Possible Interconnection scenarios and Preliminary assessment of power system interconnections between ROK, DPRK and RF

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<Backgrounds-1>

Background

- ROK is island system after separation from DPRK system in 1948
  - Needs the electricity co-operational policy with DPRK
- ROK power system has many difficulties, which means the necessity of alternatives and want to interconnect with DPRK
  - Very poor in natural resources
  - High increasing rate of load caused by economic growth
  - High cost for power system planning and operation
  - Environmental protection : NIMBY phenomena
  - Military and political tension between ROK and DPRK

<Backgrounds-2>

Background (continue)

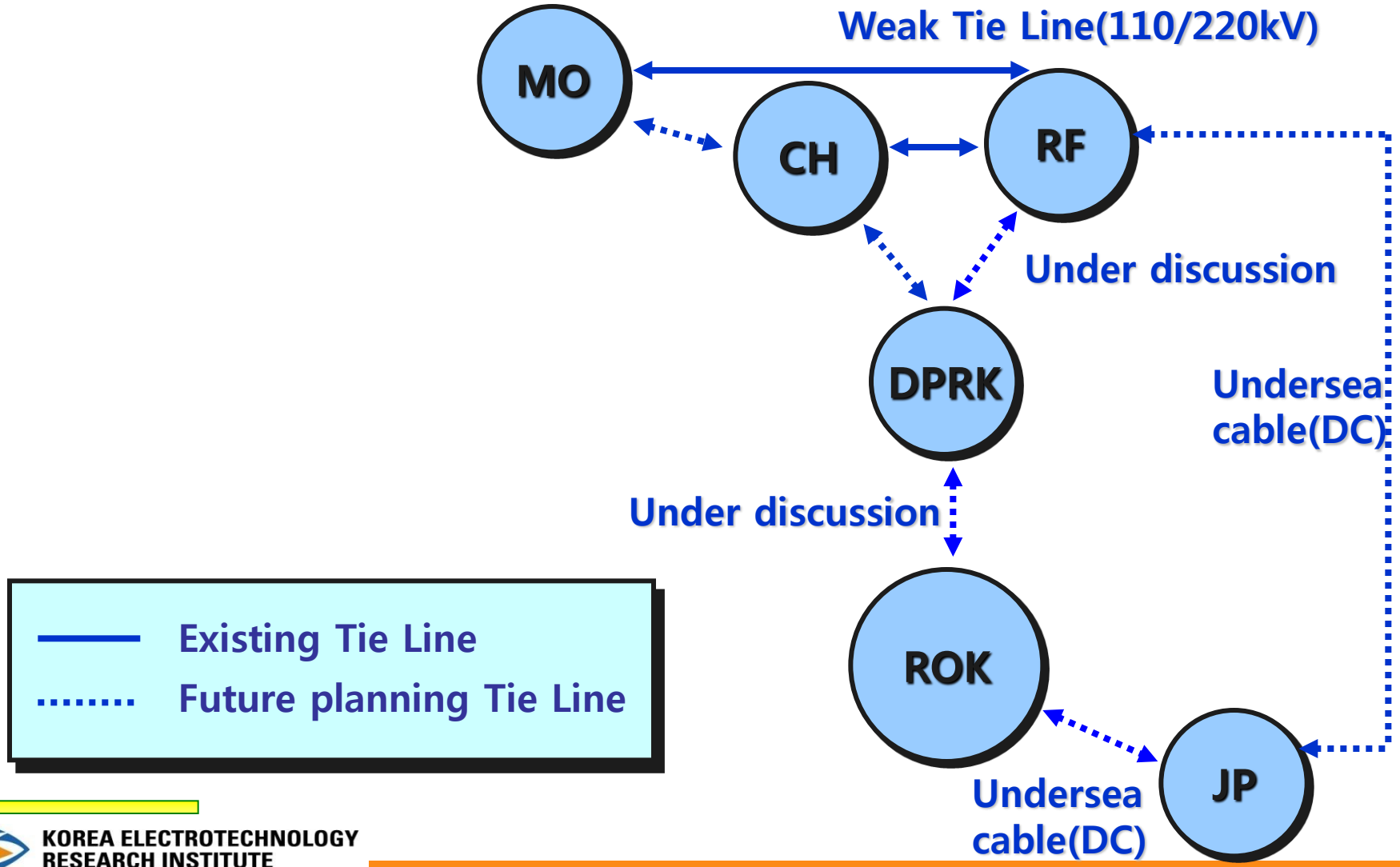
- ROK and Russia have mutual complementary characteristics
  - Natural resources, power mix ratio, electricity tariff
  - Need more power plants vs. surplus power
- NEAREST can be an alternative to …
  - Overcome difficulties in power sector
  - Utilize the complementary characteristics

