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Feasible Power Exchange between Russia and ROK Power Systems

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Abstract - This paper evaluates minimum and maximum power exchange considering economic and technical characteristics between Russia and ROK. First, we evaluate minimum power exchange to assure the economic feasibility by comparison with the total cost and benefit of the interconnected line. For evaluating maximum exchange power, system constraints are considered, which are examined through load flow and dynamic analysis by using the PSS/E program. As a result of these evaluations, we suggest the reasonable range of power exchange between ROK and Russia considering economic and technical constraints with the interconnection scenario that power system interconnection between ROK and Russia will be realized in the year 2010.

Keywords: Economic constraint, Power exchange, Power system interconnection, Technical constraint

1. Introduction

The power system of ROK is like an island after having been isolated from the DPRK network in 1945 and therefore, there has never been any effort to connect it to power systems of neighboring countries. Instead, all efforts have been focused on developing generating resources and enhancing the network in order to supply the power demand and to support the booming economy of the Republic of Korea during the last three decades. However, the Korean power industry has been confronted with many difficulties and will continue to be confronted in such a way in the future. Among the many reasons why the industry has faced such difficulties, the most important are as follows. Firstly, ROK is very poor in natural resources and must import 97.4% of the total primary energy domestically consumed. Secondly, ROK is a very small country and 70% of its territory is covered with mountains.

Furthermore, due to military and political tension between ROK and DPRK until recently, there were many limitations to developing generating resources and expanding the network for supplying the heavy load in the northern part near Seoul. In this situation, one of the best ways to overcome such difficulties in supplying reliable power seems to be cross-border system interconnection. Especially, power system interconnection in the NEA (Near East Asia) region, so called NEAREST (Near East Asian Region Electrical System Tie), is under significant scrutiny recently [1-4]. Now, the research project on NEAREST is being carried out in universities and research institutes in Korea. For the realization of power system interconnection, many economic and technical analyses must be carried out in advance.

In this paper, several interconnection scenarios between ROK and Russia in 2010 are investigated both in technical and economic aspects for verifying the feasibility of the NEAREST project. Therefore, the minimum power exchange in an economic aspect is evaluated by comparing with the life cycle cost and benefit of the interconnected line. In addition, evaluation of the maximum power exchange in a technical aspect is carried out.

For this evaluation, system constraints are investigated with the power system configuration of the year 2010.

2. Scenarios for the "Russia-ROK" Power System Inter-connection

In this paper, three different scenarios for the "Russia-ROK" power system interconnection, assuming that the power system interconnection will be set up in the year 2010, are suggested.

The characteristic of each scenario is as follows:

2.1 (Scenario-1) DPRK provides the interconnected line route

(Scenario-1) is to interconnect the power system between "Russia-ROK" by HVDC line passing through DPRK territory as shown in Fig. 1. In this scenario, only DPRK provides the interconnected line route, and does not include the "Russia-DPRK-ROK" interconnected line. Converter stations for supplying or receiving the power will be located in two places; Vladivostok and some point near Seoul and these will be two-terminal HVDC systems.

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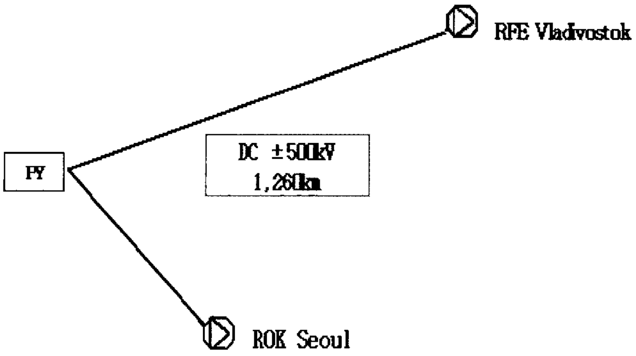

Fig. 1 Concept diagram of Russia-ROK power system interconnection: (Scenario-1)

2.2 (Scenario-2) Interconnected line via East Sea

(Scenario-2) is almost identical to (Scenario-1). The basic difference between the two scenarios is that Scenario-2 takes place via the East Sea. This is to consider the energy security problem, which can occur in the case of using the DPRK territory as an interconnected line route. It combines submarine cable and overhead line and has the merits of energy security viewpoints when importing power from Russia without the demerits of passing through DPRK territory. Also, total investment costs will be higher than (Scenario-1) because of the submarine cable application.

