452 Journal of Electrical Engineering & Technology, Vol. 2, No. 4, pp. 452~460, 2007

Economic Feasibility on the Interconnected Electric Power Systems in North-East Asia

Koo-Hyung Chung† and Balho H. Kim*

Abstract – The interstate electric power system, as an alternative for energy cooperation under regional economic block, was fervently debated prior to the restructuring of electric power industries and rapidly expanded in many regions since the 1990s. Especially, electric power system interconnection in the Northeast Asia region may bring considerable economic benefits since this region has strong supplementation in resource holdings, load shape, fuel mix, and etc. In this paper, we implement the ORIRES model, proposed by ESI of Russia, in order to analyze the economic feasibility on the Northeast Asia Region Electrical System Ties (NEAREST) project.

Keywords : Economic feasibility, Electric power system interconnection, North-East Asia, ORIRES

1. Introduction

The interstate electric power system, as an alternative for energy cooperation under regional economic block, was fervently debated prior to the restructuring of electric power industries and rapidly expanded in many regions since the 1990s. North American and European countries have already operated their interstate electric power systems, and many other countries, such as South America, Southeast Asia, and Africa etc., are also promoting electric power system interconnections. These are based on the expectations of economic electricity supply, improvement in system reliability, settlement of environmental and plant location related disputes, and international dètante etc.

With these in mind, the Northeast Asia region electrical system ties (NEAREST) project has been also under discussion since the late 1980s. In particular, since the Northeast Asia region has strong supplementations in resource holdings, load shape, fuel mix etc., electric power system interconnection in this region may bring considerable economic benefits.

However, the NEAREST project is the international cooperation case of a governmental importance including various political and technical difficulties. Moreover, since the NEAREST project requires considerable financial resources for long-term use of the interconnected electric power system, sufficient feasibility studies on the electrical system interconnection should be performed to minimize errors in policy decision as well as project planning and promoting.

As a preliminary study, we analyze economic feasibility on the NEAREST project. For this study, we implement a mathematical optimization model, called ORIRES. This is a linear programming (LP) model, proposed by ESI of Russia, to carry out the economic analysis of the NEAREST project. And, using this ORIRES model, we evaluate the economic feasibility on the NEAREST project by comparing total cost (capital investment and operating cost) involved with and without the interconnection.

2. Possibilities and Expectations on the NEAREST Project

It is expected that the Northeast Asia region is very likely to improve the electrical power cooperation due to various energy and electricity demand-supply structures and economic conditions among the countries in this region. The major causes for the possibility of the NEAREST project are as follows.

First, the electricity consumption area in Northeast Asia is far from the resource fields. Resource holders, such as Russia, have low consumption of electricity while South Korea and Japan with little resources consume electricity in large quantity. Although China is a resource holder, its electricity demand may increase significantly and the resource field is a long distance to the consumption area. Moreover, Russia has ample clean resources such as hydro and tidal energy.

Second, it is expected that electricity consumption in Northeast Asia may be increased considerably. China continues to have a high economic growth rate over 10%, and it may result in an overall increase of electricity

---

† Corresponding Author: Dept. of Electrical Engineering, Hongik University, Seoul, Korea (ga3310401@wow1.hongik.ac.kr)

* Dept. of Electrical Engineering, Hongik University, Seoul, Korea (bhklim@wow.hongik.ac.kr)

Received 19 October 2006 ; Accepted 5 March 2007

demand in Northeast Asia. In addition, electricity demand in North Korea and Mongolia may be increased according to their political changes. Japan's economic maturity results in low growth in electricity consumption. However, the large capital investment for new generating plants is inevitable since many superannuated plants may be closed in the near future. Furthermore, Japan's recent uneasiness at the operation of nuclear generating plants may give rise to the construction of numerous new plants in a short period of time.

Third, the different economic development level between Northeast Asian countries may bring great potential for electricity transactions. Coexistence with advanced and developing countries in this region gives rise to not only the different electricity patterns and unit generating costs but also investment abilities for the electric facility construction by their economic strength.

Fourth, Northeast Asian countries have different climates and this is a reason for load diversity by countries. South Korea and Japan's peak demand occurs in summer, while most countries have their peaks in winter.