* NEAREST(North East Asian Region Electrical System Ties)

<Present status>

- No inter-ties on NEA with the exception of …
  - Weak 220kV ties b/t Siberia and RFE
  - Weak 220kV ties b/t Siberia and Central Mongolia
  - Weak 110kV and 220kV ties b/t RFE and Northeast China
  - Weak ties b/t North and Northeast China
- Potentials interconnecting power system in NEA region
  - RF – CH
  - RF – JP
  - RF – DPRK – ROK
  - ROK – JP with submarine cable

<Present status>

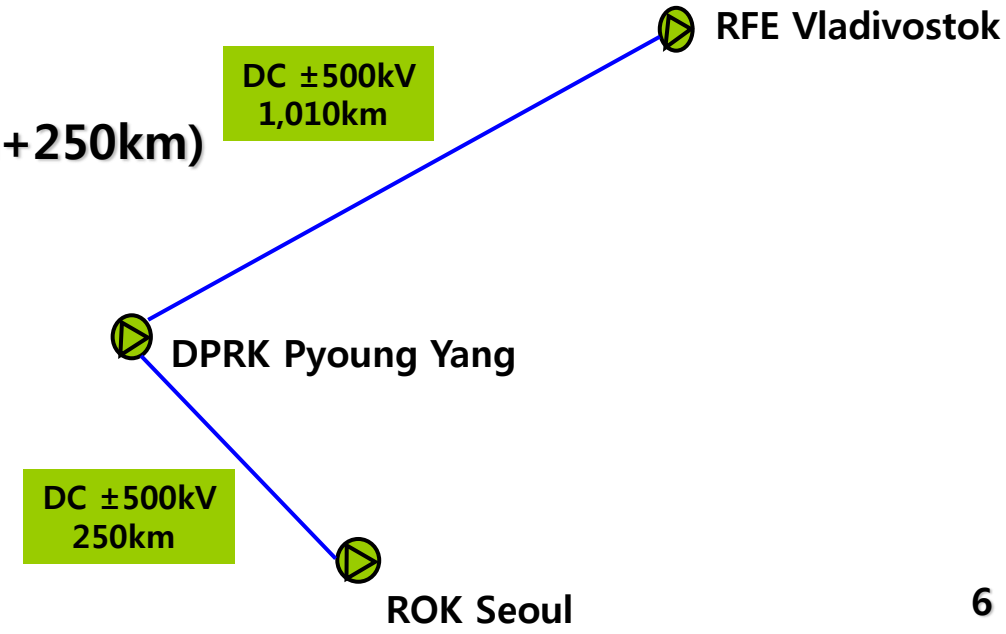


<Scenarios>

- Four Scenarios are proposed, among them …
  - ex) (Scenarios-1) is …
    - Power System Interconnection "ROK-DPRK-RF"
    - Capacity of 3~4GW HVDC, ±500-600kV about 1,000km
    - 3-C/S Terminal, Seoul(Sindeukun), Pyongyang, Vladivostok(Kraskino)
  - Composite system reliability analysis, HL II Level
    - NEAREL(NEAREST-RELIABILTY) Program is developed
    - Composite System Reliability Program considering Generation, Transmission and Interconnected Tie Line
    - TEAG (Tie line constrained Equivalent Assisting Generator Model) Considering Assisting System plus Tie Line

