STUDY FOR RUSSIA, DEMOCRATIC PEOPLE REPUBLIC OF KOREA, REPUBLIC OF KOREA AND CHINA POWER INTERCONNECTION: ANALYSIS OF CURRENT STATUS

Sergei Podkovalnikov

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

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ABSTRACT: Analysis of the Russian Far East, Democratic People Republic of Korea and Republic of Korea power systems from the viewpoint of their interconnection is done. Potential route, scheme and major technical parameters of the power grid connection are examined. Cost for the connection is estimated. Benefits from the connection including capacity and required investment saving, production cost and electricity tariff reduction, etc. are figured out. The potential benefits from incorporating the power system of Northeast China into the above power interconnection is considered. Route for the connection with Northeast China is examined. Scheme and major technical parameters of the 4-country power grid connection are considered. Cost for the connection is estimated. Other potential power grid connections in Northeast Asia are reviewed. Inferences from the analysis are drawn.

KEY WORDS: Power grid connection, Interstate electric tie, Electric power system, Power interconnection, Thermal power plant, Hydropower plant, Nuclear power plant, Generating capacity, Cost, Benefit, Route, Scheme, Economic assessment, Economic effectiveness, Electricity price, Electricity trading, Study, Estimate, Reliability, Environment.

Pages: 42 Tables: 17 Figures: 11 References: 44

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I. INTRODUCTION

Interconnection of electric power systems (EPSs) of countries and sub-regions of Northeast Asia (NEA) is in its infancy at present. In the meanwhile development of interstate electric ties (ISETs) among NEA countries may bring about substantial capacity saving, economic, environmental and other benefits for all participants engaged in power interconnection [1-3, etc.]. As studies conducted at Energy Systems Institute showed, one of the most promising power grid connections in the Northeast Asia (NEA) region is the ISET interconnecting the Russian Far East (RFE), Democratic People Republic of Korea (DPRK) and Republic of Korea (ROK) [4]. At the Workshop of the Northeast Asian Power Grid Interconnection Project held in Beijing on May 14-16, 2001 participants from Russia, ROK and DPRK stated that they are interested in studying feasibility of power grid interconnection among their countries [5-7]. Mathematical models and methodology for studying ISETs in NEA region are being developed and implemented [8]. Thus, for the time being, there are necessary foundations for complex, international study of ISET "RFE – DPRK – ROK" to be planned and conducted.

As some studies of the ISET "RFE – DPRK – ROK" and other ISETs in NEA region have been carried out, there is a need to analyze and summarize them to gain important experience to be taken into account while elaborating the program for new international study. The paper is targeted providing some kind of starting point for the study.

II. OVERVIEW OF RFE, DPRK AND ROK POWER SYSTEMS FROM THE VIEWPOINT OF POTENTIAL INTERCONNECTION

II.1. The Russian Far East

Electric power system of the Russian Far East spreads on the most inhabited and industrialized territories of the southern RFE meeting electricity needs there (Figure 1). It stretches on about 2500 km from Northwest to Southeast. The RFE EPS is made up of three regional power systems (of Amur, Khabarovsk and Primorye regions) and South Ykutia sub-regional power system. The RFE EPS operates at a frequency of 50 Hz. The maximum electric load in the RFE EPS comes in winter. The minimum electric load (about a half of the maximum value) comes in the summer. The shape of electric load is expected to remain for the future.

The highest electricity consumption in the territory served by the RFE EPS was in 1990 and reached about 30.5 Bln.kWh [7]. Thereafter, there was a decline in electricity consumption by more than 20% (lasting eight years). In 2000, electricity consumption in the territory of the RFE EPS was nearly 24 Bln.kWh. The highest electricity consumption is expected to be restored in 2005-2010. It is supposed to nearly doubled by 2025 [7].

Electricity consumption is unevenly distributed in the territory. A large share of electricity - nearly 40% - is consumed in Primorye regional EPS. The shares of other regional power systems are less. This allocation of electricity consumption is expected to remain for the future.

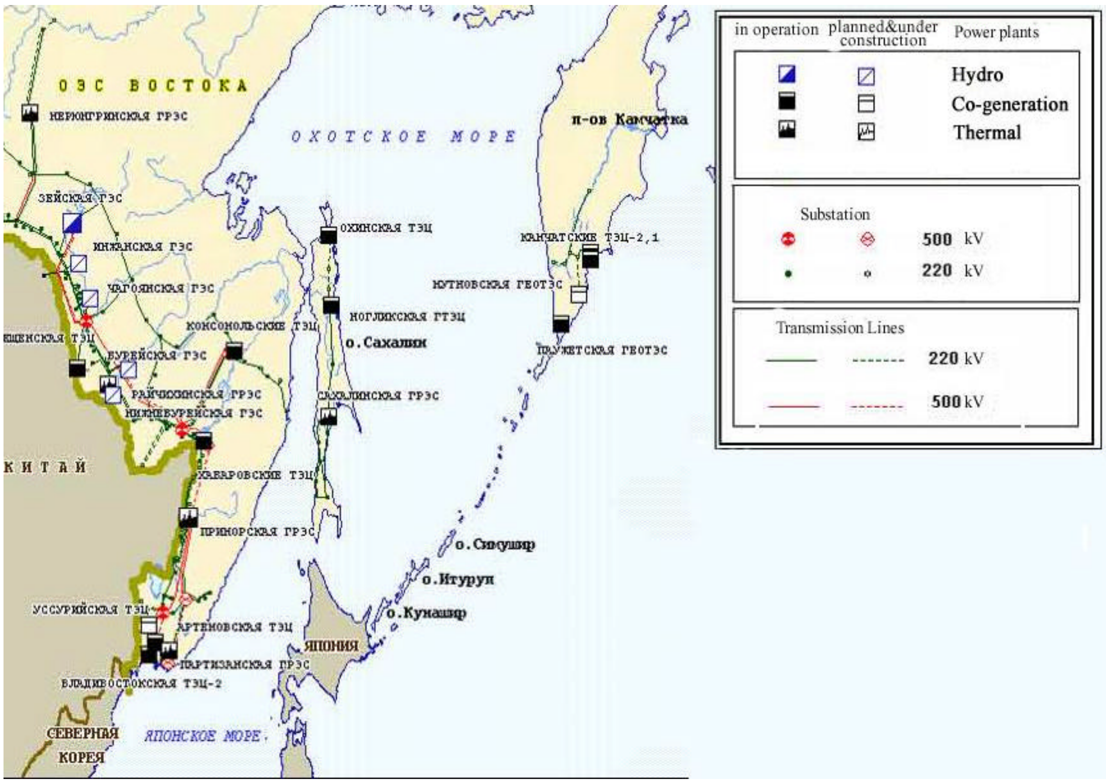


Figure 1. Power grid map of the Russian Far East [9]

Current generating capacities of the Russian Far East EPS is about 7 GW [7]. Hydropower capacity (located in Amur EPS) has nearly 20% of the total installed capacities. The rest are thermal power capacity, including co-generation. RFE thermal and co-generation power plants are almost all coal-fired. By the year 2025 RFE EPS capacities are supposed to grow more than twofold. Share of hydropower capacity will also increase to more than 35% of the total installed capacities (mainly at the cost of phasing in hydropower plants – HPPs - in Amur EPS). In 2020 nuclear power capacity of 1 GW may appear in the region [10]. In 2025 the capacity is supposed to be doubled. There are plans to install nuclear power units in Primorye nuclear power plant (NPP) located in the southern Russian Far East. NPP output may cover domestic electricity needs and be sent to power grid interconnection for trading with DPRK and ROK.

Electricity consumption decline caused a large excessive capacity in the RFE EPS, reaching nearly 40 % of maximum electric load. Power generating capacities are allocated unevenly on the territory of the RFE's EPS, volumes of excessive capacity vary on the territory. They are larger in Amur EPS and less in Primorye EPS where electricity consumption is highest. Primorye EPS, which lacks maneuverable generating capacity, has problems with meeting the cycling electric load of consumers.

The backbone power grid in the RFE EPS is comprised of 220 and 500 kV transmission lines (Figure 1). The transmission lines along the main path go along Trans-Siberian and Baikal-Amur railroads with a few cross linkages. Unlike the 220 kV grid, there is no unified 500 kV transmission grid in the RFE EPS. There are two sections of 500 kV transmissions with the length totaling nearly 1700 km. One section is in Amur and Khabarovsk EPSs and another one is in Primorye EPS. There is no linkage between them, but there are plans for interconnection.

The direction of power flows in the Russian Far East EPS transmission grid is from West to East and farther South. It is caused by uneven allocation of electricity consumption and production on the RFE territory, as was mentioned above. With new HPPs in Amur EPS and a 500 kV linkage between Khabarovsk and Primorye EPSs being commissioned, maneuverable hydropower will be brought to Primorye EPS to alleviate the problem of being able to meet the cycling electric load of consumers. Thus, the direction of west-east-south power flows in the EPS will remain the same in the future.

The EPSs of the RFE and Siberia are interconnected by weak, 220 kV transmission lines. However, there is a plan to strengthen this interconnection by 500 kV transmissions in the future. There are not any power interconnections between RFE and DPRK power systems.

Summarizing the above, the following issues are important for the future power interconnection with NEA countries and can be highlighted as follows:

1. The Russian Far East EPS operates at a frequency of 50 Hz.

2. The maximum electric load comes in the winter; the summer load valley is quite deep.

3. Electricity consumption is unevenly distributed on the territory of the RFE EPS with the largest share falling in the South.

4. Hydropower capacity is being developed in the West; new HPPs are to be commissioned there.

5. Thermal power capacity dominates in the East and South; nuclear power capacity is going to be developed in the South in order to meet domestic electricity needs and export electricity.

6. There is currently a large excess of power generating capacity unevenly allocated on the territory of the RFE EPS, but in 2005-2010 it is expected to be exhausted.

7. There is a seasonal excess of power generating capacity in the summer that is expected to remain into the future.

8. In Southern RFE there is a lack of maneuverable generating capacity to meet the cycling electric load of consumers.

9. A backbone power transmission grid of the highest voltage is not well developed or planned to be reinforced.

10. Major direction of power flows in the RFE EPS is east-southward and it is expected to remain that way in the future.

11. There are currently no power grid connections between RFE and DPRK EPSs.

II.2. Republic of Korea

The Republic of Korea has developed an electric power industry that meets its constantly growing electricity consumption. Annual electricity growth rates in ROK exceeded 10 % in 1970s-1990s [11,12] and then slowed down. In 2000, ROK electricity consumption totaled 224 TWh and by 2015 it is expected to increase up to more than 380 TWh/year [5]. More than 40% of the electric load is concentrated in the Seoul metropolitan area [13].

A schematic of ROK electric power system is presented in Figure 2. It operates at a frequency of 60 Hz. As of 2001, its generating capacity exceeded 49 GW, with the maximum electric load greater than 43 GW [14]. The annual high in the electric load comes in summer. The winter maximum load is about 80% of the summer high [15].