Under these conditions, if the NEAREST project is promoted actively, these Northeast Asian countries can reduce total costs to operate the electric power system by increasing operation efficiency and cutting down on capital investment of generation units. Moreover, developing countries can easily raise funds for construction of new generating plants, and stable electricity supply as a motivation for economic development can be guaranteed by this fund-raising. In the case of advanced countries, they can be supplied with cheaper electricity and have an opportunity to enhance additional values in the electricity generation business through the investment in new generating plants constructed in developing countries. In South Korea and Japan, securing the location for new generating plants is at issue due to confined land and residents' opposition, and it is expected that the NEAREST project can be an alternative to settle this problem.

3. Analysis of Economic Feasibility on the NEAREST Project

In general, analyzing economic feasibility is a part of adequacy evaluation in regards to policy-making or investment projects. The examination of adequacy evaluation on a project or plan should achieve the optimal decision-making by comparing and evaluating various alternatives on the basis of specific criteria. Therefore, the result from analysis of economic feasibility should show decision-makers the most profitable alternative between various candidates using qualitative and measuring methods [3].

If economic benefit obtained through a project is greater than its total related cost, that is, it has net benefit for a given period, then the project is regarded as being 'economically feasible'. Among these economically feasible alternatives, a decision-maker chooses the profitable one as the optimal alternative by comparing their net benefit. However, when benefits from proposed projects are fixed externally, the project paid the lowest cost to complete, that is, the minimum-cost alternative is chosen as the best one. Therefore, analysis of economic feasibility on a project is to investigate 'the relationship between its benefit and cost for a given period', and its economic feasibility or infeasibility is decided by the principle of 'making the maximum profit at the lowest cost'.

A typical way for international energy cooperation in the electric power industry is the electric power system interconnection through tie-lines. The electric power system interconnection means that each system is connected with AC or DC transmission lines in order to exchange electricity with each other.

The economic feasibility for power system interconnection is determined by comparing total cost involved with and without interconnection. When fulfilling a country's power demands, we determined that if the cost without interconnection (such as facility construction and operating costs) exceeds the cost involved with interconnection, the power system interconnection is deemed economically feasible.

4. Analytic Model Design for the NEAREST Project

The ORIRES model, based on the economic feasibility criteria as mentioned above, was implemented to carry out the economic analysis of the NEAREST project [4]. The ORIRES model has the greatest number of records on previous NEAREST analysis that we can verify against this research. In addition, this model is ideal for the Northeast Asia region, which boasts high data constraint, because the model has a relatively small data requirement to produce acceptable results.

4.1 Features of ORIRES Model

The objective of implementing the ORIRES model is to evaluate potential capacities on electricity transactions between Northeast Asian countries. When the Northeast Asia region is combined into one integrated power system, its peak load would be less than the sum of each individual country's load. Therefore, the NEAREST project will not warrant for new power plants, will manage all generation facilities together for fuel cost reduction, and will require less generation reserve for system reliability.

In order to gauge the effects of system interconnection, the minimum plant mix with and without interconnection must be measured and compared, and an analytic model design must be developed to obtain international transmission capacity. With these in mind, ESI developed the ORIRES as a mathematical model that evaluates the effects of power system interconnection. The ORIRES model incorporates the following points to establish an optimum scenario.

1) The load diversity of countries in the Northeast Asia region needs to be integrated: non-coincidence during highest peak load season and daily peak hour. To accomplish this, all participating countries' 24-hour loads for both weekdays and weekends (categorized by season) were applied.
2) New generating facilities or interconnected lines for power import can be built to meet the load demand. The cost model of each option must be compared to carry out an effective economic evaluation. Therefore, each facility and interconnected line expansion capacities are applied as determinant variables in the model.
3) To compare the total cost involved in a generating facility and an interconnected line expansion, the investment cost plus operating cost must be taken into consideration. Therefore, the model should be able to determine hourly power output and power transaction capacity.
4) As a long-term power planning model, generation capacity, transmission capacity, and related cost must be compared at each target year to incorporate future load growth.