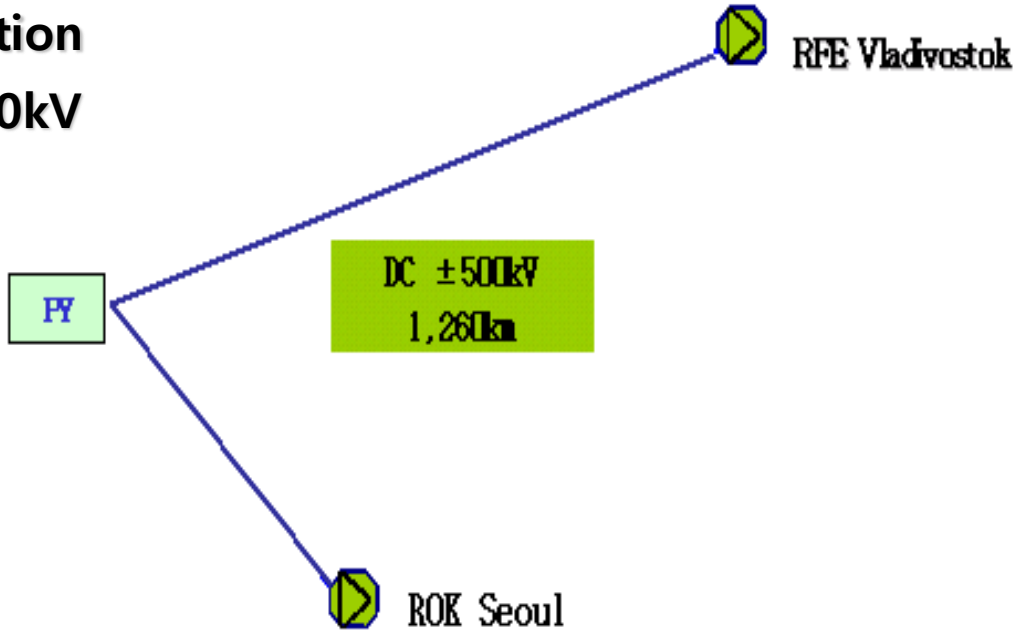
<ROK-DPRK-RF interconnection Scenario>

- (scenario-1)
  - "ROK-DPRK-RF" 3-Terminal HVDC interconnection
    - Converter stations will be located in Vladivostok, some point near Seoul and Pyoung Yang
  - HVDC system configuration
    - VSC-HVDC, DC ±500kV
    - T/L : 1,260km (1,010km+250km)



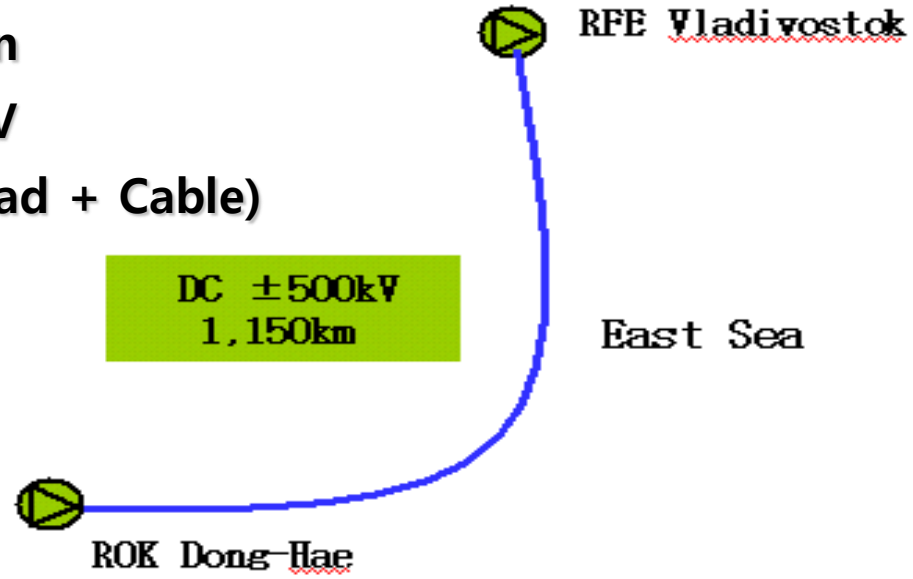
<ROK-DPRK-RF interconnection Scenario>

- (scenario-2)
  - "ROK-RF" 2-Terminal HVDC interconnection
    - DPRK provides the interconnected line route
    - Converter stations for supplying or receiving the power will be located in two places; Vladivostok and some point near Seoul
  - HVDC system configuration
    - VSC-HVDC, DC ±500kV
    - T/L : 1,260km