Being poorly endowed by hydropower resources and fossil fuel, the ROK relies on nuclear power. The current share of nuclear power capacity in total generating capacity is nearly 27% [17], and it is more than 37% in electricity generation [18]. The share of nuclear power is expected to increase in the future reaching 33% in generating capacity mix [17] and nearly 45% in electricity generation [18].

According to the 5th long-term plan for ROK power supply, it is forecasted that the power demand will increase annually by 4.3% and reach nearly 68 GW in 2015 [5]. In order to supply the forecasted demand, nearly 30 GW of installed capacities needs to be phased in. Apart from the nuclear power capacity mentioned above, other types of power capacities will be developed. Among them are coal-fired, gas-fired and pumped-storage capacities. Oil-fired power capacity will stagnate and its share in the total generating capacity mix is expected to decrease [17]. Due to the mountainous landscape of the country, environmental limitations and other factors create difficulties in finding new sites for power facilities [5].

The ROK backbone transmission grid is made up of 345 kV transmission lines. The grid of this voltage is well developed and covers almost all of the country. However, the need for bulk power supply in the Seoul metropolitan area and difficulties in acquiring corridors for new transmissions force ROK utilities to introduce a voltage of 765 kV. Two lines of this voltage are in operation and others are being planned [13]. The 765 kV transmission grid is targeted to supply the Seoul metropolitan area from power plants located in the South and East. Thus, directions of power flows in ROK backbone transmission grid are northward in the main [13]. There are currently no power grid connections between ROK and DPRK power systems.

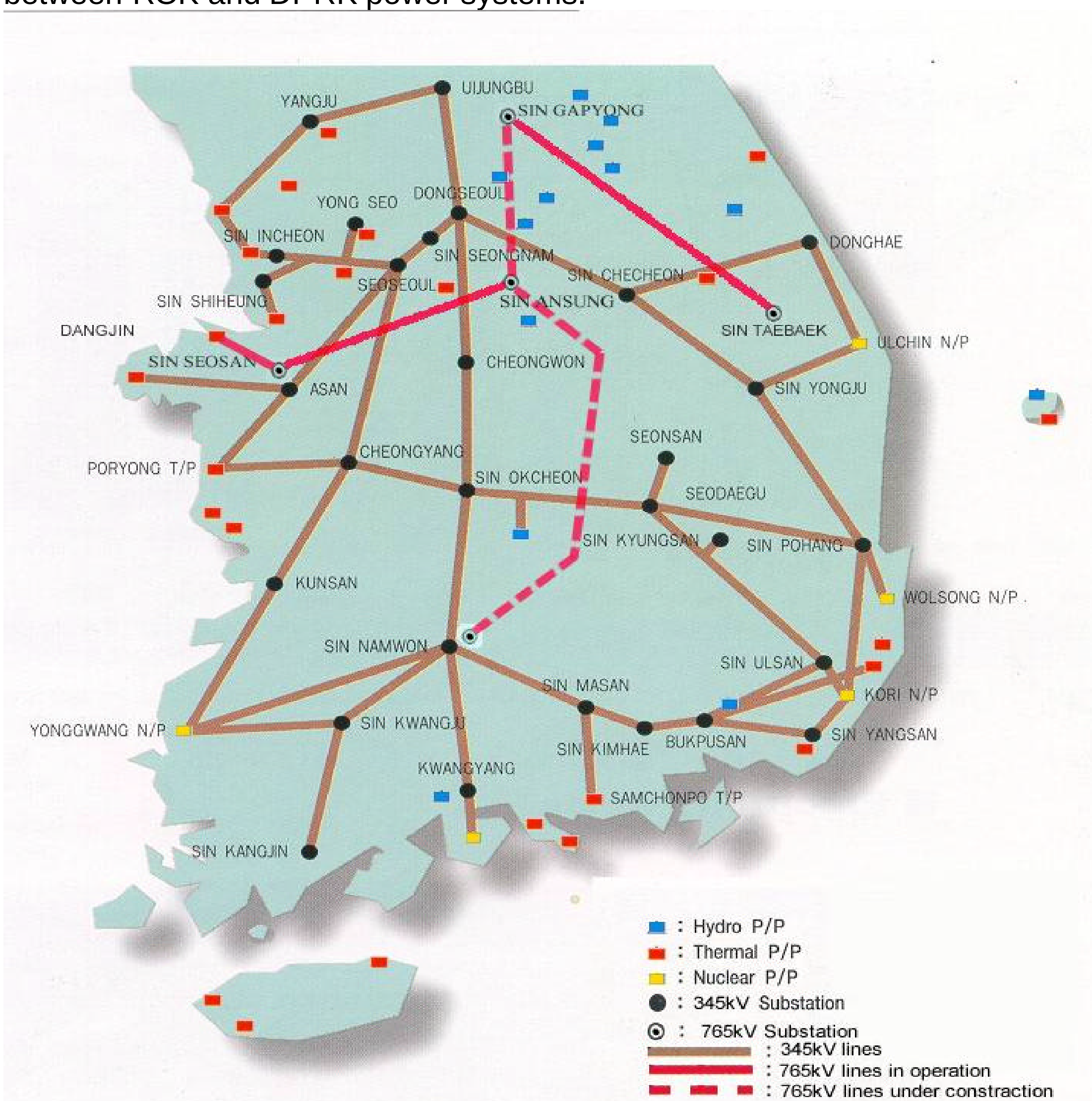


Figure 2. Power grid map of the Republic of Korea [12,16]

The following features of ROK EPS are considered to be important for the future power interconnection with NEA countries:

1. The EPS operates at a frequency of 60 Hz.

2. Maximum electric load comes in summer.

3. Electricity consumption is unevenly distributed over the territory of the EPS with very large share falling in the Seoul metropolitan area.

4. Nuclear power capacity is being further developed as a major source of electricity production, though other sources of electricity play important roles in meeting growing power demand.

5. There is an excess of power generating capacity during the winter season that is expected to remain into the future.

6. There are difficulties in finding sites for new power facilities (power plants, transmission lines and substations).

7. A backbone power transmission grid of highest voltage is well developed and being reinforced by transmissions of higher voltage.

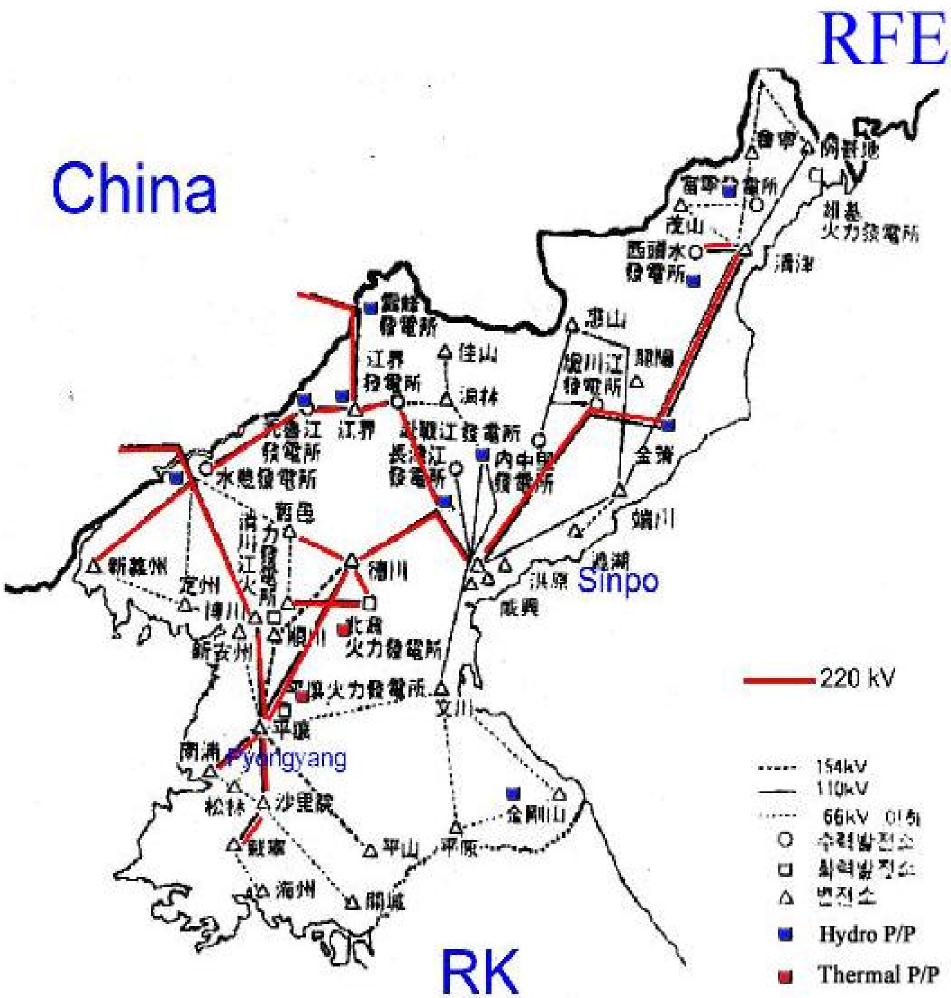
8. Major direction of power flows via backbone transmission grid is northward, and this is expected to remain for the future.

9. There are no power grid connections between ROK and DPRK EPSs.

II.3. Democratic People Republic of Korea

The DPRK electricity statistics are controversial and meager. It is known that in 1975-1985 electricity consumption in the DPRK was growing at high rates, increasing annually by more than 6% [19]. Since then, these rates have slowed down substantially and electricity consumption has decreased. Electricity consumption in 1998 was reported at 29.3 TWh [20]. As can be concluded from the location of major electricity consuming works (metallurgical, in particular aluminum, chemical, etc.) [21], major electricity consumption centers are in the Pyongyang metropolitan area and in the Northeast of the country in cities on the coast of the Sea of Japan. The maximum electric load comes during the winter [22]. Yearly and daily load shapes are unknown.

In 1990, total generating capacity for the DPRK was estimated to be about 9.5 GW, with 5 GW of hydropower capacity and 4.5 GW of thermal power capacity, including co-generation [23-24]. As of 1994, DPRK generating capacity was estimated to be 7.2 GW [25]. In [26], DPRK generating capacity for 1998 was estimated to be 10 GW with 5 GW being installed in HPPs and the same capacity in thermal power plants (TPPs). Electricity production during the same year was estimated to be nearly 31 TWh with 66% being produced by hydro and 34% by TPPs [20]. HPPs are located mainly in the North and Northeast of the country and TPPs, in particular, co-generation, are located near centers of heat and electricity consumption [21] (Figure 3). A nuclear power plant of 2 GW capacity sited in Sinpo is under construction [27]. Current volume of DPRK generating capacity is not definitely known.



The following features of DPRK EPS are important for the future power interconnection with NEA countries and can be highlighted as follows:

1. The EPS operates at a frequency of 60 Hz, though there is an area in the West of country operating with 50 Hz.

2. Maximum electric load comes during the winter.

3. Electricity consumption is unevenly distributed over the territory of the EPS with a large share falling in the Pyongyang metropolitan area.

