AND PERSPECTIVES ON THE EAST RUSSIAN ELECTRIC POWER INDUSTRY

Two interconnected electric power systems are located in East Russia. These are the IEPSs of Siberia and the Russian Far East (RFE). The interconnected EPS of Siberia is made up of ten regional electric power systems. Five of them serving the electricity needs of the Krasnoyarsk, Khakasia, Irkutsk, Buryatia, and Chita regions are located in East Siberia. The IEPS of the Russian Far East is made up of three regional power systems (of the Amur, Khabarovsk, and Primotye regions). Both interconnected EPSs spread over the most inhabited and industrialized territories of East Russia along the Trans-Siberian railroad on the South of Siberia and the RFE. The East Siberian and RFE IEPSs meet electricity needs on East Russian territory of about 4 Mln.km^2 with population of 13.5 Mln. (see Table 1). These power systems will be only considered hereafter, as they are close to adjacent NEA countries.

Table 1
Territory and population served

	Territory, Mln.km^2	Population, Mln.
East part of Siberian IEPS	2.5	8.5
Russian Far East IEPS	1.3	5
TOTAL	3.8	13.5

Each of the above-mentioned regional EPSs is intended to serve the electricity needs of its corresponding region. If it has excess capacity it sells electricity on the regional (either Siberian or Far East) wholesale market. If it has a lack of capacity it purchases electricity from the regional wholesale market. All regional EPSs are joint stock companies (JSCs). Apart from regional EPSs there are federal power plants. These are the largest hydro and thermal power plants owned by the Pan-Russian JSC "Unified Electric Power System of Russia" (called in Russian RAO "EES Rossii"). RAO also has shares in most of the regional power companies. The Russian Government has about 52% of the shares of RAO.

The highest electricity consumption by territories served by the eastern part of the Siberian IEPS and Russian Far East IEPS was in 1990 and reached about 160 Bln. kWh (see Figure1). Thereafter was decline of electricity consumption by about 20% (during eight years). Recovery started in 1998. According to plans for national economic development, the highest electricity consumption for these territories is to be restored by about 2010. By the year 2025 electricity demand for the region is expected to increase by nearly 60% more [4,5]. For the total period of 2000-2025 electricity demand is supposed to double. Average annual electricity growth rates are supposed to be 2.5-3%. The larger share of electricity demand is located in East Siberia. It is about 80% of the total value.

The total current generating capacity of the East Siberian IEPS is nearly 35 GW (see Table 2). More than 60% of this is installed on hydro power plants (HPPs). To meet projected electricity demand East Siberian capacities have to be increased by nearly 40% and will reach more than 48 GW by 2025. The share of HPPs will decrease to somewhat more than 50%. It is caused by development of large coal-burning power plants. Almost all thermal and co-generation power plants in East Siberia burn coal.

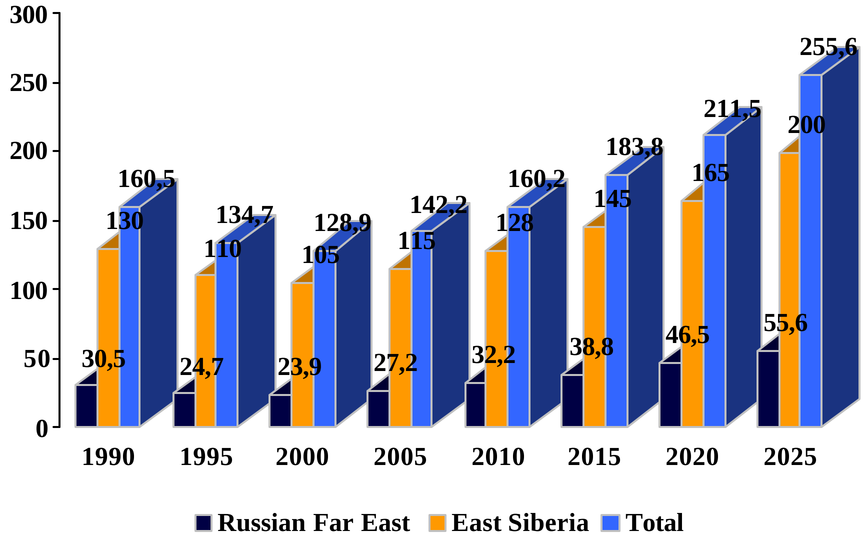


Figure1. Trend of electricity demand in East Russia, Bln. kWh/year

The current generating capacity of the Russian Far East IEPS is almost five times less than the East Siberian IEPS. RFE hydro power has nearly 20% of total installed capacity. By the year 2025 RFE capacities are supposed to grow more than twofold. Share of hydro power will also increase to more than 35%. In 2020 nuclear power may appear in the region [6]. In 2025 nuclear capacity is supposed to be doubled. Nuclear capacity is planned to be installed at the Primorye nuclear power plant (NPP) in the South of the Russian Far East. RFE thermal and co-generation power plants are almost all coal-burning.

Table 2
Generating capacities [5,7], GW

		2000	2005	2010	2015	2020	2025
East Siberia	Hydro	21.8	22.2	23.5	23.5	25.3	25.3
	Co-generation	6.1	6	6.6	6.7	7	7
	Thermal	6.8	7.1	7.1	10	10.7	16
	Subtotal	34.7	35.3	37.2	40.2	43	48.3
Russian Far East	Hydro	1.3	1.5	3.6	5.8	5.8	5.8
	Co-generation	3.3	3.5	3.7	4.2	4.8	5.4
	Thermal	2.4	2.4	2.2	2.6	2	2.8
	Nuclear	-	-	-	-	1	2
	Subtotal	7	7.4	9.5	12.6	13.6	16
TOTAL		41.7	42.7	46.7	52.8	56.6	64.3

There are very large hydro power plants in East Siberia with capacities exceeding several GW each (see Table 3). More than half of the East Russian generating capacity is installed in the 5 largest HPPs. The capacities of the 11 largest power plants of East Siberia and the RFE IEPSs exceeding 1 GW each amount to 70% of total installed capacities.

The largest prospective power projects to be developed in East Siberia and the Russian Far East are presented in Table 4. Three projects are being implemented. Their construction started in Soviet times and is still proceeding because of insufficient investment. Other hydro, thermal, and nuclear power projects are considered to be feasible [4,8] and can be realized in the future. A tidal power plant can be sited in the region in the South of the Okhotsk Sea [8]. It needs huge investments (about $12 Bln.) and is supposed to be constructed in the very remote future. All mentioned prospective power plants can meet both domestic electricity needs and supply electricity abroad.