In order to simplify the calculation, the ORIRES model determines the optimum facility level for a particular target year only, instead of compiling yearly data up to the target year. This method is called static linear programming (LP) model.

4.2 Improvement of ORIRES Model

In this paper, we make some improvements to the ORIRES model for more accurate solutions. First, we modify constraints so that power exchange between two nodes can be carried out bilaterally. However, it does not mean that each node provides electricity to the other simultaneously. Since ORIRES, based on LP, handles power exchange between nodes as a general transportation problem, it presents unilateral power flow at a specific time. The direction of exchanged power is altered by an hourly system operating state of each node.

The original ORIRES model considers the maximum available generation capacities as the constraint parameters. However, if the maximum generation capacity of a target year is lower than the base year's, the original ORIRES derives an infeasible solution. This occurs when operating facilities in the base year are superannuated and replaced by other generation types' in the target year. Our improved model resolves this problem by controlling input data separately.

Moreover, when calculating the generating cost by generation types and the investment cost of tie lines, we calculate unit fixed and operating cost to utilize input data in advance. For example, after the investment cost of tie lines is calculated in terms of US$/kW· km, this is changed in unit cost per tie line capacity as the input data of the ORIRES model. Unit generating cost is converted as ORIRES input data after comparing and adjusting items of fixed and variable cost in advance.

4.3 Objective Function of ORIRES Model

The ORIRES model gives the optimal generation and international transmission capacity at a particular target year. Therefore, the model computes a solution minimizing fuel cost of existing generating facilities, capital investment in new generating plants, and tie lines for the entire interconnected region at a target year, formulated as follows:

$$\sum_{j=1}^{J}\sum_{i=1}^{I_j}\sum_{y=1}^{Y}\sum_{t_y=1}^{48} c_{ij}\tau_{t_y}x_{ijt_y} + \sum_{j=1}^{J}\sum_{i=1}^{I_j} K_{ij}(\gamma_j + b_{ij})X_{ij} + \sum_{j=1}^{J}\sum_{\substack{j_0=2 \\ j_0>j}}^{J} K_{jj_0}(\gamma_j + b_{jj_0})X_{jj_0} \tag{1}$$

In this paper, we make use of the following standard notations:

i Index of generation types

j Index for the number of nodes in the entire interconnected electric power system. A node means a region or country subject to the NEAREST project.

y Index of seasons

t_y Index of hours representing weekdays or weekends in season y

τ_{t_y} Index for the number of weekdays and weekends

c_{ij} Operating cost (average fuel cost) for generation type i of node j

K_{ij}	Capital investment cost per unit capacity for generation type i of node j
K_{jj_0}	Capital investment cost per unit capacity for the tie line between nodes j and j_0
γ_j	Rate of return of node j
b_{ij}	Annual rate of fixed cost for generation type i of node j
b_{jj_0}	Annual rate of fixed cost for the tie line between nodes j and j_0

In addition, decision variables x_{ijt_y}, X_{ij}, and X_{jj_0} represent generation output for generation type i of node j at hour t_y, newly added capacity for generation type i of node j, and the tie line between nodes j and j_0, respectively.

4.4 Constraints of ORIRES Model

The ORIRES model computes the optimal solution minimizing the objective function value under various constraints. Mathematically formulated constraints into this model incorporate reserve requirement constraints by nodes, seasonal and hourly supply-demand balance constraints by nodes, maximum allowable capacity limits by generation types and tie lines, and characteristics of hydro and pumping-storage generating facilities, etc.

For stable system operation, total available generation capacity should be greater than the peak demand including reserve requirement. This constraint is mathematically formulated as equation (2). It means that, by nodes, total electric power supply aggregating available generation capacities, outflows to other nodes, and inflows subtracted transmission losses has to be greater than the sum of peak demand and reserve requirement.

$$a_{1jy}^{quar} \cdot X_{1j} + \sum_{i=2}^{I_j} X_{ij} - \sum_{\substack{j'=1 \\ j' \neq j}}^{J} x_{jj't_y} + \sum_{\substack{j'=1 \\ j' \neq j}}^{J} x_{jj't_y}(1-\pi_{j'j}) \geq P_{jt_y} + R_{jt_y}$$

$$\text{for } j = 1, \cdots, J; t_y \in T_y^{\max}; y \in Y^{\max} \tag{2}$$

Additional notations are defined as follows:

$T_y^{\max}$	Annual peak demand hour
$Y^{\max}$	Season having annual peak demand
P_{jt_y}	Electricity demand of node j at hour t_y
R_{jt_y}	Reserve requirement of node j at hour t_y
$x_{jj't_y}$, $x_{j'jt_y}$	Exchanged power between nodes j and j' at hour t_y
a_{1jy}^{quar}	Index for guaranteed availability of hydro generator at node j in season y. This is indicated by percentage of constructed capacity.
$\pi_{j'j}$	Transmission loss factor of the tie line between nodes j and j'

The electric power system should be balanced at every instance. Equation (3) shows this balance constraint meaning that electric power supply aggregating generation output, outflows to other nodes, and inflows subtracted transmission losses has to be greater than the sum of electricity demand and water-charging load for the pumped-storage generation by nodes, seasons and hours.

$$\sum_{i=1}^{I_j} x_{ijt_y} - \sum_{\substack{j'=1 \\ j' \neq j}}^{J} x_{jj't_y} + \sum_{\substack{j'=1 \\ j' \neq j}}^{J} x_{j'jt_y}(1-\pi_{j'j}) \geq P_{jt_y} + x_{2jt_y}^{char}$$

$$\text{for } j = 1, \cdots, J; t_y = 1, \cdots, 48; y = 1, \cdots, Y \tag{3}$$

where, x_{ijt_y} and $x_{2jt_y}^{char}$ represent the generation output of type i, node j at hour t_y and required water-charging load for the pumped-storage generation of node j at hour t_y, respectively. Equation (3) is formulated by nodes, seasons, and hours.

The ORIRES model incorporates the limits to newly added capacity by generation types and tie lines as equations (4) and (5).

$$N_{ij}^0 \leq X_{ij} \leq N_{ij}^M, \quad \text{for } i = 1, \cdots, I_j; j = 1, \cdots, J \tag{4}$$

$$\Pi_{jj'}^0 \leq X_{jj'} \leq \Pi_{ij}^M, \quad \text{for } j = 1, \cdots, J; j' = 2, \cdots, J; j' > j \tag{5}$$

where, N_{ij}^0 represents the existing generation capacity of type i, node j at the base year and N_{ij}^M represents the upper limit of the generation capacity at the target year. $\Pi_{jj'}^0$ and Π_{ij}^M indicate the existing and upper limit of the tie line capacity between nodes j and j' at the base and target year, respectively.

In addition, generation outputs reflecting various operation conditions are restricted by generation types, nodes, and seasons as equation (6).

$$a_{ijy}^m \cdot X_{ij} \leq x_{ijt_y} \leq a_{ijy} \cdot X_{ij},$$

$$\text{for } i = 1, \cdots, I_j; j = 1, \cdots, J; t_y = 1, \cdots, 48; y = 1, \cdots, Y \tag{6}$$

where, a_{ijy}^{m} and a_{ijy} represent the minimum and maximum availability of each generation type per season by nodes respectively.

For the pumped storage plant, extra constraints are added due to its own operational characteristics, as follows.

$$0 \le x_{2jt_y}^{char} \le a_{2jy} \cdot X_{2j}, \quad \text{for } j = 1,\cdots,J; t_y = 1,\cdots,48; y = 1,\cdots,Y \tag{7}$$

Hourly exchanged power between two nodes should be less than the tie line capacity. It is defined as equation (8) due to bilateral power flow through the line.

$$-X_{jj'} \le x_{jj't_y} \le X_{jj'}, \quad \text{for } j = 1,\cdots,J; j' = 1,\cdots,J; j' \ne j; t_y = 1,\cdots,48 \tag{8}$$

Hydro generation facility has the constraints on the energy supply. That is, total yearly generation output should not exceed the maximum allowable supply for its capacity.