4. Hydropower capacities, the major source of electricity, are located in the North and Northeast of the country.

5. Nuclear power capacity is being developed.

6. There is a seasonal excess of power generating capacity in the summer that is expected to remain into the future.

7. The major direction of power flows via the backbone transmission grid is roughly south.

8. There are currently no power grid connections with the adjacent RFE and ROK EPSs.

II.4. Significant issues for "RFE-DPRK-ROK" power interconnection development

Analysis of EPSs of the Russian Far East, the DPRK and the Republic of Korea shows the following issues to be important for development of the power interconnection among the countries. They are as follows:

1. There is seasonal diversity of yearly maximum loads in EPSs of RFE, DPRK and ROK. This may bring about substantial benefits while interconnecting the power systems at the cost of joint utilization of mutually supplementary seasonal excessive capacities in all EPSs [7].

2. There are difficulties in finding locations for power facilities in ROK due to environmental concerns, scarcity of suitable sites, etc. This may be alleviated by receiving electricity from interstate interconnected power grid.

3. DPRK hydropower maneuverable capacity may be utilized in the ROK EPS for meeting the cycling electric load of domestic consumers. Using the DPRK hydropower maneuverable capacity to alleviate the problem of meeting the cycling electric load of consumers in the South of the Russian Far East may

be considered as a complementary measure of transmitting maneuverable power from the Russian Far East HPPs sited approximately 1500 km away in the Northwest part of RFE EPS. ISET “RFE-DPRK-ROK” allows DPRK hydropower capacity to be utilized within interconnected EPSs.

4. Delivering electricity from the power grid interconnection “RFE-DPRK-ROK” to the electric load centers in Pyongyang and Seoul metropolitan areas may relieve constraints in the domestic electricity grids on transmitting electricity to those centers from other parts of DPRK and ROK accordingly, and, perhaps, save investing in domestic transmission lines that would be developed to transfer power to the load centers.

5. Considered power systems operate at different frequencies of 50 and 60 Hz.

6. There is not any interstate power transmission infrastructure among RFE, DPRK and ROK.

7. Attaining full benefits from power interconnection requires bulk power exchange among RFE, DPRK and ROK.

8. Using domestic power infrastructure along with intersystem links (to be constructed, back-to-back linkages included) for bulk power exchange among the EPSs is impossible owing to the transmitting capacity constraints and the high losses that occur during the transmission of large volumes of power over long distances at relatively low voltages. On the other hand, existing and planned domestic power grids may be used for distributing incoming power flows and collecting flows, being sent out to the power grid interconnection. Perhaps in some cases reinforcement of domestic grids is required for these purposes. More detailed analysis of this issue is needed.

9. Interconnection of RFE, DPRK and ROK electric power systems requires bulk power DC transmission infrastructure to be constructed, with Vladivostok, Pyongyang and Seoul tied together.

III. ISET “RFE-DPRK-ROK”

III.1. Potential route of the ISET

Usually, various communications (railroads, roads, power transmission lines, etc.) go in the same directions. Thus, a transport network in Southern RFE, the DPRK and ROK is considered a suitable route for the location of the ISET. In Figure 4, railroads for Southern RFE, the DPRK and ROK are presented. There is a direct railroad connection from Vladivostok of RFE to Pyongyang and further south to Seoul. Note that the separation of Korea on South and North the railroad between Pyongyang and Seoul was disconnected. It is reportedly being restored now.

Rough estimates of the distance by railroad are as follows: Vladivostok – Pyongyang is about 850 km and Pyongyang – Seoul – approximately 250 km. Thus, a rough estimate of the total distance from Vladivostok to Seoul by railroad is about 1100 km. From Vladivostok, the railroad passes a narrow strip of the Russian territory between China and the Sea of Japan and crosses the Russia-DPRK border. In the DPRK, the North and Northeast territories are mountainous, so the railroad goes along the coast of the Sea of Japan. Then it crosses the Korean peninsula and arrives in Pyongyang. From Pyongyang to Seoul it follows the west side of the peninsula.

Preliminary results indicate that it is reasonable for the "RFE-DPRK-ROK" route to follow the railroad "Vladivostok-Seoul" with some corners cut where possible. In the Russian territory, it is very difficult to find another route. The very narrow strip of territory connecting Russia to DPRK has a unique environment vulnerable to external impacts. Converter substations, as it follows from the analysis done in section II.4 of this paper, are supposed to be installed near Vladivostok, Pyongyang and Seoul.

Comparing the power grid map of the DPRK, ROK and RFE with the railroad network given above, it can be seen that a power grid infrastructure exists along the larger part of railroads connecting Vladivostok through Pyongyang to Seoul. Therefore, if necessary, construction sites along the ISET can be supplied by electricity from the existing power grid. In addition, railroads are usually accompanied by roads. Thus, transport and power grid infrastructure is already quite developed along the larger part of the route of "RFE-DPRK-ROK" ISET. This makes the route more accessible while reducing the cost and labor or construction. Again, these are preliminary results, and the route and location of converter substations need to be studied in more detail.

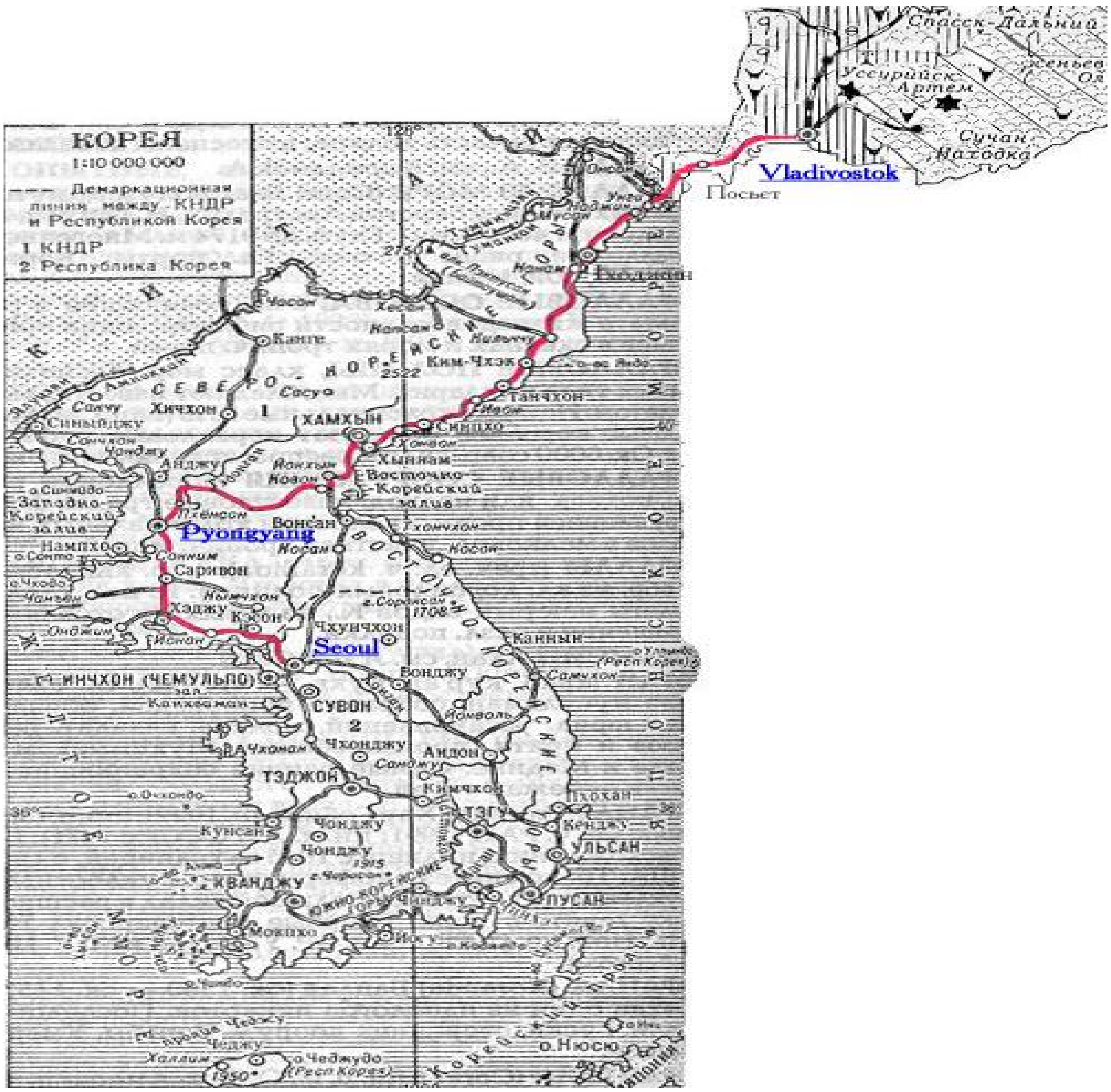


Figure 4. Map of railroads of the South of RFE, DPRK and ROK [28,29]

III.2. Cost and benefit of the ISET

III.2.1. Introductory remarks

Given below are results of an economic effectiveness assessment of the ISET. Sections III.2.2-III.2.4 summarize the results of the optimization study of the ISET [30]. Section III.2.5 shows the reduction of production costs and electricity tariffs due to "RFE – DPRK – ROK" power interconnection [31]. In e section III.2.6, some results of a reliability assessment of the ISET [30] are presented and in section III.2.7 some speculations about environmental benefits of the ISETs in Northeast Asia are given. The "RFE – DPRK – ROK" transmission line's distance that is used for calculation in the study does not necessarily correspond to those estimated in the previous section.

III.2.2. Scheme of the ISET and method for the study

The scheme for power grid interconnection was represented by four nodes (Figure 5). EPSs of the Russian Far East were set by two nodes: one node includes Amur and Khabarovsk power systems and the second one - Primorye EPS. Power systems of the DPRK and ROK were represented by two particular nodes.

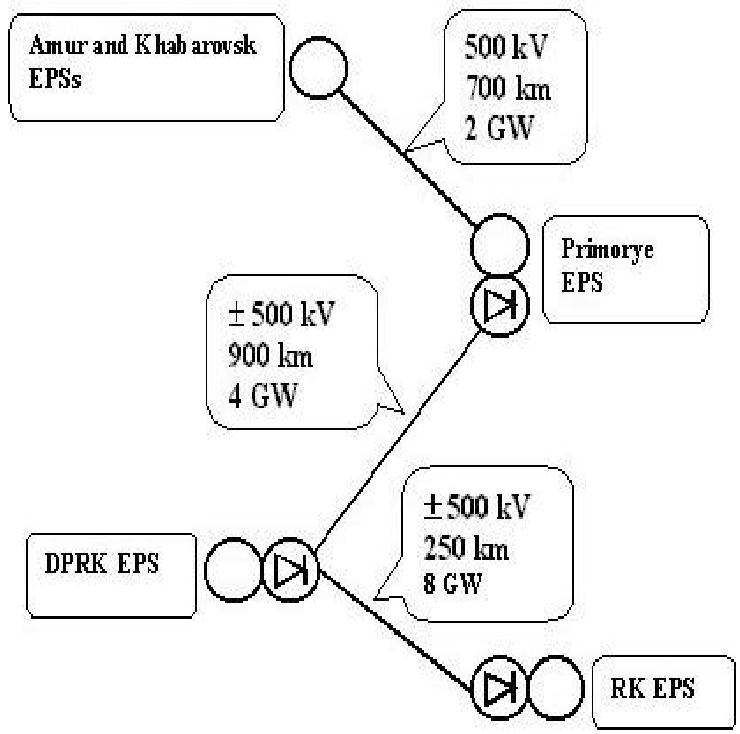


Figure 5. The scheme of “RFE – DPRK – ROK” ISET [30]

The tie lines between electric power systems of the Russian Far East operate on alternating current (AC) of 500 kV voltage. These AC lines are presented whether separate or joint operation of national EPSs is considered in the computations. ISET sections "RFE - DPRK" and "DPRK - ROK" operate on direct current (DC) with a voltage of ± 500 kV. The transfer capability of the ISET was optimized by means of ORIRES mathematical model (see below). In Figure 5 are optimized values of the ISET transfer capability. As shown, they vary by section. Section "RFE - DPRK" is supposed to be installed as a bipolar line and the "DPRK - ROK" section as a quadrapolar line (having two bipolar circuits).