Table 3
Large power plants

Power Plants			Installed Capacity, GW
Hydro	East Siberia	Sayano-Shushensk	6.4
		Krasnoyarsk	6
		Bratsk	4.5
		Ust-Ilimsk	3.8
	Far East	Zeya	1.3
	Subtotal		22
Thermal	East Siberia	Irkutsk	1.1
		Berezovsk-1	1.6
		Nazarovsk	1.3
		Krasnoyarsk	1.25
		Gusinoozyorsk	1.25
	Far East	Primorye	1.5
	Subtotal		8
TOTAL			30

Table 4
Large prospective power projects

Region	Project	Capacity, GW	Average Yearly Output, TWh
East Siberia	Boguchunsk Hydro (under construction)	3	17.6
	Moksk Hydro	1.3	5.3
	Berezovsk – 1 Thermal (under construction)	6.4	40
	Berezovsk – 2 Thermal	6.4	40
	Subtotal	17.1	102.9
Russian Far East	Bureysk Hydro (under construction)	2.4	8.8
	Uchursk Hydro	3.7	17.2
	Urgal Thermal	1.2	7.5
	Primorye Nuclear	2	15
	Sakhalin Gas	4	26
	Far East Nuclear	2.5	18
	Tugursk Tidal	6.8	16
	Subtotal	22.6	108.5
TOTAL		39.7	211.4

The backbone of the power grid in East Siberia and the RFE comprises 220 and 500 kV transmission lines. 220 kV transmission lines mostly (up to 90% of length) belong to regional power companies. The remaining lines of this voltage are owned by RAO "EES Rossii". More than 60% of 500 kV transmission line length belongs to RAO. These are transmissions connecting regional EPSs with each other. The rest of the lines of this voltage are owned by regional power companies. IEPSs of Siberia and RFE are interconnected by weak 220 kV transmissions. The backbone power grid and intersystem ties are planned to be strengthened by 500 kV transmissions.

III. POTENTIAL EFFECTS OF ELECTRIC POWER SYSTEM INTERCONNECTION IN NORTHEAST ASIA

The major effects being attained due to EPS interconnection in Northeast Asia are as follows [3].

- *Saving installed capacity of power plants* as a result of the fact that the combined annual load maximum of consumers in an interconnected power system is less than the sum of EPS annual maxima at their separate operation. This difference is especially large when annual load maxima in power systems being interconnected take place in different seasons of the year. This is exactly the case for the NEA region.

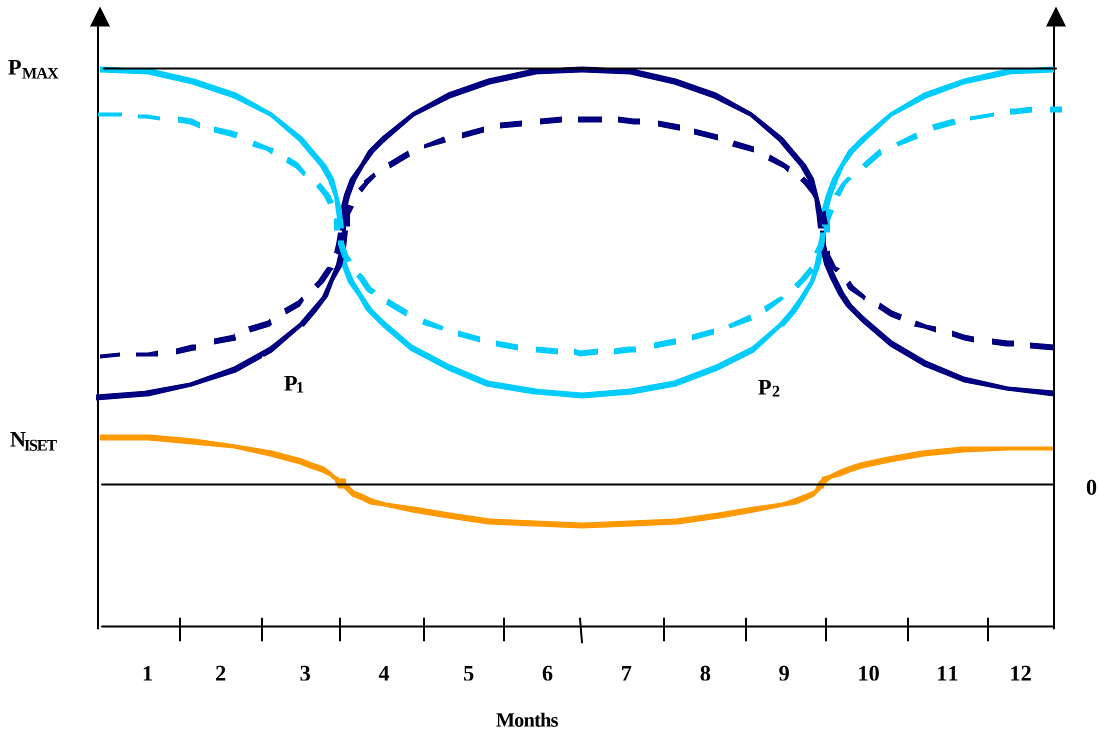
- *Decrease of fuel cost* due to possibility of joint optimization of operating conditions in interconnected power systems.

- *Reliability improvement of power systems being interconnected* or decrease in required capacity reserves with the same reliability. Reduction of reserves in each EPS is offset by receiving reserves from other EPSs through interstate electric ties. Emergencies of ISETs are also to be taken into consideration.

- *Environmental effect* can be gained when an ISET makes it possible to involve into power balances of Northeast Asian countries large environmentally cleaner power plants (hydro, nuclear with advanced types of reactors, or tidal), which otherwise will not be constructed (or will be constructed in the very remote future).

The first of the above effects seems to be the most significant. In Russia, the Northern provinces of China, the Korean People's Democratic Republic, and Mongolia the annual load maximum is in winter in the evening hours, and in Japan, the Republic of Korea, and the Southern provinces of China it is in summer in daytime. Interconnecting the EPSs of these countries will bring about sufficient effect of power plants capacity saving. The effect is explained using Figure 2 [3]. $\mathbf{P_1}$ in this figure is yearly load curve with summer peak (depicted in dark blue color). $\mathbf{P_2}$ is yearly load curve with winter peak (depicted in blue color). For the sake of simplicity summer and winter peak loads are assumed to be equal.