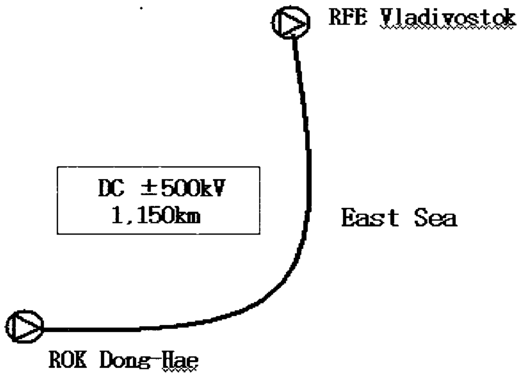

Fig. 2 Concept diagram of Russia-ROK power system interconnection: (Scenario-2)

2.3 (Scenario-3) BTB interconnected system in border area

(Scenario-3) is the case of a BTB (Back-to-Back) interconnected system without transmission line on a border area. In this scenario, each interconnected country has a responsibility of the domestic system reinforcement to exchange power. Two converter stations will be located in the border area; Russia-DPRK and DPRK-ROK, and exchange power between Russia-ROK will be delivered through the AC power systems of DPRK.

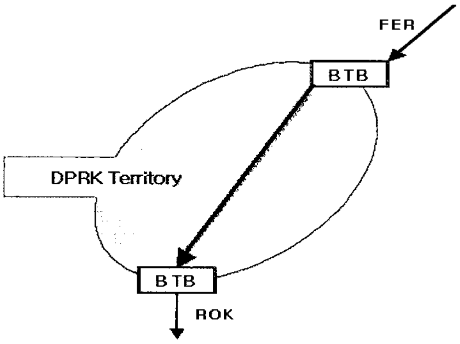

Fig. 3 Concept diagram of Russia-ROK power system interconnection: (Scenario-1)

3. CONFIGURATION of HVDC SYSTEM

HVDC was developed from technologies used in industrial drive systems. In order to obtain ideas on how HVDC can be developed, it is important to follow what is happening in that area. In industrial drives, the PCC (Phase Commutated Converter) technology that is presently used in HVDC has now almost totally been replaced by VSC (Voltage Source Converter) technology. The fundamental difference between these two technologies is that VSC requires additional components that can switch off the current, and not only turn it on as is the case with the PCC. As in a VSC, the current can be switched off, and there is no need for a network to commutate against it. In HVDC-applications it could also be of interest to use VSC technology in order to supply "dead" networks, which are areas that lack rotating machines, or "weak" power systems that have excessively low short circuit power [5]. In this paper, therefore, the VSC-HVDC system is applied to interconnect between Russia and ROK as shown in Fig. 4. Additional details are as follows:

- ±500kV two-terminal VSC-HVDC system is applied and consists of a two-bipole system, which means that the power divides into four DC transmission lines respectively. Although one-bipole transmission line is tripped due to disturbance, another bipole system can supply half of the power flowed before the disturbance. Therefore, this configuration can increase the reliability of the interconnected line.
- Interconnection bus voltage is set to 1.0pu and receives the reactive power from capacitor banks and the converter itself. Each terminal has capacitor banks for filtering the high frequency noise, which is 10% of the converter rating.
- The power exchange scenario is that ROK imports power from Russia. We assume Russia has infinite surplus power and that the Russian power system has no system constraints on the supply of power.