Converter substations with reverse operation are supposed to be located in the areas of Vladivostok, Pyongyang and Seoul. Other technical issues of the ISET were not elaborated and need to be studied.

Described above is a multi-terminal DC system. Power grid connections considered further in Section IV are also of the same type. A multi-terminal power grid connection based on voltage-sourced converters is already developed and tested [32]. Tests showed it has good operating performance. The active and reactive power can be controlled independently and active power can be flexibly interchanged among multiple terminals, even in the event of disturbances in the AC network.

ORIRES mathematical model [33] was implemented for the study. It allows optimal transfer capabilities of ties, generating capacities to mix, and operating conditions of EPSs to be figured out. The objective function of the model is annualized cost function.

When studying the ISET's economic effectiveness the following approach was used. Computations by means of the 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 EPSs). Optimal values of the objective function of the model were obtained and compared for both variants. ISET should be considered economically efficient, if the function value of the model in the first variant is higher than in the second one. This means that the costs for development and operation of all the EPSs at their separate operation exceed the costs at their interconnected operation (including cost for construction and maintenance of the ISET). In other words, ISET is economically inefficient.

III.2.3. Input data

The computations were carried out up to the year 2020. Required input information for all EPSs to be interconnected was prepared. The main technical and economic indices of transmission lines and substations used for calculations were assumed based on the data of the Direct Current Research Institute (NIIPT) and DalEnergoset' Project Institute (DalESP), both of Russia. The data on the lines are presented in Figure 5 and Table 1. Cost of substations was assumed to be $ 20 Mln. for an AC substation with the highest voltage of 500 kV and 1000 MVA capacity and 75 $/kW for converter substations.

Table 1. Input data on electric ties

Parameters / EPSs	Transfer capability per circuit, GW	Specific investment, 10^3\$/circuit-km
Khabarovsk– Primorye	0.8 - 1	250
Primorye - DPRK	3-4	400
DPRK - ROK	3-4	400

Information on generating capacities to be commissioned in the RFE territory is based on the data of DalESP and other design organizations of Russia. Information on ROK and DPRK power plants was based on the data of Korea Electrotechnology Research Institute (KERI). The main economic data on power plants are presented in Table 2. Fuel cost in the Russian Far East was based on the data of Energy Systems Institute, and in the DPRK and Republic of Korea it was based on the data of KERI. The fuel cost estimates are also presented in Table 2.

Data on prospective levels of electricity demand and electric load maximum for 2020 are presented in Table 3. The discount rate was accepted to be 8%.

Table 2. Specific capital investments and fuel cost by power plant, $/kW / $/tce

Power plants	RFE	DPRK	ROK
Coal	1250/(40-50)	1300/40	1300/40
Gas	1000/120	-	1050/150
Heavy oil	-	-	1500/100
Nuclear	1400/0.35*)	1900/0.4*)	1900/0.4*)
Hydro	2500	2000	2300
Pumped Storage	-	-	2100

*) Fuel cost for Nuclear PP is given in cents per kWh.

Table 3. Prospective electricity demand and load maxima for the year 2020,

Countries	RFE	DPRK	ROK	TOTAL
Electricity demand, TWh/year	55	60	415	530
Yearly electric load maxima, GW	9	9,5	74	92,5*)

*) This is just sum of yearly bad maxima; combined load maxima of power interconnection, figured out when different seasons and hours of particular load maximum coming are taken into account, is less.

III.2.4. Computations of ISET' economic effectiveness

Table 4 presents commissioning the capacities by type of power plants for the variants of separate (numerator) and interconnected (denominator) operation. Co-generation plants are not presented in the Table 4, since they are not optimized in the model and their commissioning is first caused by heat consumption. Nevertheless, commissioning of the co-generation plants required for the considered time period was taken into account in the input data for calculations on the model. Estimates of commissioning the co-generation plants were assumed based on the data of DalESP.

As is seen from Table 4, when interconnecting the considered EPSs the total demand for commissioning the generating capacities decreases by nearly 8 GW. This makes up about 25% of new capacities to be commissioned at separate operation of EPSs. The obtained magnitude of the capacities saved owing to the EPS interconnection exceeds the current capacity of the whole EPS of Russian Far East. It is necessary to point out that the obtained capacity saving benefit is potential (maximum) one. In fact, the benefit is supposed to be less and dependant first on the degree of the integration of operation and development of EPSs to be interconnected.

In Table 5, 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 8.75 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. Difference in the total export from Russia and DPRK and import to Republic of Korea is due to transmission losses. Electricity exchange varies by season. A larger fraction of export from Russia and the DPRK takes place in the summer when maximum load occurs in South Korea. In fact, it is a realization of the effects of interconnecting EPSs with winter and summer load maximum. Total electricity exchange among power systems exceeds 36 TWh/year.

Table 4. Commissioning new capacities, GW

EPSs / Capacity types	Amur and Khabarovsk	Primorye	DPRK	ROK
Coal	-	-	2.2/1.1	7/7
Gas	-	0.2/0.2	-	5.5/5.5
Heavy oil	-	-	-	0.9/-
Nuclear	-	1.2/2.0	2/2	12.3/6.3
Hydro	-	-	1.4/1.8	0.1/0.1
Pumped Storage	-	-	-	1.0/-
Total for each EPS	-	1.4/2.2	5.6/4.9	26.8/18.9
TOTAL for power interconnection	33.8/26.0			

separate operation/interconnection

Table 5. Electricity exchange via ISET, Bln.kWh/year

EPSs	Input	Output	Balance
Amur & Khabarovsk	From Primorye: 0.9	To Primorye: 3.5	From Khabarovsk: 2.4
Primorye	From Khabarovsk: 3.4 From DPRK: 0.4	To Khabarovsk: 1.0 To DPRK: 8.75	From Primorye: 5.95
DPRK	From Primorye: 8.4 From ROK: 6.6	To Primorye: 0.4 To ROK: 16.0	From DPRK: 1.4
ROK	From DPRK: 15.6	To DPRK: 6.7	To ROK: 8.9

Cost for ISET was estimated to be about $ 2 Bln., with cost for converters being $ 1.2 Bln. and cost for transmission $ 0.8 Bln. Cost for ISET maintenance was estimated to be about $ 150 Mln./year. Cost for transmitting electricity can be estimated as an annualized cost for the ISET divided by total yearly electricity exchange among EPSs. Thus, cost for electricity transmission via the ISET is calculated to be 0.85 ¢/kWh.

Table 6 presents economic indices of variants of jointly and separately operating EPSs. As is seen in 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. Taking into account the cost of the ISET, the resulting decrease in demand for capital investments is $ 12.3 Bln. Unlike capital investment, fuel cost increases with interconnecting EPSs (by $ 0.45 Bln./year). The increase in fuel cost is mainly caused by power transmission losses. Comparison of annualized cost (incorporating both investment and fuel cost) of the considered variants showed that the variant of EPSs interconnection has a lower magnitude of these costs ($ 14.3 Bln./year against $ 16.2 Bln./year for the variant of separate operation) and is more economically efficient. Thus, the net annualized economic benefit of "RFE-DPRK-ROK" ISET, determined as a difference between the above two values, is estimated to be nearly $ 2 Bln./year.

Table 6. Economic estimates by EPS

Indices	Units	Amur and Khabarovsk	Primorye	DPRK	ROK
Capital investment for power plants	$ Bln.	-	1.9/3.0	9.5/8.8	41.9/27.2
Capital investment for ISET		0/2.0			
Total investment		53.3/41.0			
Fuel cost	$ Bln./year	0.38/0.42	0.29/0.32	0.58/0.56	5.5/5.9
Total fuel cost		6.75/7.2			
Total annualized cost		16.2/14.3			
Net annualized economic benefit		1.9			

separate operation/interconnection

The above estimates yield economic benefit due to the capacity saving when interconnecting the EPSs. However, this benefit substantially differs by country. Thus, installed capacities of 0.8 GW at a cost of $ 1.1 Bln. are required for it to be in place in Russia when interconnecting with North and South Korea (see Table 4 and Table 6). This means a negative effect of capacity saving for Russia, though it causes additional revenue from electricity export. The DPRK experiences a decrease of required capacities by 0.7 GW (with cost $ 0.7 Bln.) due to interconnection. South Korea acquires substantial capacity saving 7.9 GW ($ 14.9 Bln.) through participating in power interconnection. Such a distribution of capacity commissioning and decrease by country is due to lower costs on of electricity production of RFE power plants in comparison with South Korean ones. This fact causes export of electricity from Russia (see Table 5).

There was an attempt to estimate complex economic benefits from interconnection for each country. The benefit was supposed to incorporate revenue from electricity export, benefit from capacity saving, and costs for additional capacity and electricity import. This incorporation was fulfilled by subtracting the annualized cost for additional capacity commissioning along with the cost for electricity import from the revenues of electricity export and annualized cost of capacity saving. Price for electricity trading among countries was tentatively assumed to be in the range of 6-7 ¢/kWh. Fixed costs and annual fuel cost for various kinds of power plants were taken into account as well. The cost for the ISET was not taken into account while estimating the benefit. The economic benefit of power interconnection for each country (though very tentative) is presented in Table 7.

Table 7. Economic benefit and electricity demand

	RFE	DPRK	ROK	TOTAL
Benefit, $\frac{\$ \text{ Mln./ year}}{\%}$	$\frac{200-280}{9-12}$	$\frac{270-280}{12}$	$\frac{1830-1740}{79-76}$	$\frac{2300}{100}$
Electricity demand, $\frac{\text{TWh / year}}{\%}$	$\frac{55}{10}$	$\frac{60}{11}$	$\frac{415}{79}$	$\frac{530}{100}$

Left figures are benefits calculated at 6 ¢/kWh price for electricity trading, right figures are those calculated at 7¢/kWh price.