In EPS_1 with the summer maximum electric load during winter period of electricity consumption decrease, temporarily unused capacities of thermal power plants (TPPs) can be additionally loaded. This additional power output is represented in the Figure 2 as the area between the lower spotted dark blue curve and curve $\mathbf{P_1}$. The additional power generation can be transmitted via an ISET to EPS_2 having maximum load at that time. Transmitted power meets peak load in EPS_2 and replaces TPPs in energy and power balances there.



Replaced output of TPPs in EPS_2 is represented in Figure 2 as the area between curve $\mathbf{P_2}$ and the upper blue spotted curve. The saved capacity in EPS_2 is equal to the maximum difference between curve $\mathbf{P_2}$ and the upper blue spotted curve.

Figure 2. Effect of interconnecting EPSs with different seasons of load maxima

In the summer, to the contrary, TPPs of EPS_2 with the winter load maximum can be additionally loaded and their generation transmitted to EPS_1. The additional power output is represented as the area between the lower spotted blue curve and curve $\mathbf{P_2}$. In EPS_1 the transmitted power meets electric load and replaces power plant capacities. Replaced output of TPPs in EPS_1 is represented in Figure 2 as the area between curve $\mathbf{P_1}$ and the upper spotted dark blue curve. The saved capacity in EPS_1 is equal to the maximum difference between curve $\mathbf{P_1}$ and the upper spotted dark blue curve.

The magnitude and directions of power flows via ISET are also shown in Figure 2 by curve $\mathbf{N_{ISET}}$. Parts of the curve being above the zero axis represent power flow via ISET from EPS_1 to EPS_2 during winter months. Part of the curve $\mathbf{N_{ISET}}$

being below zero axis represents power flow from EPS_2 to EPS_1 via ISET during summer months.

Thus, installed capacity of power plants in power systems with different seasons of load maxima can be saved only by commissioning intersystem/interstate electric ties. This savings will be approximately equal to an ISET transfer capability in each EPS. The total value of the potential effect of capacity saving due to interconnection of EPSs with different seasons of load maxima can reach 30-40% of the capacity of a smaller EPS (it is equal to seasonal fall in power demand). This effect makes ISETs much more feasible than in the case of the one-season load maxima.

When interconnecting power systems with different seasons of load maxima, power plant capacities are utilized in a way explained in Figure 3. In winter a power plant with capacity N_{PP} meets maximum load in EPS_2. Electricity demand met by the power plant is represented in Figure 3 as the area between curve P_2 and the spotted blue curve. In summer, when power demand decreases in EPS_2, and EPS_1 conversely experiences maximum load, the power plant N_{PP} can meet load in EPS_1. It is necessary to point out that such "switching" of the power plant from EPS_2 to EPS_1 does not cause any deficiency of electricity for consumers of EPS_2 and no expenditures are required for commissioning additional capacities in EPS_2 to compensate for this "switching". Electricity demand met by the power plant in EPS_1 is represented in Figure 3 as the area between curve P_1 and the dark blue spotted curve.

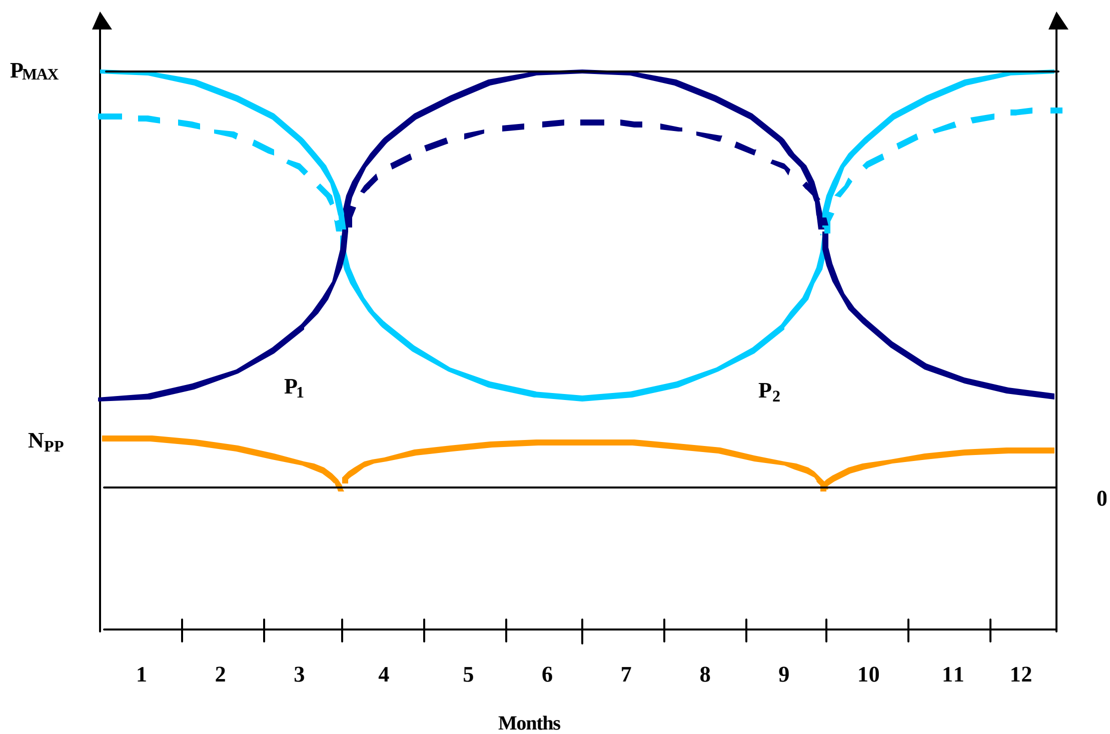


Figure 3. Utilization of power plant capacity in interconnected EPSs with different seasons of load maxima

Thus, there is a so-called "double effect" when a power plant meets power demand in both EPSs but in different seasons. So, 1 kW of generating capacity of this plant can, in principle, meet 2 kW of power demand in both EPSs: 1 kW in EPS_1 in summer and 1 kW more in EPS_2 in winter. This fact illustrates clearly the reason for saving power plant capacities due to interconnecting EPSs with different seasons of load maxima.