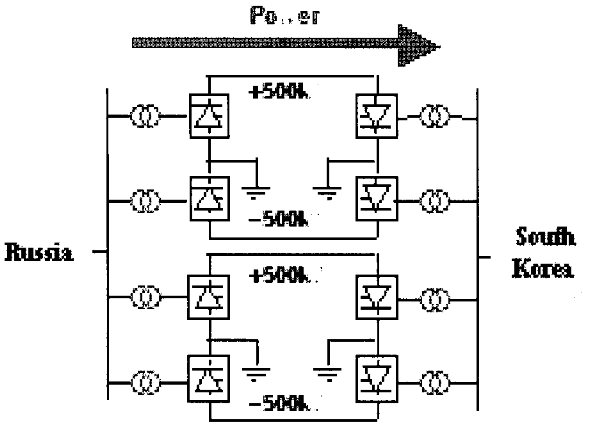

Fig. 4 Configuration of HVDC system for interconnection scenario 1

4. Methodology for evaluating the minimum and maximum POWER exchange

The minimum power exchange is evaluated through comparison of the total cost and benefit of the interconnected line during the life cycle span of 30 years. The components of cost and benefit are as follows;

4.1 Minimum power exchange

4.1.1 Cost of interconnected line

Total life cycle cost of the interconnected line consists of initial and operating costs. Initial cost includes the construction cost of the transmission line (T/L) and the converter station (C/S). Operating cost involves the maintenance cost and power losses of the transmission line and converter station. In this paper, annual maintenance cost can be calculated by multiplying the initial cost with the annual maintenance rate of the transmission line and converter station. The cost from power losses is also evaluated by using power loss factor [6-8]. As mentioned before, the interconnected line will go through the territory of DPRK, which means Russia and ROK should pay for using the ROW (Right of way) of DPRK. The cost of the ROW is calculated by multiplying the cost rate of the ROW with the annual electricity tariff benefit between Russia and ROK. If the BTB system is used for interconnection, the cost rate of the ROW is much more than (scenario-1) because this BTB interconnected system must not only use the territory but also the AC network of DPRK. As mentioned before, however, we assume that the domestic system reinforcement to exchange power is charged by each interconnected country. Therefore, no investment cost for reinforcement of the DPRK AC network is considered here.

4.1.2 Benefit of interconnected line

The benefit of interconnection comes from the electricity tariff difference between ROK and Russia. The electricity tariff difference in 2001 was $0.0383/kWh, but this difference has been decreasing because the annual increase rate of electricity tariff in Russia is higher than that of ROK.

Therefore, the decreasing rate of electricity tariff difference between ROK and Russia is one of the key factors for assuring economic feasibility. In this paper, we assume that the initial annual decreasing rate of electricity tariff difference is 10% and that it will decrease annually until 2030, at which point it will be 0%. Another key aspect is the average utility factor of the transmission line. The higher utility factor makes interconnection more beneficial. The 60% of T/L annual capacity factor is used to calculate the benefit.

Table 1 shows the input parameter for estimating the life-cycle cost and benefit of the interconnection transmission line.

Table 1 Input Prameter

Items		Data
Life-cycle span		30 years
C/S	Maintenance cost	4% of initial cost
	Power Loss factor	0.7%
T/L	Maintenance cost	4% of initial cost
	Power Loss factor	2%/1,000km
Cost rate of ROW	(Scenario-1)	20% of tariff benefit
	(Scenario-3)	35% of tariff benefit
Electricity tariff	FER	$0.0259/kwh
	ROK	$0.0642/kwh
Annual capacity factor		60%

4.2 Maximum power exchange

Maximum power exchange is evaluated by taking account of the following technical aspects:

4.2.1 System constraints

To evaluate maximum exchange power with Russia considering the system constraints, we carry out power system analysis such as load flow and dynamic analysis by using the PSS/E program. Because the objective of this study is to investigate the system constraints from the standpoint of ROK, the Russia system constraints are excluded. Firstly, we look into the methodology and results of the PSS/E load flow analysis to determine maximum exchange power without any violation like overload and voltage problems in the ROK power system. Secondly, we carry out PSS/E dynamics analysis to evaluate the impact of interconnected line trip caused by disturbance on the

ROK system in terms of frequency.

a. Load flow analysis

Load flow analysis is very important in operating and planning a power system. It is the method used to calculate bus voltage, power flow and power loss, using generation/load data and network data in the power system. Load flow analysis is carried out in case of not only steady state but also N-1 contingency. In normal state, all transmission lines and transformers should have loading of lower than 100% of rating, and bus voltage should keep the range from 0.95pu to 1.05pu. In contingency, loading of lower than 120% is allowed and voltage operation range is the same with normal state.

The PSS/E program and peak load data of the Korea Electric Power Company (KEPCO) in 2010 are used. For the load flow analysis on the interconnected power system, we've made the equivalent network model of an interconnected power system including reduction of generation in ROK. Based on this equivalent network model, load flow analysis is done as follows.

(1) Equivalent network model

Fig. 5 shows the equivalent network model of the ROK-Russia interconnection. In this equivalent network, a detailed network of Russia is not included, therefore, a detailed ROK power system is considered and the Russian power system is represented as an equivalent source that has infinite capacity.

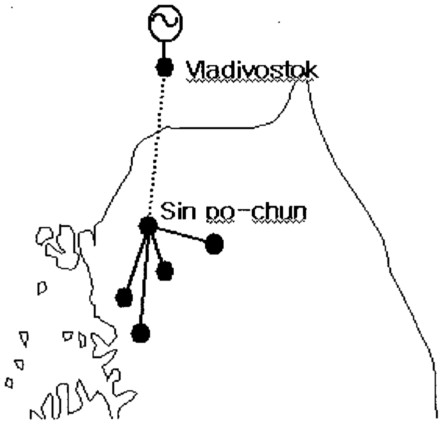

Fig. 5 Equivalent network model

(2) Reduction of generation in ROK

In the case of importing power from Russia, the total generation of ROK should be decreased to meet the power balance.

The installed generating capacity of ROK in 2003 is shown in Table II. In 2003, total installed generating capacity was 50.4GW, for which nuclear, steam, combined cycle and hydraulic generation capacities accounted 31.2%, 43.0%, 20.0% and 5.8% of the total generating capacity in ROK, respectively [9].

Because of the lack of hydraulic resources, ROK must be highly reliant on nuclear and steam power.

Table 2 Installed Generating Capacity (GW)

Generation	Capacity	%
Nuclear	15.7	31.2
Steam	21.7	43.0
C/C & Internal Combustion	10.1	20.0
Hydro	2.9	5.8
Total	50.4	100.0

Table 3 shows the production of electricity that was generated in 2003: 42.3% from nuclear plants, 45.7% from steam turbine plants, 10.9% from C/C & internal combustion and 1.1% from Hydro plants. 88.0% of the total electricity produced in 2003 was generated by nuclear and steam turbine power plants. As mentioned above, the production of electricity in ROK has been highly relying on nuclear and steam turbine power plants [9].

Table 3 Production of electricity (TWh)

Generation	Production	%
Nuclear	129.7	42.3
Steam	140.3	45.7
C/C & Internal Combustion	33.4	10.9
Hydro	3.5	1.1
Total	306.9	100.0

In considering the unit cost of electricity of each generation type, nuclear generation is the cheapest followed by coal-fired generation. Otherwise, LNG and C/C generation is more expensive than any other types of generation. Considering the above statistics, we reduce the generation of ROK in accordance with inflow power from Russia through disconnecting some of LNG, and C/C generators from the ROK power system.

b. Dynamic analysis

In dynamic analysis, we look at the impact of the interconnected line trip on ROK power system in terms of frequency. When the interconnected line is tripped by a certain disturbance in one of the interconnected power systems, it will impact on the other interconnected power systems. This impact can be evaluated in terms of power system frequency deviation. If the HVDC transmission line between Russia and ROK is tripped, the power system frequency of ROK is fluctuated and undergoes transient state for a few seconds. After transient state, it settles into a new steady state with deviation from normal operating frequency of 60Hz. Fig. 6 shows the frequency variation caused by the interconnected line trip.