As is seen in the table the total annualized economic benefit from the power interconnection is high, well exceeding $ 2 Bln. Meanwhile, the sharing of benefit among countries is very uneven with the largest share falling on ROK and least on the RFE and DPRK. At the first glance, this looks unfair. However, such sharing follows the allocation of prospective electricity demand among countries (Table 7). Like values of annualized economic benefit, electricity demand is given for the year 2020. Thus, from comparing shares of economic benefit and prospective electricity demand it can be concluded that the specific economic benefit per 1 kWh of the demand gained by each country due to power interconnection is almost equal for all countries. Therefore, sharing economic benefit among RFE, DPRK and ROK presented in Table 7 is fairly accurate. However, elaboration of more developed approaches for sharing costs and benefits of power grid interconnection among countries is needed.

As it follows from Table 7, the total annualized economic benefit of power interconnection exceeds the cost for the ISET. This means that investment for the ISET can be recovered in less than one year. That is, the payback period for the ISET is less than one year. It makes economic sense to proceed with interconnecting power systems of NEA. It should be noted that changing the price of electricity trading results in a redistribution of economic benefit among countries. For example, an increase in electricity trading price causes an increase in economic benefit derived by Russia and, to some extent, the DPRK. In this situation, the benefit for ROK correspondingly decreases.

III.2.5. Benefit of decreasing electricity production cost and tariff

Saving investment for power plant capacities due to interconnection of power systems results in recovering less investment and interest from electricity tariffs. In other words, saving investment brings about a decrease in electricity tariffs. Based on the results described above, this decrease for the Russian Far East, DPRK and ROK power systems interconnection is roughly estimated to be nearly 2 $/MWh in comparison with separate the operation of these EPSs for the year 2020.

Saving investment due to power interconnection also results also in a decrease of power plant fixed costs. In the case of the RFE, DPRK and ROK power system interconnection fixed costs for power generation is estimated to decrease by about 2.5 $/MWh. Meanwhile, fuel costs for the power interconnection increases by approximately 1 $/MWh. Nevertheless, the total decrease in operating costs (incorporating fixed and fuel costs) when interconnecting the above power systems amounts to 1.5 $/MWh for the year 2020. According to [30] average operating costs for the considered EPSs at their separate operation is estimated to be about 25.5 $/MWh for 2020. Thus, power interconnection reduces this cost by nearly 6%.

Total decrease of electricity production cost and tariff due to power interconnection is estimated to be about 3.5 $/MWh. It causes total yearly savings of electricity consumers of RFE, DPRK and ROK power interconnection to be nearly $ 2 Bln.

III.2.6. Reliability improvement benefit

Power interconnection either improves the reliability of the power supply or decreases the required capacity reserve with the same reliability. This is due to a nonlinear relation of the reserve needed to provide the required reliability level on the total system capacity. The number of power plant units grows with an increase in system capacity and the probability of failure of $\mathbf{N}$ units reduces with the increase of $\mathbf{N}$. Reduction of reserves in each EPS is compensated by receiving reserves from other EPSs through interstate electric ties. This compensation is possible because coincidence of large fault in EPS, which requires receiving reserve from other power systems, with ISET failure is supposed to have low probability.

The reliability effect is illustrated on the example of “RFE – DPRK – ROK” power interconnection. YANTAR mathematical model [34] was used for the reliability study of the interconnection.

The conducted studies [30,35] showed that reliability standards are observed both for separate and interconnected operation of the considered EPSs. In variant of EPSs separate operation average total system reserve was calculated to be 24 %. Such reserve guarantees the probability of failure-free operation to be 0.999657 that meets the standard. In variant of EPSs interconnection the reserve was estimated to be somewhat higher in comparison with the former variant – 26 %. Probability of failure-free operation for the EPSs interconnection was figured out to be 0.which is higher than the standard.

Although relative values of system reserve slightly increase for the case of power interconnection, their absolute values decrease because reserve is figured out for combined load maximum of power interconnection which is lower than sum of EPS load maximum at their separate operation. In the variant of the EPSs interconnection reserve increases in the Russian Far East and decreases in South and North Korea. This is caused by the fact, pointed out above, that ISET construction allows generating capacities to be redistributed among power systems (phasing in additional comparatively cheap power plants in the Russian Far East and decreasing more expensive power plants in other EPSs).

III.2.7. Environmental benefit

Development of “RFE-DPRK-ROK” ISET makes it possible to utilize hydropower resources of the Russian Far East and the DPRK within the power interconnection. Besides, nuclear power capacity is planned to be located in the RFE, is being constructed in the DPRK, and is a major source of electricity in ROK. These non-fossil fuel sources of electricity may substitute fossil fuel-burning power plants in the power interconnection and relieve environmental impact by reducing emission of greenhouse and other harmful gases and particulates (sulfur and nitrogen oxides, etc.).

A decrease in the environmental impact from domestic power plants may also take place in electricity importing countries independent from what type of power plants they import electricity from.

Power exchange caused by a growth in fossil fuel consumption while interconnecting power systems of RFE, DPRK and ROK (as it was shown in the section III.2.5) is accompanied by an increase in pollution, but the effect of maximum load seasonal diversity contributes to environmental benefits. At the period of maximum load (say in ROK), when power plants have to operate at their full capacities and produce greater pollution, the electricity flows via ISET from a neighboring country (either RFE or DPRK), substituting for ROK power plants and decreasing pollution. Receiving power from the grid interconnection in peak hours and seasons when pollution in the receiving country is at its highest is most valuable from an environmental viewpoint.

Obviously, construction of the ISET "RFE-DPRK-ROK" will also result in some negative environmental impacts. A complex study of environmental benefits and costs is needed.

III.3. Inferences

1. There is transport (railroads and roads) and power grid networks along the larger part of potential route of "RFE-DPRK-ROK" ISET. This makes the potential route more accessible while reducing the cost and labor of construction of the ISET.

2. As the preliminary study shows, "RFE-DPRK-ROK" ISET may ensure high economic benefits for all countries to be engaged in power interconnection. Reliability is also improved and environmental benefits may be gained.

3. Available mathematical models and methodology allow the preliminary study of the ISET to be conducted, though their further development is needed.

4. Verification of input data by experts from all countries engaged in power interconnection is needed.

IV. ISET "RFE-NEC-DPRK-ROK"

IV.1. Benefits from connecting Northeast China EPS with "RFE-DPRK-ROK" power interconnection

As is seen in Section II, the total current installed capacities of the EPSs of RFE and DPRK, with a winter maximum load, amounts to 16.5 GW, whereas current generating capacity of ROK, with a summer maximum load, exceeds 49 GW. It means that the effect of maximum load seasonal diversity is not realized fully. Additionally, including some EPS with a winter maximum load in the power interconnection would allow the effect to be realized more completely and bring about additional benefits for participants. An EPS with a winter maximum load may be NEC.

Current generating capacity of the NEC EPS is about 38 GW with 85 % occupied by thermal capacity and the rest by hydropower capacity [36]. The NEC EPS is comprised of Liaoning, Jilin, Hei Longjiang, and East Inner Mongolia provincial power grids (Figure 6). The largest provincial power grid is in Liaoning. It has 40 % of the NEC generating capacity and nearly 50 % of the NEC electricity consumption [36]. Total electricity consumption in NEC was 154 TWh. in 2000 [36]. Due to slow growth of electricity consumption and the rapid construction of new power plants, there is a surplus of generating capacity in the whole region. However, since the hydropower capacity share is low, peak capacity is not enough for the region and the EPS of NEC has problems with meeting peak power load of consumers. This problem will remain into the future, as hydropower utilization is already high and only 4000 MW of hydropower capacity in Jilin province is planned to be put online within the next five years [36]. There is an integrated backbone transmission grid of 500 kV in EPS of NEC. 500 kV transmission line connects EPSs of NEC and North China. The NEC power grid is connected with RFE EPS and purchases about 100 GWh/year from Russia [36]. There are some jointly operated HPPs sited on the China-DPRK border, with output shared between the countries. There are no electrical connections between Chinese and DPRK EPSs.

If NEC joined the 'RFE-DPRK-ROK" power interconnection, they could reap benefits: a) save capacity at the cost of seasonal diversity power exchange with EPS of ROK; b) receive maneuverable hydropower from DPRK; c) make a profit from electricity trades in seasons of low power loads from domestic consumers; d) relieve the environmental burden during the highest winter loads at the cost of receiving power from the interconnection. ROK may also obtain (a), (c) and (d) benefits from joining NEC in the interconnection. DPRK may also benefit from

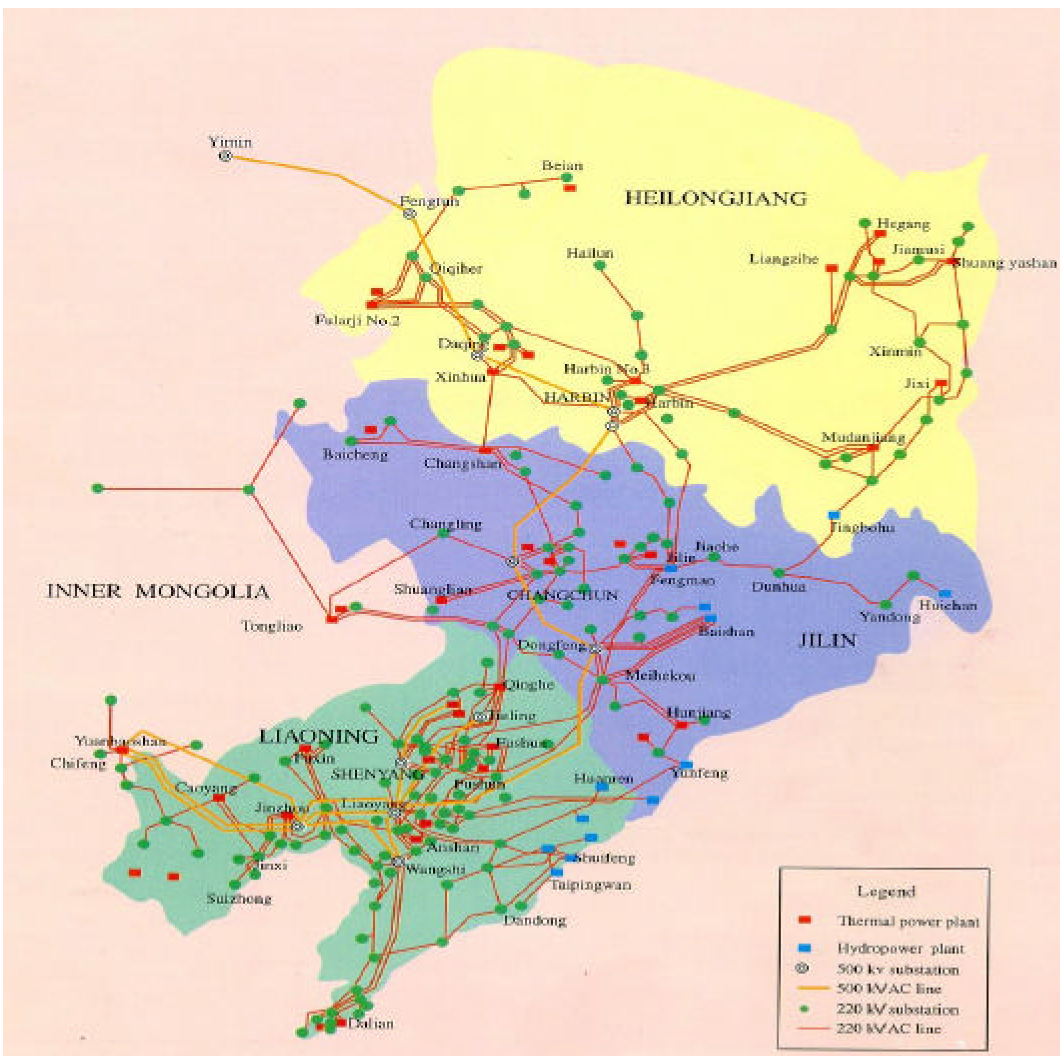


Figure 6. Power grid map of Northeast China [37]

trading its maneuverable hydropower. All participants may benefit from an increase in reliability and sharing of the reserve margin.