Curve $\mathbf{N_{PP}}$ in Figure 3 shows yearly operating modes of a power plant in interconnected EPSs with different seasons of load maxima. This power plant meeting maximum power demand in both interconnected EPSs operates in fact as base load plant. In the case of separate operation of EPSs the power plant operates as a cycling plant because it meets maximum power demand only in one EPS. Another EPS needs its own cycling power plant to meet its own maximum power demand. Thus, interconnecting EPSs both saves capacities, as already mentioned above, and also changes generation capacities mix: increasing share of base load capacities having low electricity production cost and decreasing cycling capacities with high production cost.

IV. PROSPECTIVE ELECTRIC TIES OF EAST RUSSIA WITH NORTHEAST ASIAN COUNTRIES

Russian research and design institutes have studied the potential for developing electric ties between EPSs of East Russia and NEA countries [3,4]. These ISETs can serve both for the realization of power interconnection effects and the electricity export from East Russia. Some of the ISETs with their major characteristics are listed in Table 5. These projects are in various stages of development. Some of them are only preliminarily studied, and some are more developed.

The most developed is the "Bratsk-Beijing" ISET project [9]. The ISET was planned to be of direct current (DC) and intended to export electricity surplus from East Siberia to North China. The surplus was estimated to be about 25 TWh/year for the region and formed due to electricity consumption decline. The project was launched in the early nineties by the Irkutsk Regional Administration and the regional power company "Irkutskenergo" with support of the Russian Ministry of Energy. In 1997 "Irkutskenergo," along with companies from the USA, Canada, and Sweden, conducted the pre-feasibility study "Russia-China power export project". The project was proved to be feasible. Major characteristics of the project were determined in the study. They are given in Table 5.

Table 5
Prospective electric ties of East Russia with Northeast Asian countries

ISET	Length, km	Voltage, kV	Transfer Capability, GW	Transmit. Electricity, TWh/year	Cost for ISET, $Bln.	Cost for Power Plants, $Bln.	Total Cost, $Bln.
Bratsk-Beijing	2600	± 600	3	18	1.5	2.7 (Bogu-chansk Hydro*)	4.2
Bureysk Hydro – Kharbin	700	± 400	1	3	0.3	1.8 (Bureysk Hydro*)	2.1
RFE – KPDR – Republic of Korea	1150 (700)**	± 500	4/8	8.5	2	2.8 (Primo-rye Nuclear)	4.8
Sakhalin – Japan	1800	± 600	4	23	5.5	4.1 (Sakhalin Gas)	9.6
Far East Nuclear – China – Republic of Korea	2300	± 500	2.5	18	3	4 (Far East Nuclear)	7
Uchursk Hydro – China – Republic of Korea	3500	± 500	3.5	17	4.5	6 (Uchursk Hydro)	10.5

*) Under construction; **) Reinforcement of 700 km of additional transmission lines on RFE territory is needed.

It was planned to realize the Russia-China power export project on the basis of a "Build-Own-Operate" (BOO) scheme. According to the BOO scheme it was mutually agreed to create an international transmission company responsible for development of the project and construction and operation of the transmission line. Most of the construction materials for the Russian section of the transmission line were supposed to be supplied by Russian industry. In 1999 the Chinese side made the decision to postpone the project's development for the next 5 years. In 2000 the decision was confirmed. However, it was considered to be reasonable to continue studying the project.

Taking into account postponement of the project's development and its construction time, the transmission can be phased in no earlier than about 2010, when the electricity surplus in East Siberia is expected to be exhausted (see Figure 1). It requires power sources in the region specially designated for electricity export. Boguchansk hydro can be one such source. In that case the cost of this HPP has to be taken into account in the project of electricity export to China (see Table 5). This additional cost will make the project more expensive and worsen its feasibility.

There is one more cooperatively studied interstate power project. In 1999 the Pan-Russian JSC RAO "EES Rossii" and the Marubeni Corporation jointly conducted a pre-feasibility study of the "Russia-Japan Power Bridge" [10]. The project includes a large gas-burning power plant on Sakhalin Island and a high voltage DC transmission line from the plant to EPSs of Hokkaido and Honshu Islands. Major characteristics of the project are given in Table 5. The project is intended to export electricity from the Sakhalin gas-burning power plant to Japan and planned to be implemented in the following two stages:

1. Commissioning the first phase of the power plant of 2000 MW capacity and installation of the power transmission line to Honshu island in 2010;

2. Commissioning the second phase of the power plant of subsequent 2000 MW capacity and strengthening transmission line to Honshu Island with supplying 1000 MW power to Hokkaido Island by 2012.

Possible schemes of the Power Bridge project implementation are supposed to be BOO or BOOT (Build, Own, Operate, and Transfer). According to these schemes a specially established company will build, own, and operate the Power Bridge during the approximate nine-year construction period, including development period, and, then the thirty-year operation period. Upon completion of the operation period, according to the second scheme, ownership and operation rights will be transferred to some other specially designated organizations.

The Power Bridge project was estimated to be technically, economically, and financially feasible. Further more detailed studies of the project are needed.

One of the most interesting interstate power projects in the NEA region is newly studied by the Energy Systems Institute (ESI) ISET "Russian Far East – KPDR – ROK" [4]. The ISET is supposed to be installed as DC transmission line and is intended to attain effects of EPS interconnection and electricity export. Major parameters of the project obtained in the study are given in Table 5.

A special mathematical model called ORIRES (acronym standing for "Optimization of Development and Operating Conditions of Electric Power Systems" in Russian) worked out at ESI was implemented in the study [11]. The model allows one to optimize generating capacity mix and operating conditions of power plants, as well as transfer capabilities of electric ties between the nodes and operating conditions of power flows via ISETs. It is linear, static, and multi-nodal. Balance equations in the model are compiled for a studied year. These balances take into account existing and predetermined power plants and transmission lines, as well as new power plants that can be put into operation in the period before the studied year. The model considers all four seasons of year. For each season 24-hour load curves typical (average) of a weekday and a holiday are set. Optimal solutions of the model are obtained by minimizing an objective function of annualized costs. The multi-nodal calculating scheme for the model is given in Figure 4. The Russian Far East is represented by two nodes. The KPDR and ROK are represented by one node each.