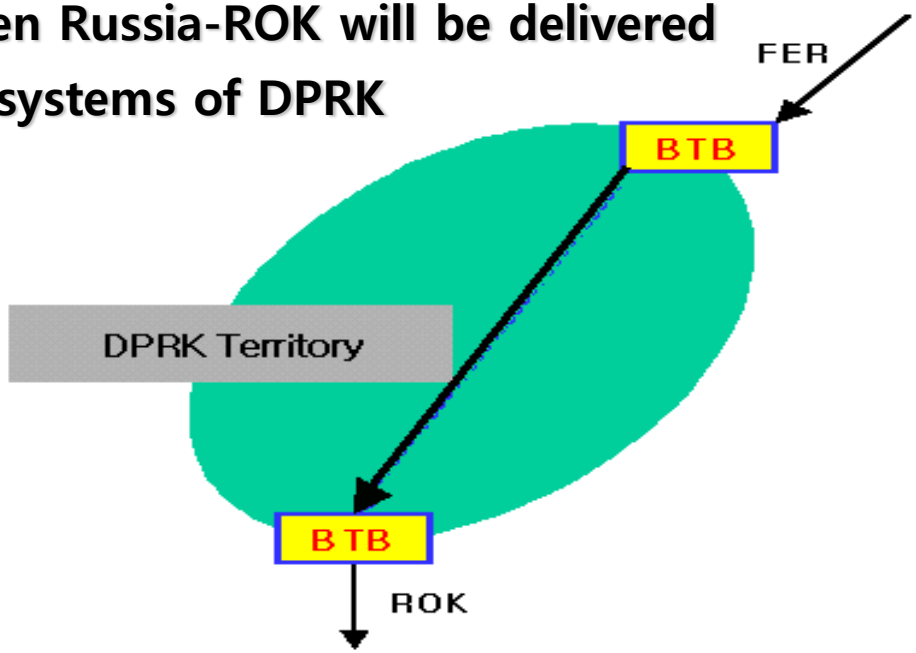
<ROK-DPRK-RF interconnection Scenario>

- (scenario-3)
  - "ROK-RF" 2-Terminal HVDC interconnection
    - Interconnected line via East Sea
    - It has the merits of energy security viewpoints when importing power from Russia without the demerits of passing through DPRK territory
  - HVDC system configuration
    - VSC-HVDC, DC ±500kV
    - T/L : 1,150km (Overhead + Cable)



<ROK-DPRK-RF interconnection Scenario>

- (scenario-4)
  - "ROK-RF" BTB interconnection
    - BTB interconnected system in border area
    - Two converter stations will be located in the border area
      : Russia-DPRK and DPRK-ROK
    - Exchange power between Russia-ROK will be delivered through the AC power systems of DPRK
  - HVDC system configuration
    - VSC-HVDC, DC ±500kV



<Technical Analysis : Evaluation of maximum exchange power>

- Using the EMTDC & PSS/E Program
- System constraints
  - Load flow analysis
    - Find maximum exchange power without violations of overload and bus voltage profile
    - Consider steady state and N-1contingency
  - Dynamic analysis
    - Evaluate the impact of interconnected line trip on ROK power system, especially for frequency variation
- Interconnected line constraints
  - Geographical constraint of Korean peninsular
  - Current rating constraint of conductor

<Economic Analysis>

★ ex) Comparison of system interconnection costs (Independent system vs. interconnected system)

<Table> Economic evaluation: (Million $)

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

*) I/L : Interconnected Transmission Line Investment
G/F : Generating Facility Investment_

<Economic Analysis : CO2 Emission Comparison>

★ In special cases of interconnected system, CO2 emission rather increases
This is caused by the economic optimization and rapid rise in coal/cogeneration in RF to supply power to ROK and DPRK

<Table 4> CO2 emission level per node (Unit: Million tC)