$$\sum_{t_y=1}^{48} \tau_{t_y} x_{1jt_y} \le h_{1jy} X_{1j}, \quad \text{for } j = 1,\cdots,J; y = 1,\cdots,Y \tag{9}$$

where, h_{1jy} represents the maximum operating hours of the hydro generation facility at node i in season y. The pumped-storage plant should keep the balance of charging and discharging water for generation.

$$\sum_{t_y=1}^{24} x_{2jt_y} - \eta_j^{PSPP} \sum_{t_y=1}^{24} x_{2jt_y}^{char} \le 0, \tag{10}$$

$$\sum_{t_y=25}^{48} x_{2jt_y} - \eta_j^{PSPP} \sum_{t_y=25}^{48} x_{2jt_y}^{char} \le 0, \quad \text{for } j = 1,\cdots,J; y = 1,\cdots,Y \tag{11}$$

η_j^{PSPP} represents the pumped-storage plant efficiency at node j implying energy loss between charging and discharging process. Moreover, pumped-storage plants are constrained on the volume of water-storage, as follows. h_{2j} defines the volume of water kept in storage implying the maximum daily operating hours of a pumped-storage plant.

$$\sum_{t_y=1}^{24} x_{2jt_y} \le h_{2j} X_{2j}, \tag{12}$$

$$\sum_{t_y=25}^{48} x_{2jt_y} \le h_{2j} X_{2j}, \quad \text{for } j = 1,\cdots,J; y = 1,\cdots,Y \tag{13}$$

4.5 Computation and Interpretation of the Optimal Solution

If the optimal solution derived in the ORIRES model has positive values of $X_{ij} - N_{ij}^{0}$ or $X_{jj'} - \Pi_{jj'}^{0}$, that is, being greater than zero, it means that the new generating facility of type i at node j or system interconnection between nodes j and j' are economically feasible respectively. In practice, deriving positive values of $X_{ij} - N_{ij}^{0}$ and $X_{jj'} - \Pi_{jj'}^{0}$ is determined by X_{ij} and $X_{jj'}$ since N_{ij}^{0} and $\Pi_{jj'}^{0}$ are not deterministic values in the objective function (1). x_{ijt_y} and $x_{jj't_y}$ represent the operation result of all generators and tie lines considered in the ORIRES model and they provide the information corresponding to hourly generation output by nodes and seasons, exchanged power between two nodes, and total operating cost, etc.

For the concrete evaluation of the NEAREST project's economic feasibility, ESI used the ORIRES model to compare the total cost of two alternatives when operating independent and interconnected systems in a target year.

5. Computational Results

In this paper, we implement the ORIRES model using GAMS/CPLEX solver [7] and apply this model to analyze the economic feasibility of the NEAREST project integrating South Korea (ROK), North Korea (DPRK), Russia Far East (RF), and East Siberia (ES). Each electric power system of the regions is considered as one node. In an effort to reflect the rapidly changing power industry and ensure accurate economic analysis, the economic feasibility reference date was adjusted to 2005, and all data were updated. For ROK, the input data were completely rewritten based on the 2nd National Demand-Supply Planning; and RF and ES input data were replaced by the most updated data from ESI. For DPRK, input data were inferred from the most recently published DPRK documents.

In this paper, the economic analyses are performed independently for years 2010, 2015, and 2020 with 2005 as the base. The economic feasibility for power system interconnection is determined by comparing total cost involved with and without interconnection at each target year. Contrary to other generation planning models, ORIRES computes annual cost for a particular target year only, instead of total payment compiled during a concerned period. Therefore, incorporating the results derived in a previous target year may cause considerable errors in ORIRES based economic analyses.