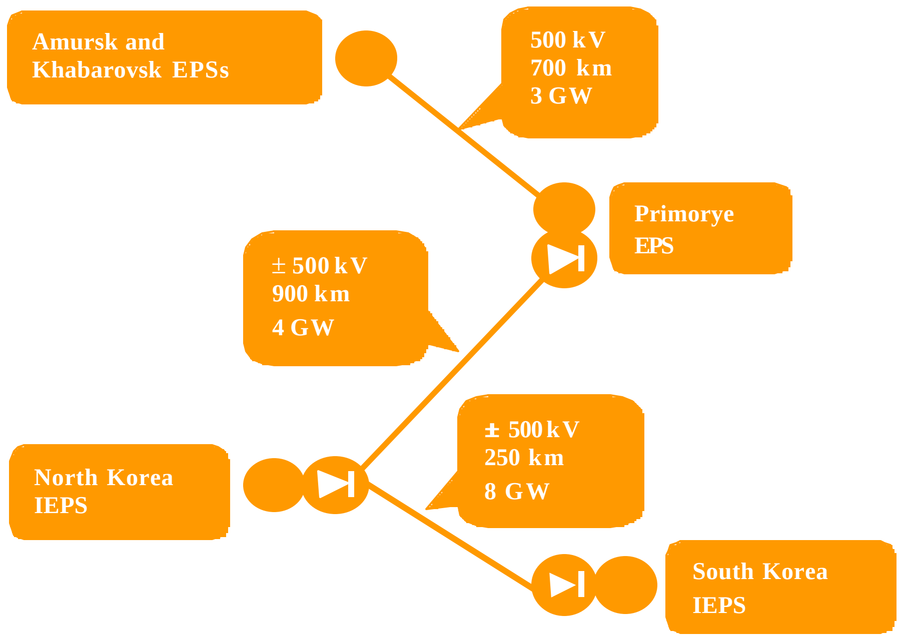


Figure 4. Scheme of ISET "Russian Far East – North Korea – South Korea"

When studying the ISET's economic effectiveness the following methodical approach was used. The computations by means of the ORIRES model were made for the two variants of the scheme indicated above: 1) when there was no ISET (separate operation of the EPSs) and 2) when there was an ISET (joint operation of the EPSs). Optimal values of the objective function of the model for each variant were compared. An ISET should be considered economically efficient if the function value of the model in the first variant is higher than in the second one (i.e. the costs for development and operation of all the EPSs with their separate operation exceed the costs for their interconnected operation). Otherwise an ISET is economically inefficient. Computations were made for the year 2020.

Table 6 presents commissioning of capacities by power systems for the variants of separate and interconnected (joint) operation. As is seen from the table when interconnecting the considered EPSs the total commissioning of generating capacities decreases by nearly 8 GW. This makes up about 25% of new capacities to be commissioned under separate operation of EPSs. The obtained magnitude of the capacities saved owing to the EPS interconnection is comparable with the current capacity of the whole IEPS of Russian Far East. More detailed consideration of Table 6 shows that capacities reduce in power systems of KPDR and Republic of Korea. Installed capacities of the RFE IEPS increase somewhat compared to their separate operation. Such redistribution is due to lower costs of electric power production by Russian Far East power plants.

Table 6
Commissioning of new capacities, GW

<table>
<tr><td colspan="2">EPSs
Variants</td><td>Russian Far East</td><td>KPDR</td><td>Republic of Korea</td></tr>
<tr><td colspan="2">Separate operation</td><td>1.4</td><td>5.6</td><td>26.8</td></tr>
<tr><td colspan="2">Joint operation</td><td>2.2</td><td>4.9</td><td>18.9</td></tr>
<tr><td rowspan="2">TOTAL</td><td>Separate operation</td><td colspan="3">33.8</td></tr>
<tr><td>Joint operation</td><td colspan="3">26.0</td></tr>
</table>

In Table 7 figures on electricity exchange via ISET among countries of the region are given. As can be seen, the Russian Far East is a major exporter. It exports about 8.4 Bln. kWh in 2020. At the same time South Korea is a major importer. It imports 8.9 Bln. kWh in the same year. North Korea exports 1.4 Bln. kWh. The difference in the total export from Russia and the KPDR and the import to the Republic of Korea is due to transmission losses. Electricity exchange varies by season. A larger fraction of export from Russia and the KPDR takes place in summer when maximum load comes in South Korea. It is, in fact, the realization of the effects of interconnecting EPSs with winter and summer load maxima.

Table 8 presents economic indices of variants of jointly and separately operating EPSs. As is seen from the table, the total decrease in capital investments for power plants in the variant of interconnecting EPSs makes up a great magnitude: $14.3 Bln. ISET cost was estimated at about $2 Bln., i.e. the resulting decrease in capital investments is $12.3 Bln. Unlike capital investment, fuel cost increases when interconnecting EPSs (by $0.55 Bln./year). The increase is mainly caused by power transmission losses. Comparison of annualized costs (incorporating both investments and fuel cost) of the considered variants showed that the variant of EPS interconnection has a lower magnitude of these costs ($14.3 Bln./year against $16.2 Bln./year for the variant of separate operation) and, hence, is more economically efficient.

Table 7
Electricity exchange via ISET, Bln. kWh/year

EPSs	Input	Output	Balance
Russian Far East	From North Korea: 0.4	To North Korea: 8.75	From RFE: 8.35
North Korea	From Primorye: 8.4 From South Korea: 6.6	To RFE: 0.4 To South Korea: 16.0	From North Korea: 1.4
South Korea	From North Korea: 15.6	To North Korea: 6.7	To South Korea: 8.9

Table 8
Economic indices by variant

EPSs / Indices	Russian Far East	North Korea	South Korea
Capital investment for power plants, $Bln.	1.9/3.0*)	9.5/8.8	41.9/27.2
Capital investment for ISET, $Bln.	0/2.0		
TOTAL investment, $Bln.	53.3/41.0		
Fuel cost, $Bln./year	0.67/0.74	0.58/0.56	5.5/5.9
TOTAL fuel cost, $Bln./year	6.75/7.2		
TOTAL annualized cost, $Bln./year	16.2/14.3		

*) Separate/joint operation

The above estimates show total potential effects for power interconnection as a whole. Substantial positive effects due to construction of ISET "RFE – KPDR – ROK" will also take place for each country-participant. Given below are estimates of interconnection effects for Russia.

- *Benefit from export* amounts to $420-585 Mln./year. The benefit was estimated with the supposition of 5-7 c/kWh export tariffs.

- *Reduction of fixed costs of power plants* by about 7% due to increasing capacity factors. In the case of interconnected operation, RFE power plants increase their output, and this reduces fixed costs for power generation.

- *Investment decrease* for Primorye nuclear power plant by more than 25%. Power interconnection with EPSs of neighboring countries allows large power units of 1000 MW to be commissioned on Primorye NPP in the Russian Far East. In the case of separate operation only small nuclear power units of 640 MW can be phased-in due to reliability requirements. However large power units have less specific capital investment and this brings about total investment saving.

