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A feasibility study of interconnection between ROK and Russia

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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.

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, interconnection scenarios between ROK and Russia in 2010 are investigated both in technical and economic aspects for verifying the feasibility of the NEAREST project.

2. "ROK-Russia" Power System Interconnection

In this scenario, we assume that power system interconnection between Russia and ROK will be set up in the year of 2010 and DPRK will provide its land only for interconnected line as shown in Fig 1. The elements of this interconnection scenario are:

- The length of interconnected line between Vladivostok and Sin Po-Chun is 1,260km.
- ±500kV two-terminal HVDC system is applied and consists of 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 a half of power flowed before disturbance.
- The power exchange scenario is that ROK imports power from Russia. We assume Russia has infinite surplus power and Russia power system has no any system constraint to supply power.

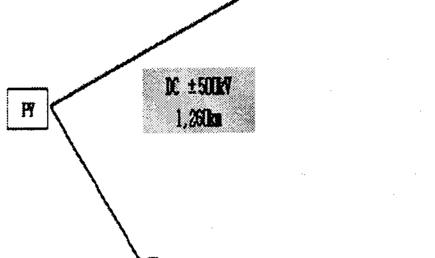

Fig.1. Concept diagram of Russia-ROK power system interconnection

3. Evaluation Methodology of the Feasible Power Exchange

3.1 Minimum power exchange

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 [5-7]. 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.

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.

3.2 Maximum power exchange

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.

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.

We have used the PSS/E dynamic simulation program and peak load data of KEPCO in 2010. 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 interconnection 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.

4. Evaluation Result of Feasible Power Exchange

4.1 Minimum exchange power

Tables I shows 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. 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.

TABLE I.
total cost and benefit

Power Exchange	Cost (billion $)	Benefit (billion $)
1GW	2.144	1.739
2GW	3.335	3.477
3GW	4.433	5.216

4.2 Maximum exchange power

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

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 4GW of power is the maximum power that can be exchanged. More detailed results are as follows:

■ Load flow 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.

■ 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 taking account of the technical aspect.

5. 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 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 4GW as the maximum power exchange with Russia in the year of 2010.

As a conclusion, 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.

6. References

[1] KERI, KEPCO, "A preliminary study of the power system interconnections in Northeast Asia countries", Tech Rep. 2000.

[2] L. Belyaev and S. Podkovalnikov, "An approach to and results of effectiveness assessment of inter-tie <<RFE – DPRK – ROK>>", 2000.

[3] Asia Pacific Energy Research Institute, "Cross-border power", 2002.

[4] Belyaev L.S., Chudinova L.Yu.,·, Podkovalnikov S.V. "Studies of Interstate Electric Ties in Northeast Asia", International Journal of Global Energy Issues.- 2002.- Vol. 17.- ' 2.- pp. 228-249.

[5] CIGRE Working Group 14.20, "Economic Assessment of HVDC Links", CIGRE Annual Report, 2000.

[6] D. Wilhelm, "High-Voltage Direct Current Handbook", Electric Power Research Institute, TR-104166, 1994.

[7] Harold L. Hill, "Transmission Line Reference Book HVDC To ±600kV", Electric Power Research Institute, RP-104.