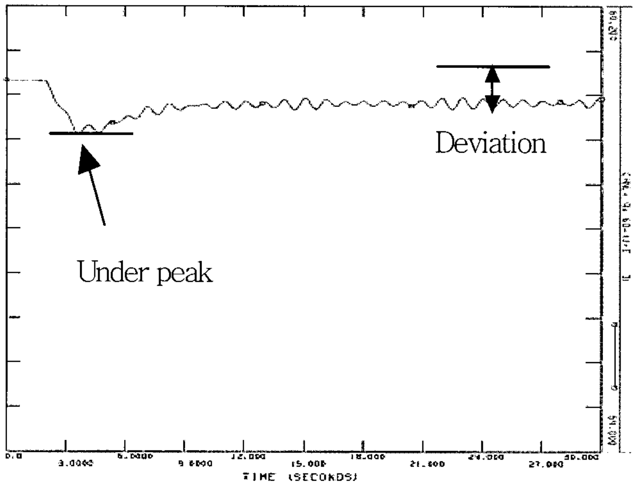

Fig. 6 Frequency variation under contingency

In Fig. 6, some amount of power is coming from Russia in normal operating condition and then one-bipole or two-bipole is tripped caused by disturbance, which means that ROK loses some portion of generation. The power system frequency of ROK will be dropped to under peak frequency due to unbalance of generation and load. After transient state for a few seconds, frequency converges to a new steady state by AGC and governor free with some frequency deviation. We have used the PSS/E dynamic simulation program and peak load data of KEPCO in 2010. In power system analysis, only the Korean power system is considered, therefore, Russia in scenarios 1 and 2, and DPRK in scenario 3 can be presented as an equivalent source. That means the Korean power system has a certain generator, which is connected with an interconnection bus through the HVDC system. The equivalent network model and generation reduction method are the same as those of the load flow analysis. As mentioned before, we assume that the two-bipole HVDC system is built for inter-connection between Russia and ROK and the one-bipole trip is considered. The operating standard of power system frequency of KEPCO asks frequency in steady state to be maintained in the range of 59.8Hz to 60.2Hz and under peak should be over 59.6Hz in transient state. So, we can expect acceptable maximum power exchange without severe violation of frequency operating standard under interconnected line trip.

5. Evaluation Results of Minimum and Maximum Power Exchange by Scenarios

5.1 Minimum exchange power by scenarios

Tables IV, V and VI show the total cost and benefit of the interconnected line. In these Tables, the benefit is equal because it is determined by electricity tariff and the amount of exchange power. Conclusively, economic feasibility of the interconnected line depends on total cost. In (Scenario-1), if 1GW of power is exchanged between ROK and Russia, the total cost is much more than the benefit, which can't assure economic advantage. However, more than 2GW of power exchange can guarantee the interconnection project to be in the black. Therefore, we propose that minimum power exchange in an economic aspect is 2GW. In (Scenario-2), breakeven point of the interconnected line has a range from 2GW to 3GW.

Therefore, over 3GW of power exchange is needed to assure profit. When compared with (Scenario-1), the minimum exchange power of (Scenario-2) is larger due to expensive undersea transmission line construction costs. For (Scenario-3), 1GW is the minimum exchange power for (Scenario-3) as shown in Table 4.

5.2 Maximum exchange power by scenarios

In load flow analysis, overload of the transmission line and transformer and voltage profile are investigated with the case of steady state and contingency.