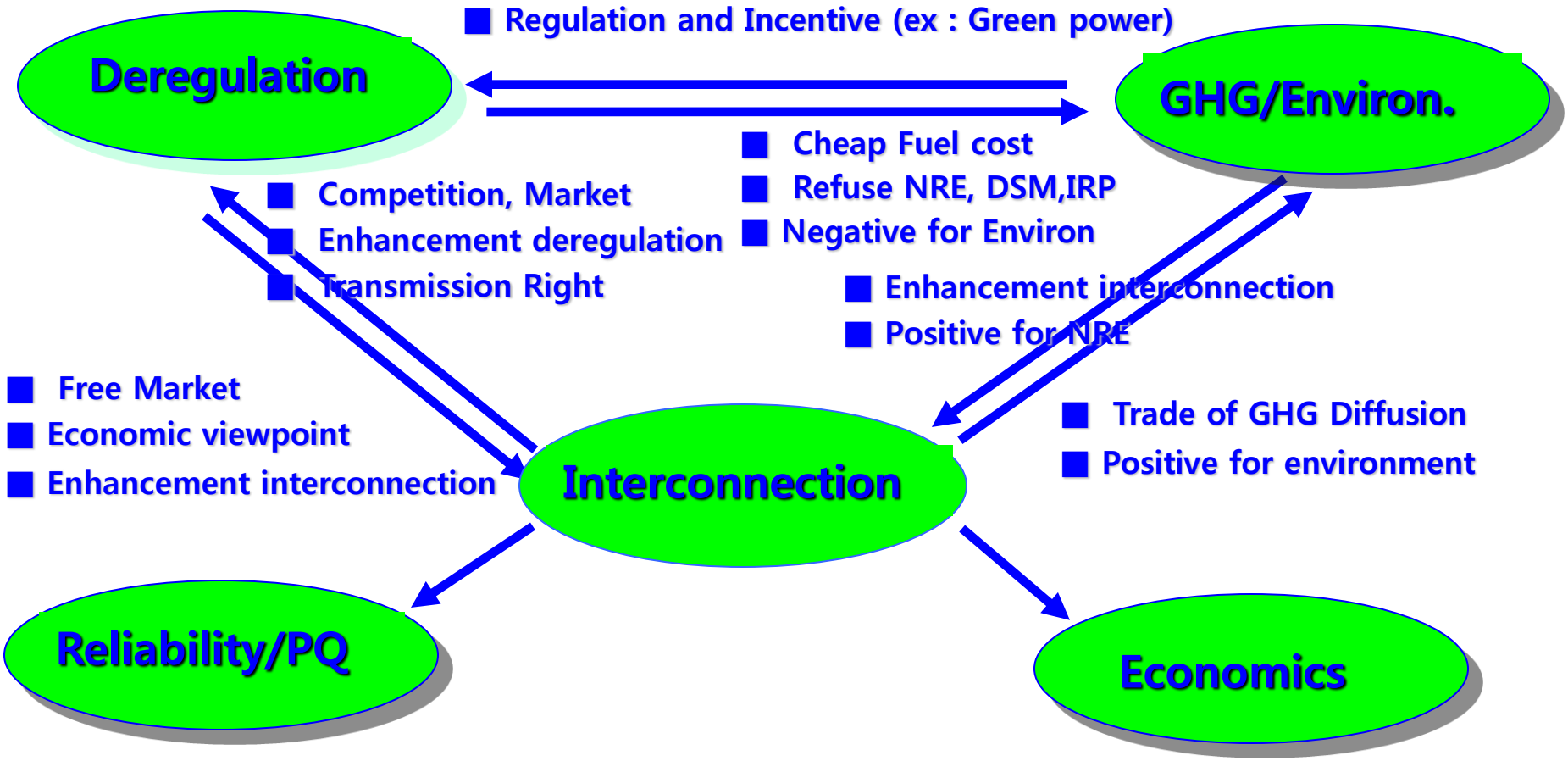
	2010			2015			2020		
	IDP	ITP	Change	IDP	ITP	Change	IDP	ITP	Change
ROK	52.03	51.30	- 1.4%	46.00	47.37	3.0%	51.31	51.27	- 0.1%
DPRK	-	-	-	-	-	-	-	-	-
RFE	6.61	9.19	39.1%	7.64	10.03	31.3%	8.13	9.12	12.1%
ES	23.50	23.65	0.6%	28.18	30.30	7.5%	34.29	38.72	12.9%
Total	82.14	84.15	2.4%	81.83	87.70	7.2%	93.73	99.11	5.7%

*) IDP : Independent Power System, ITP : Interconnected Power System

<Marketability Analysis>

Category	Results
Power exchange model	★ Simple power exchange model ★ Develop guidelines for power exchange.
Overseas benchmarking model	★ Review NORDEL, SAPP, and England - France power exchanges. ★ Introduction of a new trade market due to market restructuring. ★ Organize a derivative product market in preparation of unstable pricing.
Financing	★ directly related to economic feasibility, political and diplomatic relationship, law/regulation and policies support. DPRK uncertainty requires participants' government guarantee and international financial institutions' participation. ★ Consider long term contract, project collateral, and risk management for sound finance enhancement.
Politics and energy security	★ DPRK nuclear is the main issue. Necessity to forecast DPRK's political change by phase.
Obstacles and solutions	★ No issue is raised in legal aspect, but DPRK laws should be examined if power system interconnection passes through DPRK. Establish a NEA Energy Charter Treaty as a long term perspective.