For the time being, China prefers developing a backbone power transmission grid among regions of China rather than developing power interconnections with neighboring countries. It was clearly stated by Chinese participants at the Workshop of the Northeast Asian Power Grid Interconnection Project held in Beijing on May 14-16, 2001. Unless China changes its attitude, the power interconnection between RFE, DPRK, ROK and NEC is unlikely. The study for “RFE-DPRK-ROK-NEC” interconnection is useful to demonstrate advantages of the interconnection for potential participants, in particular for China.

IV.2. Potential route of the ISET

The railroad network of the South of RFE, NEC, DPRK and ROK is presented in the Figure 7. There is railroad connecting Vladivostok through Northeast China and the DPRK to the ROK. From Vladivostok, the railroad goes to the Northwest and crosses the Russia-Chinese border to reach Harbin. Then it turns to the Southwest and goes to Shenyang. After Shenyang it goes to the Southeast and crosses the China-DPRK border to reach Pyongyang. From Pyongyang it goes farther to the Southeast and arrives in Seoul. Rough estimates of the distance by railroad are as follows: Vladivostok – Shenyang is about 1150 km, Shenyang – Pyongyang – nearly 400 km and Pyongyang – Seoul – approximately 250 km. Thus, a rough estimate of the total distance from Vladivostok through NEC and DPRK to Seoul by railroad is about 1800 km.

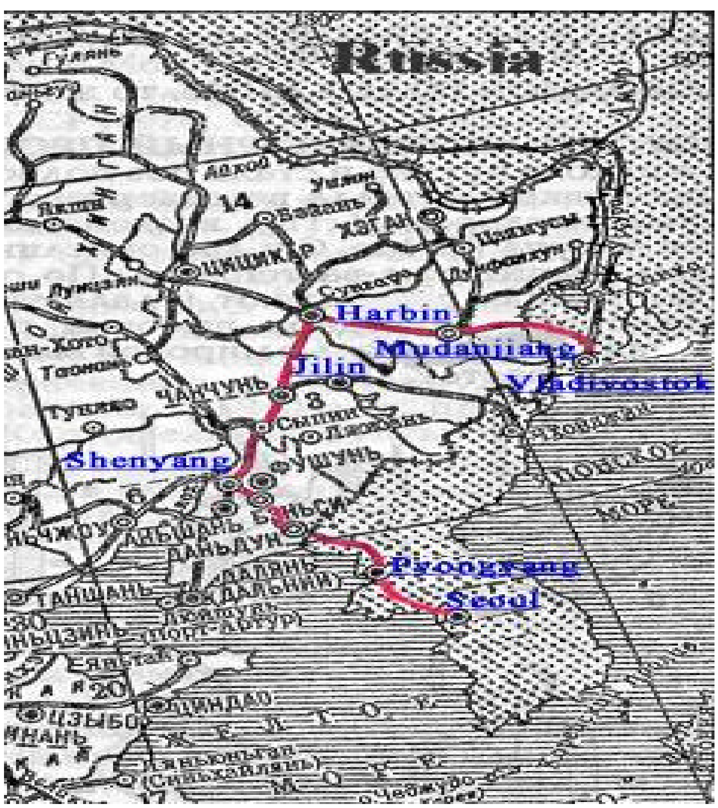


Figure 7. Map of railroads of the South of RFE, NEC, DPRK and ROK [28]

The above route can be optimized. In particular, landscape and other conditions allowing, the ISET route after Mudanjiang can be direct to Jilin and then to Shenyang. This shortens the ISET route.

Comparing a power grid map of NEC, DPRK, ROK and RFE with the railroad network given above, it can be seen that power grid infrastructure is developed along the larger part of the railroads connecting Vladivostok through Shenyang and Pyongyang to Seoul. Also, railroads are usually accompanied by roads. Thus, transport and power grid infrastructure is already quite developed along the larger part of the route of "RFE-NEC-DPRK-ROK" ISET. This makes the route more accessible and reduces the cost and labor for the construction of the ISET. However, the route of the ISET needs to be studied in more detail.

IV.3. Cost and benefit of the ISET "RFE-NEC-ROK"

IV.3.1. Scheme and use of the ISET

Economic effectiveness of power interconnection of EPSs of the RFE, Northeast China (NEC) and ROK was preliminary studied in [38]. The terminals of the ISET were supposed to be sited near Vladivostok, Seoul and Shenyang, with no terminal being sited in DPRK. This certainly reduces the benefits gained from the power interconnection. This study assumed that the DPRK would participate in the power interconnection by providing the corridor for the ISET. The study was carried out for the year 2020.

Location of the ISET terminal near Shenyang was determined by the following: Liaoning provincial power grid is the largest in NEC and the province consumes nearly half of NEC electricity consumption (see Section IV.1). As the capital of Liaoning province, Shenyang is supposed to be the major center of electricity consumption in the province.

The scheme of "RFE – NEC –ROK" ISET is given in Figure 8. The ISET was supposed to be constructed as a single-circuit ± 500 kV DC transmission line. The choice was based on the results of a reliability study for ISET "Russia-Japan" which showed that the single-circuit DC ISET ensures an acceptable reliability of consumers' power supply in the receiving EPS [39]. The voltage level was not proven in detail. It was accepted in view of the required distance and volumes of power needed to be transferred via the ISET. Technical issues of the ISET need to be further studied.

As is seen from the scheme, transfer capability varies by section. The "Vladivostok-Shenyang" section has a transfer capability of 1.3 GW that is almost equal to generating capacity of Primorye NPP[1]. In the summer months, when RFE electricity consumption declines, the section is loaded by power flow from

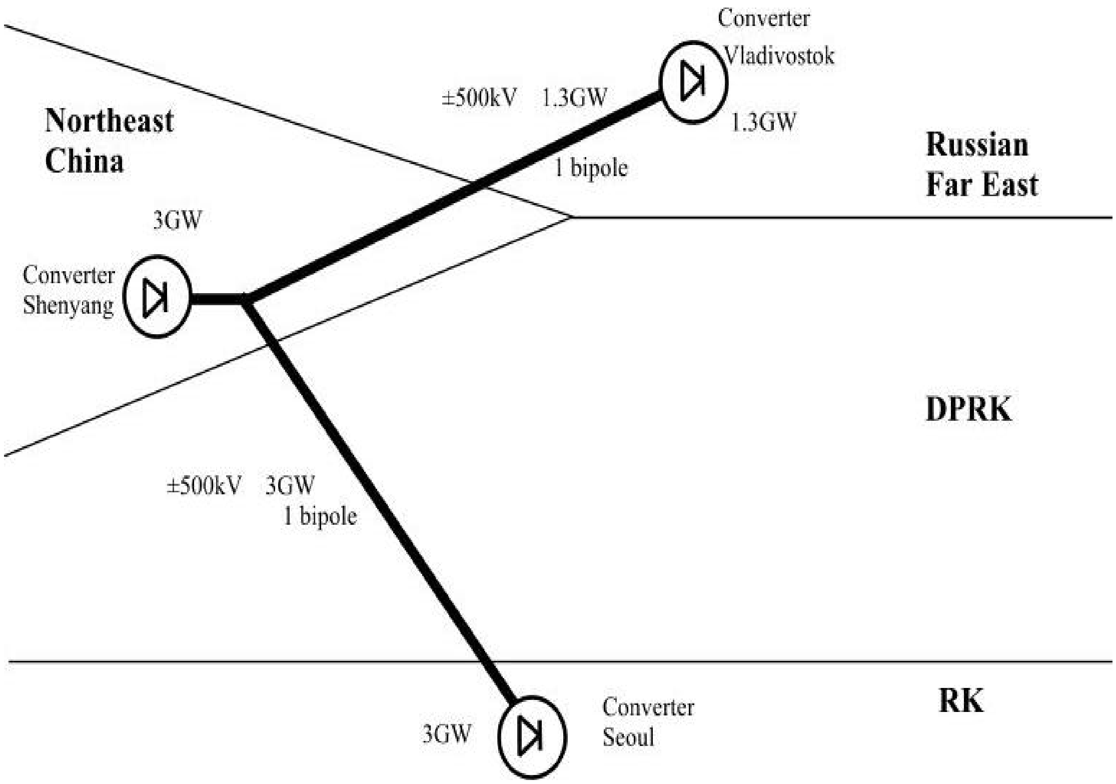


Figure 8 The scheme of ISET "RFE – NEC – ROK" [38]

Primorye NPP directed to ROK. This flow equals the total available capacity of the NPP. In the winter, as domestic power consumption rises, power flow in the section lessens. Its value equals the difference between total available capacity of the NPP and its share consumed at the RFE. In winter the power flow goes to NEC.

The section "Shenyang-Seoul" has a transfer capability of 3 GW and in the summer months is loaded by power flows from Primorye NPP and NEC thermal power plants, whose capacities are not fully utilized as electricity consumption decreases during this period in the RFE and NEC. The flow is the reverse during the winter. While domestic load sinks, idle ROK TPPs are additionally loaded and the additional power generation is transmitted to NEC.

Both sections are also intended for power exchange in emergency between EPSs of RFE, NEC and ROK during the whole year.

[1] In this study generating capacity of Primorye NPP was accepted to be nearly 1.3 GW (two units of 640 MW each)

IV.3.2. Capacity saving benefit

The power exchange described above allows the following capacities to be saved (Table 8) [38]. Due to the summer power flow from Primorye NPP to ROK, 1.2 GW (accounting for transmission losses) of TPP's capacity was estimated to be saved there. In the winter, power flows from the NPPs save a capacity of 0.5 GW in the RFE and 0.7 GW in NEC. Additional summer generation of NEC TPPs is transmitted to ROK allow 1.3 GW capacity to be saved there. Additional winter generation of ROK TPPs transmitted to NEC allow 2.7 GW capacity to be saved there. Emergency flows between EPSs of RFE, NEC and ROK by ISET allow saving operating reserves by 0.25, 0.5, and 0.25 GW accordingly. The total potential savings due to power interconnection was estimated to be about 7 GW.