- *Receiving electricity in peak hours* from abroad is 0.4 Bln. kWh/year.

- *Decreasing power under-supply* by 235 MWh/year. Power interconnection improves the reliability of the power supply. Reliability of the power systems of the RFE, the KPDR and the ROK under their interconnected and separate operation was estimated by ESI using the mathematical model "Yantar" [12].

- *Fossil fuel savings* is about 2.5 Mln.tce/year. As has been said above, due to reliability requirements only small nuclear power units will be commissioned in the RFE IEPS in the case of its isolated operation. Under the uncertainty of future fossil fuel prices these nuclear power units having high investment costs may not be competitive with domestic thermal power plants. Thus, in the case of separate operation of the RFE IEPS from the power systems of North and South Korea and low fuel prices, small nuclear power units may be replaced by less capital intensive TPPs with their fossil fuel consumption. Therefore, power interconnection may cause the phasing in of more economically efficient large nuclear power units in the IEPS of the Russian Far East that brings about fossil fuel savings.

- *Carbon oxide emissions reduction* is estimated to be nearly 6 Mln.t/year. Saving fossil fuel results in carbon oxide emissions reduction and also tens of thousands of tonnes of other harmful gases diminishing.

V. BARRIERS TO POWER GRID INTERCONNECTION IN NORTHEAST ASIA

Construction of ISETs in Northeast Asia, though resulting in great effects, will meet certain barriers. These barriers are of different natures and need various ways to be overcome. They are thought to be the following.

- *Dependence of importing countries on external electricity supply*. Power interconnection lowers national energy security of importing countries because it makes them dependent on an external power supply. That is why conclusion of bilateral and multilateral agreements among participating countries on conditions and guaranties of power supply and exchange is strongly needed.

- *Different technical standards in power industries* of various countries of the region. The frequency of alternating current is different in the EPSs of the NEA region. It is 50 Hz in Russia, Mongolia, China, and North Japan. In the KPDR, the ROK and South Japan it is 60 Hz. Thus, DC transmission lines are needed to interconnect such power systems. Even though frequency is the same there are different approaches to maintaining power quality and control in various EPSs of NEA countries. This also makes desirable implementing DC interconnections. For example, Russia and China having the same frequency however developed transmission project "Bratsk-Beijing" on the basis of DC technology.

- *Different energy legislation in countries* of the region. National power legislation has to be mutually accorded. International legislation is thought to be put in force in the NEA region. Special Working Groups have to be formed to meet this challenge. They have to be formed when political decisions on power interconnection by NEA countries are made.

- *Long distances, difficult routes, and high cost for ISETs*. The necessity to cross large rivers (like the Amur, for example, in the Russian Far East) and sea straits (for example, to connect Russia with Japan) makes routes for ISETs in the NEA region very difficult. Implementing DC lines allows power losses to be substantially reduced when transmitting power over long distances. Implementing DC submarine cables allows wide rivers and sea straits to be crossed. Technological progress in power apparatus and electronics and effect of scale are supposed to reduce cost for ISETs in the NEA region. For example, 1400 km of the 1800 km of transmission from Sakhalin to Hokkaido and Honshu Islands of the "Russia-Japan Power Bridge" project mentioned above are supposed to be installed as DC submarine cable [10]. Marubeni Corporation believes that effect of scale lowers cost for this submarine cable, and it is supposed to be competitive with overhead transmission lines built otherwise in Japan.

- *Financing*. For the time being financing is great problem for Russia. Hopefully in the future, when the national economy has recovered, the problem of financing power interconnection projects in Russia will be relieved. Russian industry can supply most of the construction materials for the Russian sections of ISETs [9].

- *Necessity to open up internal information for other countries and to accord national energy and power strategies and plans with other countries*. Some countries may be reluctant to open up their internal information for and accord national power and energy strategies with other countries. This reluctance is caused by the fact that, in principle, some countries may use this information to be better off at the cost of others (being so-called "free riders"). It is a national security issue, and it should be taken into account in international legislation regulating relationships among NEA countries involved in power interconnection.

- *Political tension among some countries*. This barrier also takes place in NEA region. However, power interconnection itself can be one of the policy tools improving the political climate in the region.

These barriers are sought to be overcome by cooperative efforts of concerned countries.

Deregulation and restructuring of the Russian power industry were not mentioned as barriers to power interconnection in the region. Any significant negative influence of these issues on power interconnection in the case of Russia is hardly foreseen.

Restructuring and deregulation processes started in the Russian power industry in the early nineties. For the time being a new round of reforms is taking place in the industry. There are hot discussions among concerned parties about ways of restructuring and deregulation. However, many experts express the idea that due to the severe climate in East Siberia and the Russian Far East, huge territory, long distances, and, particularly, strategic importance of the region for the country, the state (both Federal Government and Regional Authorities) is supposed to retain and probably restore its role in East Siberian and RFE power industry. Thus, state bodies like the Ministry of Energy (along with power companies like RAO "EES Rossii" and East Siberian and RFE regional power companies, research and design institutes) are supposed to be major participants in developing the Northeast Asian power grid interconnection project from the Russian side.

VI. FORMATION OF POWER GRID INTERCONNECTION IN NORTHEAST ASIA

Formation of ISETs and power grid interconnection in NEA will require a wide range of various activities starting with conducting preliminary studies and finishing with construction and operation of ISETs. These activities are given in the middle row of Figure 5. Presented in the upper row are institutions to be involved in these activities. These are research and design institutes, task forces and working groups of different types, designated state bodies, power utilities, etc. Outcomes of activities undertaken by the mentioned institutions are shown in the lower row of the figure and include estimates of potential effects of power interconnection, methodology, legislation, and standard basis for power interconnection, parameters and design of primary ISETs, etc.