Table 1. Generating capacity per node (unit: GW)

	Year 2010			Year 2015			Year 2020		
	Independent	Interconnected	Changes	Independent	Interconnected	Changes	Independent	Interconnected	Changes
ROK	70.52	65.64	-6.9%	77.37	71.52	-7.6%	83.68	76.85	-8.2%
DPRK	13.64	10.92	-19.9%	14.95	11.36	-24.0%	16.79	12.58	-25.1%
FER	8.10	8.10	0.0%	8.90	8.20	-7.9%	9.92	7.30	-26.4%
ES	37.79	37.31	-1.3%	42.44	40.84	-3.8%	48.44	45.69	-5.7%
Total	130.04	121.97	-6.2%	143.65	131.92	-8.2%	158.83	142.42	-10.3%

Table 2. Generating facility investment cost per node (unit: Million $)

	Year 2010			Year 2015			Year 2020		
	Independent	Interconnected	Changes	Independent	Interconnected	Changes	Independent	Interconnected	Changes
ROK	1,900	1,121	-41.0%	4,185	3,501	-16.4%	5,732	4,643	-19.0%
DPRK	1,172	497	-57.6%	1,468	576	-60.8%	1,900	846	-55.5%
FER	0	0	0.0%	151	0	-100.0%	593	0	-100.0%
ES	522	434	-16.8%	1,465	1,079	-26.3%	2,670	1,973	-26.1%
Total	3,595	2,052	-42.9%	7,268	5,156	-29.1%	10,895	7,462	-31.5%

The ORIRES model input data can be classified into three major categories; generating facility related data, seasonal facility characteristics data, and load characteristics data.

The generating facility related data include generating capacity for each generation type (hydro, pumped storage, fossil, oil, natural gas, cogeneration, and nuclear power), maximum generating capacity of the target year, operating cost (US $/kWh, including fuel cost per generation type), new generating facility construction cost (US $/kW), fixed cost ratio for each generation type, pumped storage plant efficiency and its maximum daily operating hours.

The seasonal facility characteristics include generating facility availability and minimum operating capacity of each generation type per season, and mandatory hydro power plant operating capacity and its maximum operating hours.

For load characteristics data, the hourly load of each node was utilized. The hourly load is classified into weekdays and weekends, and seasonal peak load is expressed into percentage.

In addition, it is required for the tie line related data such as maximum transmission capacity, loss rate, and capital cost of each tie line. In this paper, we define three tie lines connecting ROK-DPRK, DPRK-RFE, and RFE-ES with 5GW, 2GW, 1.5GW in 2010, 6GW, 3GW, 2.25GW in 2015, and 7GW, 4GW, 3GW in 2020, respectively.

As shown in Table 1, power system interconnection significantly reduces the generating capacity of all regions. ROK, where peak load temporarily soars during summer, can refrain from expanding power plants by importing power. DPRK will have the most capacity gain due to its poor existing generating facility and geological advantage (a pathway between RF and ROK). On the other hand, RF will not experience generating capacity reduction since it has more ample supply than demand. Interestingly according to the scenario, FER will lose a small portion of its generating capacity in 2020 with system interconnection because ES does not expand any capacity as its energy surplus and importing power increased while an old existing coal plant (900 MW) is shut down.

Examining specifics, system interconnection will allow pumped storage and gas power (peak facilities) capacities to stay at current levels, and even reduce coal facilities. However, nuclear power (base facility) will be expanded regardless of interconnection status. This result suggests that the power exchange will yield economic feasibility similar to that of the coal power plant. For hydro power, no expansion was observed mainly due to its low generating capacity (rising from operating limitation) against high investment cost. Even though fuel cost is not involved, economic feasibility is, therefore, relatively low. Similar findings are displayed for all other regions.

The benefits of system interconnection are illustrated below in respect to investment cost (Table 2). As seen below, eliminating the need for new generating facility brought substantial economic benefits.

Table 3 describes the yearly generating capacity of each node. In 2010, the interconnection increased overall generating capacity because interconnected lines inevitably lose a portion of the transmission. The loss amount is proportional to the quantity of transacted power. In 2015 and 2020, the overall generating capacity slightly dropped with interconnection, possibly resulting from ROK's

Table 3. Yearly generating capacity per node (unit: TWh)

	Year 2010			Year 2015			Year 2020		
	Independent	Interconnected	Changes	Independent	Interconnected	Changes	Independent	Interconnected	Changes
ROK	446.04	444.88	-0.3%	490.26	494.54	0.9%	531.57	539.74	1.5%
DPRK	74.88	62.09	-17.1%	85.01	64.24	-24.4%	95.52	75.18	-21.3%
FER	39.27	51.69	31.6%	44.33	55.70	25.6%	49.38	51.44	4.2%
ES	201.78	203.44	0.8%	229.90	234.47	2.0%	265.51	274.47	3.4%
Total	761.97	762.10	0.02%	849.51	848.73	-0.1%	941.97	940.84	-0.1%