Table 4 Total Cost and Benefit FOR (scenario-1)

Power Exchange	Cost (billion $)	Benefit (billion $)
1GW	1.62	1.29
2GW	2.51	2.59
3GW	3.31	3.88
4GW	4.12	5.18

Table 5 Total Cost and Benefit FOR (scenario-2)

Power Exchange	Cost (billion $)	Benefit (billion $)
1GW	2.08	1.29
2GW	2.88	2.59
3GW	3.59	3.88
4GW	4.32	5.18

Table 6 Total Cost and Benefit FOR (scenario-3)

Power Exchange	Cost (billion $)	Benefit (billion $)
1GW	1.16	1.29
2GW	2.27	2.59

There are a total of 59 cases of N-1 contingency that consist of one circuit transmission line or one transformer outage nearby an interconnection bus. In dynamic analysis, as inflow power increases gradually, frequency deviation and under peak become larger when the transmission line is tripped. In the real power system, the two-bipole trip at the same time is a very rare situation because two-bipole means four AC transmission lines.

Therefore, we evaluate the maximum power exchange taking into account the one-bipole trip. Considering the above results, we can say that 3GW to 4GW of power is the maximum power that can be exchanged. More detailed results are as follows:

5.2.1 Scenario-1

a. Loadflow analysis

There is no violation of overload and voltage in steady state up to 6GW of inflow power. In N-1 contingency, however, some violations appear as the inflow power exceeds 4GW.

b. Dynamic analysis

The power system frequency of ROK can maintain the standard when losing the one-bipole system, which is 2GW of power. Therefore, considering the one-bipole trip, 4GW is the possible power exchange considering the viewpoints of dynamic analysis.

Finally, 4GW of power exchange is the maximum acceptable power of (Scenario-1) taking account of the technical aspect.

5.2.2 Scenario-2

a. Loadflow analysis

There is a violation of overload in steady state over 3GW of inflow power. In N-1 contingency, some violations happen as the inflow power exceeds 3GW.

b. Dynamic analysis

Considering the one-bipole system trip, power system frequency can maintain the standard up to 1.5GW. Therefore, 3GW is a possible power exchange considering the standpoints of dynamic analysis.

Therefore, 3GW of power exchange is the maximum acceptable power of (Scenario-2).

5.2.3 Scenario-3

a. Loadflow analysis

There is no violation of overload and voltage in steady state up to 6GW of inflow power. In N-1 contingency, however, the inflow power exceeding 4GW causes some violations.

b. Dynamic analysis

The power system frequency of ROK can maintain the standard up to loss of the 2GW of power. Considering one-bipole trip, 4GW is the maximum power exchange.

As a conclusion, 4GW of power exchange is the maximum acceptable power of (Scenario-3).

6. Conclusion

This paper evaluates minimum and maximum exchange power between Russia and ROK in 2010 from both economic and technical aspects. In evaluation of minimum exchange power, we estimate total cost and benefit of the interconnected line. The 2GW to 3GW seems to be a minimum power exchange needed to assure the economic feasibility. In addition to minimum power exchange, maximum power exchange is also evaluated through two technical constraints. For this, system constraints such as overload of transmission line and transformer, voltage profile of bus and frequency variation caused by interconnection trip are investigated. As a result of these investigations, we propose 3GW to 4GW as the maximum power exchange with Russia in the year of 2010.

As a conclusion, even though the feasible exchange of power in each scenario is slightly different, we can say that the range of 3GW to 4GW seems to be a reasonable power exchange level of the ROK-Russia interconnected line in the year 2010. This study is performed under hypothesis and based on a research concept. Therefore, more detailed engineering works from the technical and economic viewpoints are required for the realization of NEAREST.

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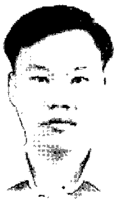

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