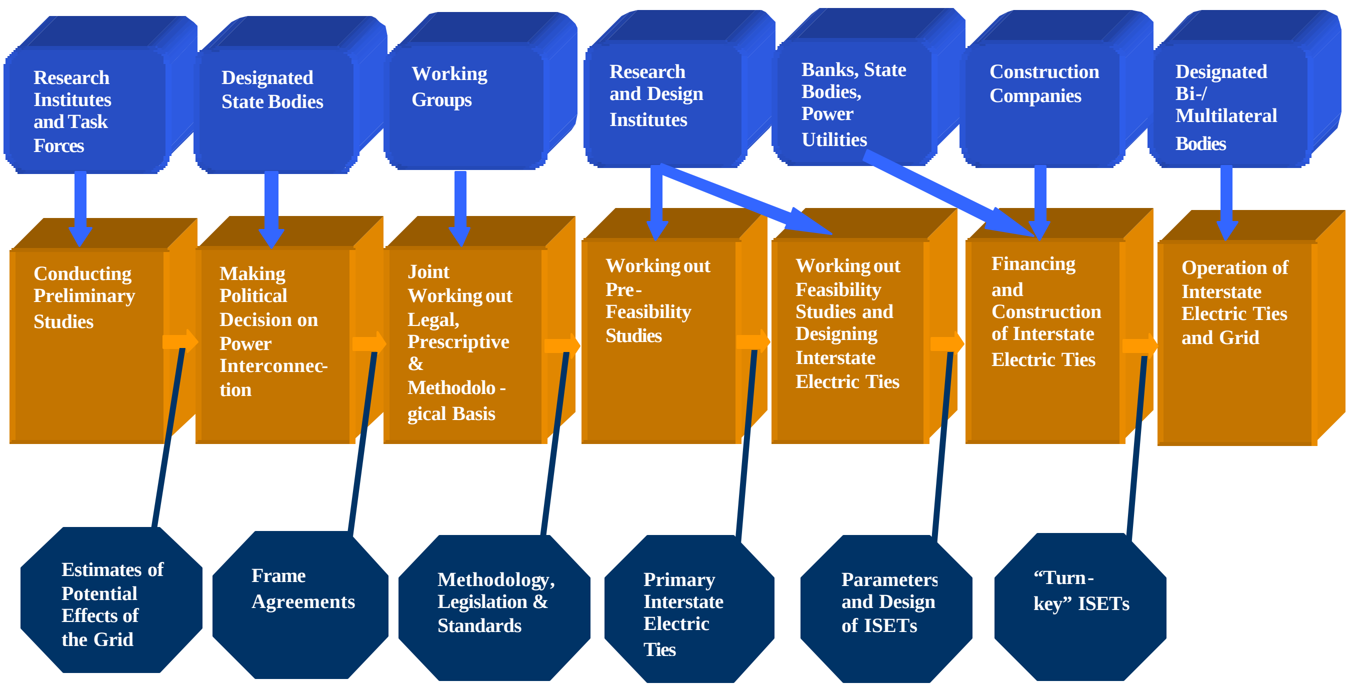


Figure 5. Development of Northeast Asia Power Grid Interconnection Project

Such a structural decomposition of power grid project development is given tentatively here and needs to be further specified. Nevertheless it demonstrates how complex, difficult, and long-term is the problem of formation of ISETs and power grid interconnection in NEA. For the time being, the first activities mentioned above are only being taken. Thus, there is a long way to go.

There are a few weak and short transmission lines in the NEA region. These are a) 220 kV ties between IEPSs of Siberia and the Russian Far East; b) 220 kV ties between IEPS of Siberia and Central EPS of Mongolia; c) 110 kV and 220 kV lines of local significance between Russian Far East IEPS and Northeast EPS of China; d) lines of local significance from hydropower plants of the KPDR to China; e) weak ties between EPSs of North and Northeast China.

Therefore, formation of power grid interconnection in Northeast Asia will start from scratch. That is why it will proceed by stages, which can only presumably be set up now.

At the first stage, as can be supposed, the domestic transmission lines within China and East Russia will be reinforced and some primary ISETs will be constructed. These are supposed to be electric ties between Russia and China, Russia and Korea, the KPDR and the ROK. Electric ties between Mongolia and Russia will be reinforced. The length of the first stage can be tentatively assumed up to the years 2020 – 2025. On the whole, the first stage of power grid formation will be characterized by the isolated or bilateral solving of the problems of construction and control of power flows for each ISET.

The second stage of power grid formation will start after the constructed ISETs begin noticeably affecting the energy and power balances and operating conditions of the interconnected EPSs. Here, the power flows on each ISET can affect operating conditions of several EPSs. There can be transit power flows across some countries (for instance across the KPDR from East Russia or China to the Republic of Korea). This will require coordination of ISET construction and modes of power flow among several countries and later, probably, within the whole NEA power grid. By the end of the second stage the scheme of ISETs presented in Figure 6 is thought to be formed.