Table 4. Yearly fuel cost per node (unit: Million $)

	Year 2010			Year 2015			Year 2020		
	Independent	Interconnected	Changes	Independent	Interconnected	Changes	Independent	Interconnected	Changes
ROK	8,227	8,436	2.5%	8,138	8,024	-1.4%	8,175	8,730	6.8%
DPRK	494	592	19.8%	538	588	9.3%	558	648	16.1%
FER	338	470	39.1%	391	513	31.3%	416	466	12.2%
ES	600	605	0.7%	718	773	7.6%	874	987	13.0%
Total	9,660	10,103	4.6%	9,785	9,898	1.2%	10,022	10,831	8.1%

pumped storage capacity change. Following the interconnection, the pumped storage capacity can be significantly reduced by 2015 and 2020. This reduction removes pumped storage's loss factor, which is greater than transmission loss from interconnection; thus, decreases the overall generating capacity.

RF's generating capacity dramatically rose with interconnection. It may be due to RF's surplus power and the fact that this economical power replaces other regions' power sources. DPRK reduced a considerable amount of generating facilities with interconnection; hence, its generating capacity decreased as well.

During system interconnection, existing facilities with surplus power are further utilized via interconnected lines instead of constructing new facilities to avoid high cost. Therefore, generating facilities with high fuel cost make up a larger portion in interconnection than independent systems. Table 32 reflects the above increases in the generating cost. For an independent system, ROK displayed less fuel cost in 2015 and 2020 than 2010 as nuclear plants (low fuel cost) have increased and expensive oil and natural gas plants have decreased. However, the fuel cost decreased in 2015 with interconnection because decreasing natural gas capacity is replaced by low-cost coal and nuclear powers. A caution should be taken when comparing generating capacity and fuel cost since a number of variables (such as changes in generating facility capacity for each target year, seasonal/hourly load level, and difference in power exchange level for each target year) are implicated.

During system interconnection, most interconnected lines are increased to the maximum capacity. As a result, NEAREST is expected to bring tremendous economical benefit (Table 5).

Table 5. Tie line capacity per target year (unit: MW)

	ROK-DPRK	DPRK-FER	FER-ES
Year 2010	5,000	2,000	1,500
Year 2015	6,000	3,000	2,250
Year 2020	7,000	3,949	3,000

Table 6. Seasonal power exchange per node – Year 2010 (unit: GWh)

	ROK -> DPRK	DPRK -> FER	FER -> ES	ES -> FER	FER -> DPRK	DPRK -> ROK
Winter	3,345	548	768	1,142	2,093	-
Spring	468	-	-	3,240	4,320	24
Summer	-	-	-	3,312	4,416	5,212
Fall	1,258	10	28	2,584	3,644	178
Total	5,071	557	796	10,279	14,472	5,414

The power exchange through interconnected linesfluctuates with regional load pattern and plant mix, although it mostly concentrates in DPRK. This concentration came from DPRK's lack of adequate generating facility. For ROK, the power exchange converges during summer because its peak load occurs in summer. Table 34 illustrates power exchange per season.

Table 7 is the comparison of system interconnection costs (including interconnected line investment cost) for each target year. When system interconnection is established, additional cost accrues from interconnected line construction. Moreover, the utilization factor of existing facilities increases and fuel cost also rises.

Table 7. Economic evaluation: independent system vs. interconnection system (Units: Million $)

		Interconnected line investment cost	Generating facility investment cost	Fuel cost	Total
Year 2010	Independent	-	3,595	9,660	13,254
	Interconnected	168	2,052	10,103	12,323
	Changes				-7.0%
Year 2015	Independent	-	7,268	9,785	17,053
	Interconnected	234	5,156	9,898	15,288
	Changes				-10.4%
Year 2020	Independent	-	10,895	10,022	20,918
	Interconnected	298	7.462	10,831	18,591
	Changes				-11.1%

However, benefits from not constructing new facilities far outweigh the above costs. Considering all factors, the power interconnection will produce immense economic gain.