Table 8. Capacities saved due to “RFE-NEC-ROK” power interconnection

Country	Capacity saved, GW
RFE	0.75
NEC	3.7
ROK	2.75
Total	7.2

As is seen from the above table, NEC has the largest capacity savings. Its caused by the following: Under the accepted constrained transfer capability of the ISET, NEC, being between RFE and ROK, benefits from exchanging power flows both with RFE and ROK. During the winter, NEC receives power flows from capacity excess in the RFE (Primorye NPP) and additionally loaded TPPs of ROK. The generating capacity savings in NEC is larger then the transfer capability of either the “RFE-NEC” section or the “NEC-ROK” section. As for ROK, its capacity saving, taking into account transmission losses, is less than the transfer capability of the “NEC-ROK” section. Thus, ROK benefit from capacity saving is less than the NEC one. RFE was assumed to receive only emergency power flow from the power interconnection. The rest of the capacity saving in RFE is due to power flow from Primorye NPP sharing its winter output between RFE and NEC. Thus, the total RFE capacity saving is less than the ROK one.

IV.3.3. Assessment of economic effectiveness

Economic effectiveness was determined in [38] for the ISET and Primorye NPP on the whole. It somewhat obscures the economic benefit of the ISET itself. Cost for the ISET is less than that of an NPP and economic benefit of the ISET by itself would be higher.

The economic effectiveness was determined by the criterion of net economic benefit. It is the difference between the cost of construction and maintenance of the saved capacity and that of the ISET and NPP. The cost was assumed to be annualized (incorporating both investment and maintenance costs). The positive value of the net economic benefit (when cost for the ISET and NPP is less than that of saved capacity) means that the ISET (together with NPP) is a more economically attractive option than that of separate operation of EPSs of the RFE, NEC and ROK.

Input data for calculating economic effectiveness of the ISET (in particular specific costs for Primorye NPP, saved TPPs in RFE, NEC and ROK, the ISET) are given in Table 9 and Total costs for the ISET (together with NPP) and saved capacities are given in Table 11 and Table 12 accordingly.

Table **10**. The input data were taken from [40-42] and based on estimates made by NIIPT Institute of Russia.

Table 9. Costs for power plants

	Specific investment, $/kW	Fixed cost, % of specific investment	Fuel cost, ¢/kWh
Primorye NPP	2000	15	0.7
TPPs in RFE and NEC	1200	10	2.8
TPPs in ROK	1600	10	3.5
Capacity reserve in RFE and NEC	300	8	-
Capacity reserve in ROK	400	8	-

Total costs for the ISET (together with NPP) and saved capacities are given in Table 11 and Table 12 accordingly.

Table 10. Costs and losses for the ISET transmission and converter

	Specific investment, 10^3 $/kW, $/km	Fixed cost, % of specific investment	Transmission losses, %/10^3 km, %/1 convertor
Transmission	650	3	5
Converter	100	10	2

Presented in Table 13 are the results of economic effectiveness of the ISET (along with NPP). Annualized costs and benefits were calculated for various discount rates. As is seen from the Table the ISET ensures positive annualized economic benefit in a range 0.8-1$Bln./year. Thus, power interconnection "RFE-NEC-ROK" is estimated to be economically feasible.

Table 11. Total cost for the ISET and NPP

	Investment, $Mln.	Yearly cost, $Mln./year
Transmissions	1170	40
Converters	900	90
Total for the ISET	2070	130
NPP	2600	470
TOTAL	4670	600

Table 12. Total cost for saved capacity

	Investment, $Mln.	Yearly cost, $Mln./year
TPPs of RFE	680	120
TPPs of NEC	4000	500
TPPs of ROK	4100	480
TOTAL	8780	1100

Table 13. Economic effectiveness estimates, $ Mln./year

Discount rate, %	8	10	12
Annualized cost for the ISET and NPP	970	1070	1160
Annualized cost for saved capacities	1800	1970	2150
Net annualized benefit	830	900	990

The obtained estimates cannot be compared with those obtained in Section III.2 because the method of study and input data are different. So, if the ISET "RFE-NEC-ROK" ensures a benefit of 1 Bln.$/year and the ISET "RFE-DPRK-ROK" ensures benefit of 2 Bln.$/year, this does not mean that the former is worse than the latter. Comparison is only possible when a unified method and data are applied for the study of both ISETs.

IV.4. Cost and benefit of "RFE-NEC-DPRK-ROK" ISET

IV.4.1. Assumptions and input data

The "RFE-NEC-DPRK-ROK" ISET was a preliminary studied by ROK scientists [1]. The ISET schematic is presented in Figure 9. As is seen, the considered ISET, like the "RFE-NEC-ROK" one, is assumed to be constructed as a bipolar (single-circuit) ± 500 kV DC transmission line. Unlike the "RFE-NEC-ROK" ISET the considered one has one more converter substation sited near Pyongyang. Transfer capacity of the ISET is 3 GW on the section "RFE-NEC" and 2.7 GW on the section "NEC-ROK". Converter capacity depends on the mode of power exchange among countries and is shown in the Figure. Seasonal power exchange among countries is given in Table 14. As seen in the table, RFE is assumed to be the exporter with other countries being importers.

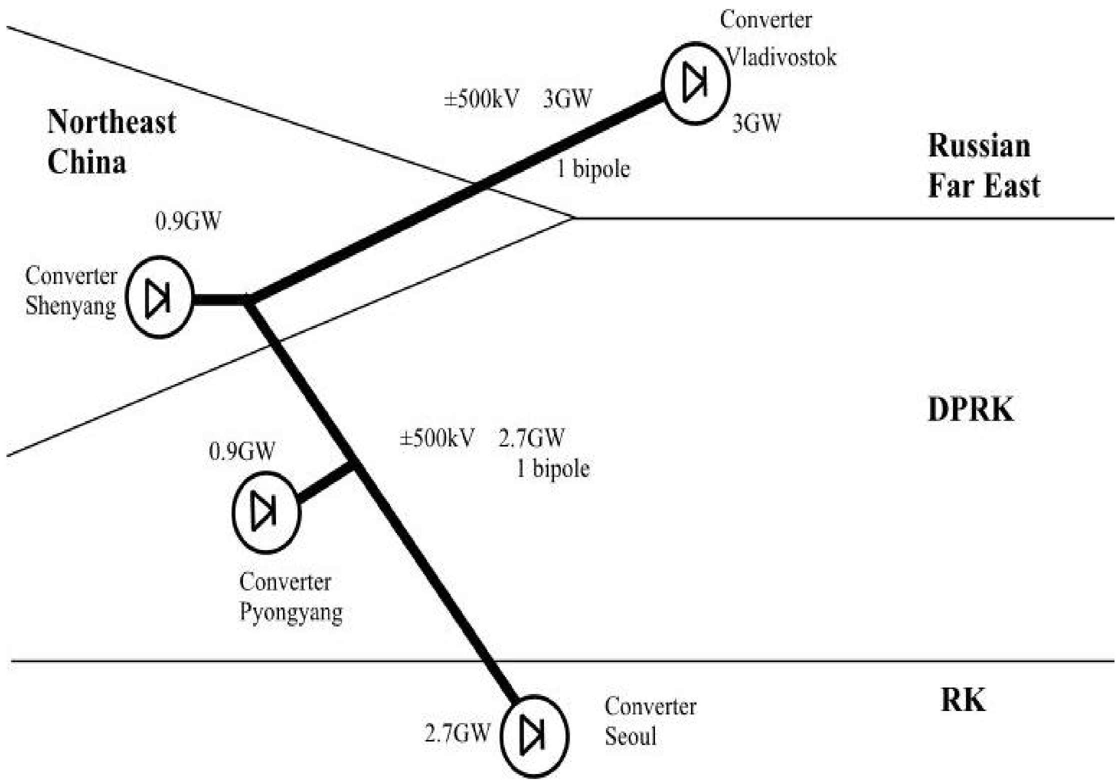


Figure 9. The scheme of ISET "RFE – NEC – DPRK – ROK"

Table 14. Seasonal power exchange mode among countries, GW

Seasons / Countries	Spring	Summer	Fall	Winter
ROK	1.2	2.7	1.2	0.0
DPRK	0.9	0.3	0.9	0.6
NEC	0.9	0.0	0.9	0.9
RFE	-3.0	-3.0	-3.0	-1.5

(–) means export of power, otherwise country imports power

Given in the Table 15 are costs for transmission and converters. They somewhat differ from those accepted for previous study (Total costs for the ISET (together with NPP) and saved capacities are given in Table 11 and Table 12 accordingly.

Table 10).

Table 15. Costs and losses for the ISET transmission and converters

	Specific investment, 10^3 $/kW, $/km	Fixed cost, % of specific investment	Transmission losses, %/10^3 km, %/1 converter
Transmission	600	2	1.5
Converter	100	4	1

IV.4.2. The method and results of the study

The following method of study was accepted. The net profit of the ISET is calculated as gross benefits minus gross costs. Gross benefits are comprised of benefits from capacity saving, benefits from reduction of electricity tariffs, and environmental benefits. The benefit from capacity saving is determined as the difference between the cost for power plant development with and without ISET. Benefit from the reduction of electricity tariffs is determined as the difference between the tariff of a particular country and the electricity trading price among countries multiplied by transmitted electricity. Environmental benefit was determined for CO_2 emissions reduction. Gross costs are comprised of the cost of construction and maintenance of transmission and converters. All costs and benefits are accumulated over a 15 year period.

Results of the ISET preliminary economic assessment are presented in Table 16. As follows from the table, gross benefits exceed gross costs by more than $ 2 Bln. for the fifteen year period. The ratio of net profit to gross costs is calculated to be 1.45. Thus, the ISET “RFE-NEC-DPRK-ROK” is estimated to be an attractive investment option, although a more detailed study is needed.

As for the distribution of costs and benefits, it is said in [1] that they have to be divided into equal amounts among the concerned parties.

Table 16. Economic estimates of the ISET, $ Bln.

Gross benefits	Benefit from capacity saving	3.7
	Benefit from reduction of electricity tariffs	3.5
	Environmental benefit	0.15
	Total	7.35
Gross costs	Transmission cost	2.4
	Converters cost	1.2
	Maintenance cost	1.45
	Total	5.05
Net profit		2.3

IV.5. “RFE-DPRK-ROK” ISET with extension “DPRK-NEC”

As can be seen from the above, incorporation of NEC into the "RFE-DPRK-ROK" power interconnection brings about benefits for all participating countries. On the other hand, this makes the interconnection route longer. Thus, the distance from Vladivostok to Pyongyang by the "RFE-DPRK-ROK" route is estimated to be about 850 km. Meanwhile, the distance from Vladivostok to Pyongyang by the "RFE-NEC-DPRK-ROK" route is about 1550 km, which is 700 km longer. Taking "RFE-DPRK-ROK" ISET with extended section " DPRK-NEC " (from Pyongyang to Shenyang) of 400 km long, we would cut the total route distance by about 300 km. Besides, the distance of power exchange between RFE on the one end and DPRK and ROK on the another would decrease by 700 km. This would reduce power transmission losses.