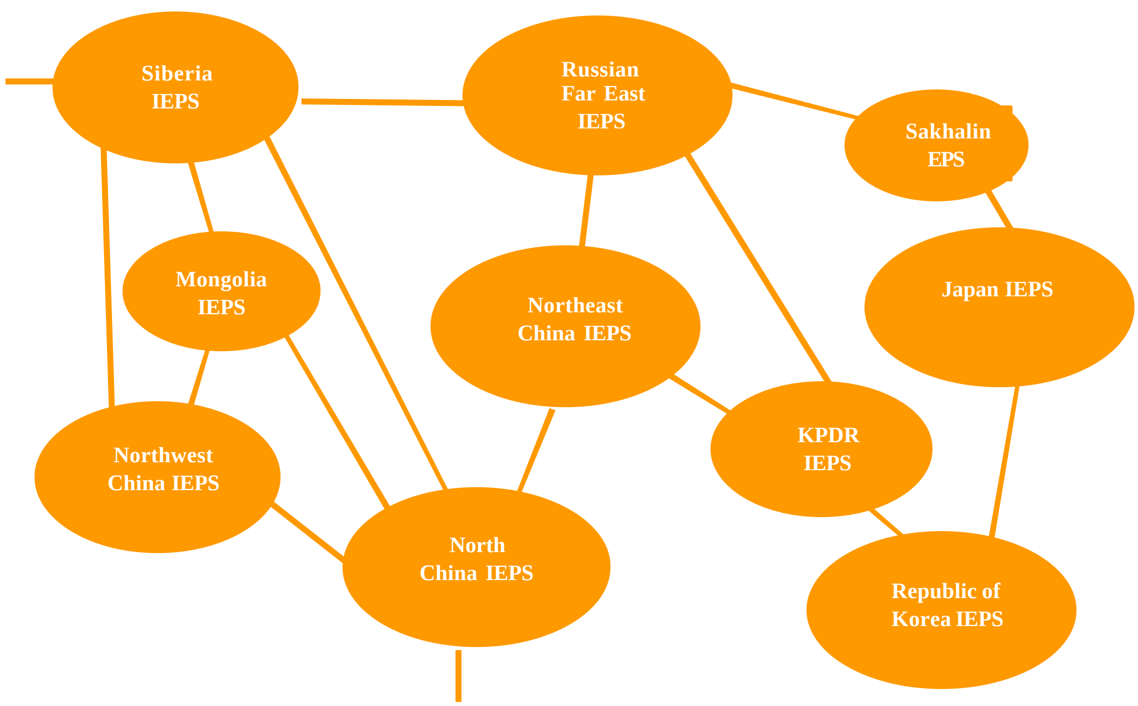


Figure 6. Power grid interconnection in Northeast Asia

VII. METHODOLOGY FOR THE STUDY OF INTERSTATE ELECTRIC TIES IN NORTHEAST ASIA.

Though some studies of ISETs have been done, the methodology for such studies is not completely developed. Study of ISETs has special features and meets certain difficulties. A number of problems (tasks) take place in ISET assessment. These tasks are given below [13].

Optimization of capacity mix of the interconnected EPSs and transfer capability of ISETs. This task should be solved for a certain future time horizon during which a commissioning of ISETs is possible for variants of isolated and joint EPS operation. Optimization should take into account investments in new power plants and electric networks (including ISETs) as well as EPS operating costs. Solving the problem allows one to determine (for the variants of isolated and joint EPS operation): optimal commissioning of power plants and transmission lines—in particular, optimal ISET transfer capability, power generation and its flows through ISETs, capital investments, fuel costs, etc. Comparing these results for the variants of isolated and joint EPS operation, it is possible to determine energy and economic effects of EPS interconnection and ISET construction.

Determination of EPS reliability indices. This problem is also solved for the variants of isolated and joint EPS operation. Used here is information on the installed capacities of power plants and transfer capabilities of transmission lines obtained from solution of the previous task, as well as statistical data on emergency rates of different power plant units and transmission lines. The task solution allows one to determine reliability indices of electricity supply to EPS consumers, power undersupply, required capacity reserves, etc. If the reliability of a power system proves to be insufficient it may be necessary to resolve the previous problem and increase capacity reserves or change the scheme of EPS ties.

Optimization of daily operating conditions of EPSs. This problem appears as a separate task if it can not be solved simultaneously with the first task (optimization of EPS structure). This task should be solved for the same variants of separate and joint EPS operation for certain typical days of the year considered in the previous tasks. They may include, for instance, weekdays and weekends of different seasons of the year (winter, spring, summer, fall). The obtained results allow one to: a) specify electricity generation of different power plants and their fuel costs in comparison with the results of the solution of the first task; b) have a more complete understanding of flows via ISETs in different days and seasons; c) determine the volumes of electricity export-import by ISETs in each direction in different seasons and for the whole year. In particular, the obtained flows by ISETs and volumes of electricity export-import can be required for solving the following task.

Determination of export-import tariffs. This task is of great importance for estimation of incomes and expenses of electricity export-import when assessing ISET effectiveness for each country. With rise of export tariff the effectiveness will increase for the exporting country and, on the contrary, decrease for the importing country. Hence, changing this tariff, it is possible to redistribute the total effect, achieved for power interconnection as a whole, among countries and make this effect positive for each country. When determining export tariffs the modes of flows by ISETs (results of the previous task solution) should be taken into consideration.

*Estimation of environment effects/impacts***.** Positive effects follow from the decrease in harmful emissions from thermal power plants: emissions of sulfur and nitrogen oxides, carbon dioxide, particulates, and others. At the same time there can be negative environmental impacts. Studies comparing environmental effects (or impacts) for ISETs and different types of power plants which account for their complete life and fuel cycles have to be carried out within ISET effectiveness assessments.

Identification of ISET complex effect for each country. The resulting effect gained by each country is made up of differences in investments, operating (fuel) expenses, and environmental impacts for the variants of isolated and joint EPS operation and incomes (or expenses) from power sale (purchase). This effect can be expressed as an integral (for the ISET service life) or can be annualized. When solving the given task the results obtained from all previous tasks are used.

Splitting ISET construction cost among countries-participants. In principle, the costs can be split by different methods, including negotiations. One of the methods that seems to be reasonable (fair) consists in splitting the ISET construction costs proportionally to effects obtained when solving the previous task.

ISET financial effectiveness assessment. For the ISETs being constructed for electricity export such an assessment can be made by standard methods. For the ISETs realizing the EPS interconnection effects, the financial effectiveness assessment is more complicated and methods for this assessment are to be specified.

Energy security of countries-participants. Electricity differs greatly from the other kinds of commodities: it can not be purchased or brought from any place, it is of vital importance for the economy and population, and the damage due to unexpected electricity undersupply is much higher than its cost. Thus, creation of ISETs requires serious studies of the energy-security problem. Assessment of electricity import volumes, which are considered to be proper for the country-importer in terms of energy security, power and fuel source diversity, etc. is required. Results obtained when solving the above tasks are needed to solve the energy-security problem.

The first through the third tasks have been solved when studying the ISET "RFE-KPDR-ROK" (see section IV above). Specific models were developed and implemented in these studies [11,12]. However, the solution of all above tasks requires more approaches and mathematical models to be developed. The Energy Systems Institute is working intensively on developing methodologies for studying ISETs in the NEA region.

VIII. CONCLUSION

The following inferences can be drawn from the above:

- ♦ Formation of ISETs and power grid interconnection in Northeast Asia will bring about substantial effects to the countries-participants. Russia can be one of these participants supplying electricity to the power markets of NEA countries and sharing interconnection effects and costs incurred.

- ♦ There are barriers to power systems interconnection in the NEA region, but they can be overcome by cooperative efforts of countries-participants with Russia among them.

- ♦ Russian Governmental Bodies and power companies are interested in penetrating the power markets of Northeast Asia and in building and strengthening partnerships with NEA countries in the field of power industry.

- ♦ Development of methodology, mathematical models, and collecting information on the power industries of Northeast Asian countries for studies of power grid interconnection project are required. Russian research institutes, in particular the Energy Systems Institute, are developing methodologies and mathematical models to study ISETs in the NEA region and sharing obtained results with potential participants of power grid interconnection.

- ♦ Cooperation of all concerned Governmental, power, financial, and other institutions of various countries is needed to develop the Northeast Asia power grid interconnection project. The Energy Systems Institute and some other Russian concerned institutions are open for cooperation in this field.

IX. ACKNOWLEDGMENT

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