6. Conclusions

The Northeast Asia region has strong supplementation in resource, load shape, fuel mix etc. Interconnection of electric power systems in this region may bring considerable economic benefits. However, despite its considerable economic benefits, the NEAREST project is the international cooperation case of a governmental importance including various political and technical difficulties. In addition, since the NEAREST project requires tremendous financial resources for long-term use of the interconnected electric power system, sufficient feasibility studies on the electrical system interconnection should be performed to minimize errors in policy decision and project planning and promoting.

For this study, we implement a mathematical optimization model, ORIRES, proposed by the Energy System Institute (ESI), Russia. And then, using this model, we evaluate the economic feasibility on the NEAREST project by comparing total cost involved with and without electrical system interconnections. The economic feasibility for power system interconnection is determined by comparing total cost involved with and without interconnection. As a result, when system interconnection is established, additional cost accrues from interconnected line construction according to the increasing utilization factor of existing facilities and fuel cost. However, the benefits from not constructing new facilities far outweigh the above costs. Considering all factors, the power interconnection will produce immense economic gain.

This paper is of significance in that hypotheses related to the NEAREST project can be verified using the quantitative analysis technique. Investigations of technical feasibility and system reliability will be transacted in additional papers.

Acknowledgements

This work was funded by Ministry of Education and Human Resources Development for BK21 (2^{nd} phase) Project entitled 'Research on New Energy Resource & Power System Interface.'

References

[1] *National Demand-Supply Planning* 2004, Ministry of Commerce, Industry and Energy, 2004.

[2] *Energy Cooperation in Northeast* Asia, Korea Energy Economics Institute, 2003.

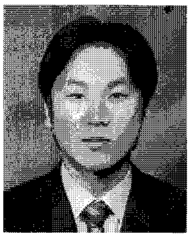
[3] *Economic Feasibility Estimation of Investment Project (Methodology and Procedure),* Korea Electric Power Corporation, 1994.

[4] L.S. Belyaev, L.U. Chudinova, S.V. Podkovalnikov, and V.A. Saveliev, "A mathematical model for effectiveness assessment of interstate electric ties in North-East Asia," *Proceedings of POWERCON '98, Beijing, China,* Aug., 1998, pp. 730-734.

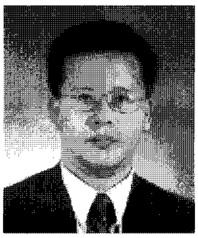
[5] L.S. Belyaev, G.F. Kovalev, and S.V. Podkovalnikov, "Efficiency assessment of 'Russia-China-South Korea' electric tie with power export from Prymorye nuclear power plant", *Proceedings of 1996 World Energy System Conference, Canadian Institute World Energy System, Toronto, Canada,* 1996, pp. 3.4.1 - 3.4.6.

[6] L.S. Belyaev, G.F. Kovalev, and S.V. Podkovalnikov, "Ties in North-Eastern Asia", *Perspectives in Energy,* vol. 3, 1994-1995, Pion Publication, pp. 321-330.

[7] B.A. McCarl, *GAMS User Guide: 2003,* Developed in cooperation with GAMS Development Corporation, Dec., 2002.



Koo-Hyung Chung
He received his B.S., M.S., and Ph.D degrees from Hongik University, Seoul, Korea, in 2001, 2003, and 2007, respectively. He is currently working as a BK21 post-doctoral researcher at Hongik University. His research interests are market analysis, public pricing, and power system operation & planning.



Balho H. Kim
He received his B.S. degree from Seoul National University, Korea, in 1984, and his M.S. and Ph.D. degrees from the University of Texas at Austin in 1992 and 1996, respectively. He was with KEPCO (the Korea Electric Power Corporation) from 1984 to 1990 and joined Hongik University in 1997 where he is presently Associate Professor of Electrical Engineering. His research fields include distributed optimal power flow, public pricing, B/C analysis, and power system planning and operation.