Thus, it looks reasonable to study the "RFE-DPRK-ROK" ISET with the extension "DPRK-NEC". The scheme of the ISET is presented in Figure 10. In this scheme benefits from shortening the route and including NEC in the power interconnection are accompanied by flexibility of the scheme. It can be developed in stages. At first "RFE-DPRK-ROK" ISET can be constructed. Than, if China decides to join the interconnection, "DPRK-NEC" section can be extended, with other sections developed as necessary.

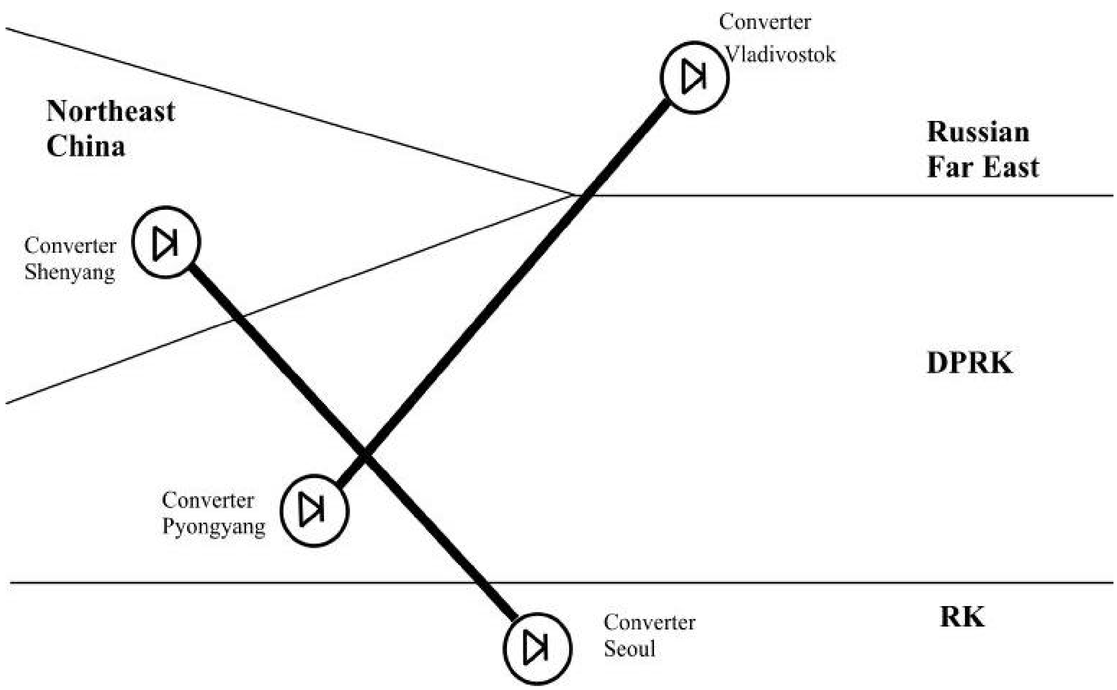


Figure 10. The scheme of "RFE-DPRK-ROK" ISET with extension "DPRK-NEC"

IV.6. Inferences

1. There is local scale power transmission infrastructure between RFE and NEC EPSs.

2. Transport (railroads and roads) is very developed and power grid networks along the larger part of the expected route of the "RFE-NEC-DPRK-ROK" ISET. This makes the routes more accessible and reduces the construction costs for the ISET.

3. There are mutual advantages for incorporating NEC into "RFE-DPRK-ROK" power interconnection.

4. As preliminary studies show, the examined variants of the ISET ensure high economic benefits. Such inferences were drawn independently by both South Korean and Russian researchers.

5. In examining the "RFE-DPRK-ROK" ISET, it seems reasonable to extend the "DPRK-NEC" section. This incorporates NEC into power interconnection making the distance of the route considerably shorter (in comparison with "RFE-NEC-DPRK-ROK" route), lessening transmission losses and therefore decreasing costs for construction and maintenance of the power grid interconnection. The scheme also is flexible in terms of when NEC joins the power interconnection.

V. ISETS IN NORTHEAST ASIA

Research and design institutes of the Northeast Asia region have studied the perspectives for developing electric ties among NEA countries [1-4,27,43,44, etc.]. Some of the ISETs major characteristics are listed in Table 17. These ISETs can serve both for the realization of power interconnection effects and electricity export-import. These projects are in various stages of development. Some of them are only preliminarily studied; some are more developed. The ISETs considered in Sections III and IV are not included in the Table. The ISETs from the Table 17 are given in
Figure 11.

As is seen from the table, all countries in Northeast Asia are examined from the viewpoint of potential power interconnection. Power grid connections are considered to tie East Siberia, Mongolia, North China, RFE, NEC, DPRK, ROK, and Japan. Most of them are expected to use DC transmission technology, though some are supposed to operate an AC current (ROK-DPRK, East Siberia-Mongolia). Economic estimates were done for the considered ISETs (except for Mongolia). The costs of some ISETs reach several billion dollars. Besides, the construction of power plants is required along with ISETs. This makes the power interconnection projects expensive. Nonetheless, the economic benefit, though preliminary studied and varying by ISET, is estimated to be in a range from hundreds of millions to several billions of dollars. Thus, there seems to be potential for developing power grid connections in Northeast Asia region.

VI. CONCLUSION

The following inferences can be drawn from the above:

1. Power systems of RFE, DPRK and ROK are mutually supplementary in terms of diversity of available power resources and power demand. There is a lack of energy resources in some regions and there are abundant energy resources in another ones; in some regions highest power demand comes during the winter, others in summer; some regions have maneuverable hydropower capacity while other regions lack capacity for meeting cycling demand of consumers; etc.

2. NEC joining the “RFE-DPRK-ROK” power interconnection seems to be mutually beneficial for all participating countries.

3. Interconnection of RFE, DPRK, and ROK along with NEC requires the construction of a new bulk power grid infrastructure based on modern DC transmission and conversion technology. Local scale power connections between adjacent countries allow small cross-border trading without attaining all the benefits of interconnection.

4. The preliminary analysis indicates that there is a developed transport and power grid infrastructure along a larger part of the potential routes of the ISETs. This makes the routes more accessible and reduces the costs of construction of the ISETs.

5. The power grid interconnections “RFE-DPRK-ROK”, “RFE-NEC-ROK” and “RFE-NEC-DPRK-ROK” bring high economic benefits to all participating countries.

6. It is reasonable to examine the “RFE-DPRK-ROK” ISET, with the section “DPRK-NEC” extended from that.

7. The methodology and mathematical models for studying prospective power grid interconnections in NEA already exist. These models need to be developed.

8. Sharing of verified input data among experts of all countries engaged in power interconnection is needed.

9. There seems to be agreement between experts from Russia, the DPRK and ROK about the need for expediency in the study of the “RFE-DPRK-ROK” ISET. China is reluctant about joining the study despite the benefits for China in developing the project.

10. Conditions appear to be mature for the complex international pre-feasibility study of the "RFE-DPRK-ROK" ISET, with technical, economic, reliability, environmental, and institutional issues examined. Examining the "DPRK-NEC" ISET extension depends on China's willingness to provide the necessary experts and data for the study.

11. There is a potential for the further study and development of power grid interconnections in Northeast Asia.

Table 17. Prospective electric ties among Northeast Asian countries

##	ISET	Length, km	Voltage, kV	Transfer Capability, GW	Transmitted Electricity, TWh/year	Cost for ISET, $ Bln.	Cost for Power Plants, $ Bln.	Total Cost, $ Bln.	Economic estimates
1.	East Siberia (Bratsk) – –- North China (Beijing)	2600	± 600	3	18	1.5	2.7 (Boguchansk Hydro*)	4.2	Net present value – $ 460 Mln., internal rate of return – 29%
2.	RFE (Bureya Hydro) – NEC (Harbin)	700	± 400	1	3	0.3	1.8 (Bureysk Hydro*)	2.1	Net annualized benefit – $ 120 Mln./year
3.	ROK – DPRK		154/345 (AC)	n.a.	n.a.	0.85	n.a.	n.a.	Total costs saving – $ 2.2 Bln.
4.	RFE (Sakhalin) – Japan (Honshu)	1800	± 600	4	23	5.5	4.1 (Sakhalin Gas)	9.6	Net annualized benefit – $ 600 Mln./year
5.	RFE (Uchur Hydro) – NEC (Shenyang) – – ROK (Seoul)	3500	± 500	3.5	17	4.5	6 (Uchursk Hydro)	10.5	Net present value – $ 2.3 Bln.
6.	East Siberia (Buryatia) – Mongolia (Ulan-Bator)	500	500 (AC)	0.5	2.5	n.a.	n.a.	n.a.	n.a.

*) Under construction

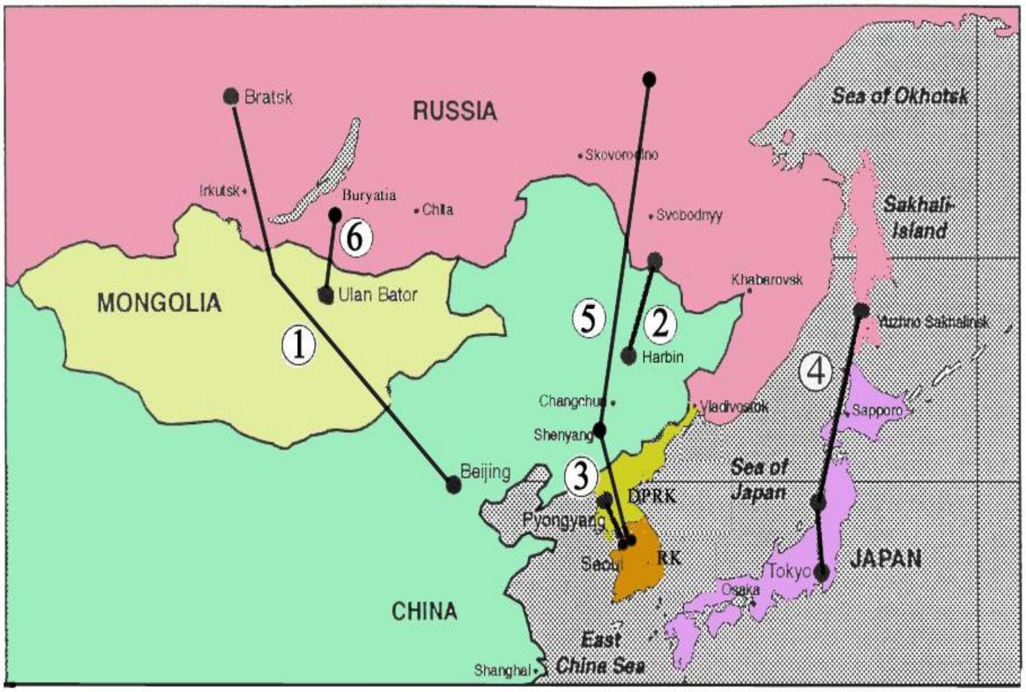


Figure 11. Prospective ISETs among Northeast Asian countries

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