<Co-relation effects between PSI & Other Issues>



<*Conclusions* for feasible power exchange>

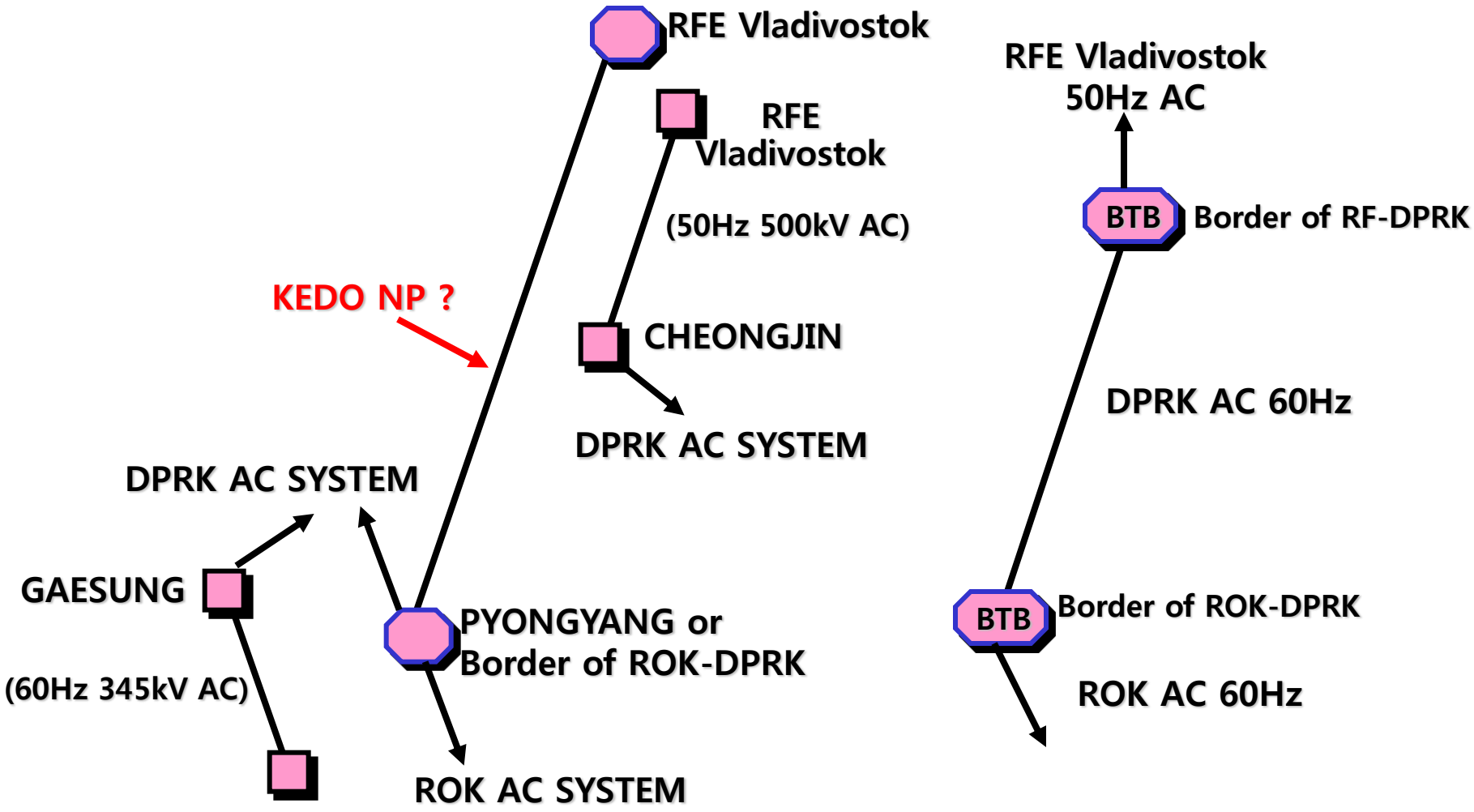
◆ Summary for "ROK-DPRK-RF" interconnection scenarios

Item	Scenario-1	Scenario-2	Scenario-3	Scenario-4
Interconnection Type	3 Terminal	2 Terminal	2 Terminal	BTB
Route	ROK-DPRK-RF	ROK-RF via DPRK	ROK-RF via East Sea	DPRK internal power system
Min Power	2GW	2GW	3GW	1GW
Max Power	4GW	4GW	3GW	4GW
Cost	Medium	Medium	Large	Small
HVDC Type	VSC	VSC or CSC	VSC or CSC	VSC
Energy Security	Normal	Bad	Good	Bad
Reliability	Normal	Good	Good	Bad
Priority	1	2	3	4

<*Conclusions* for feasible power exchange>

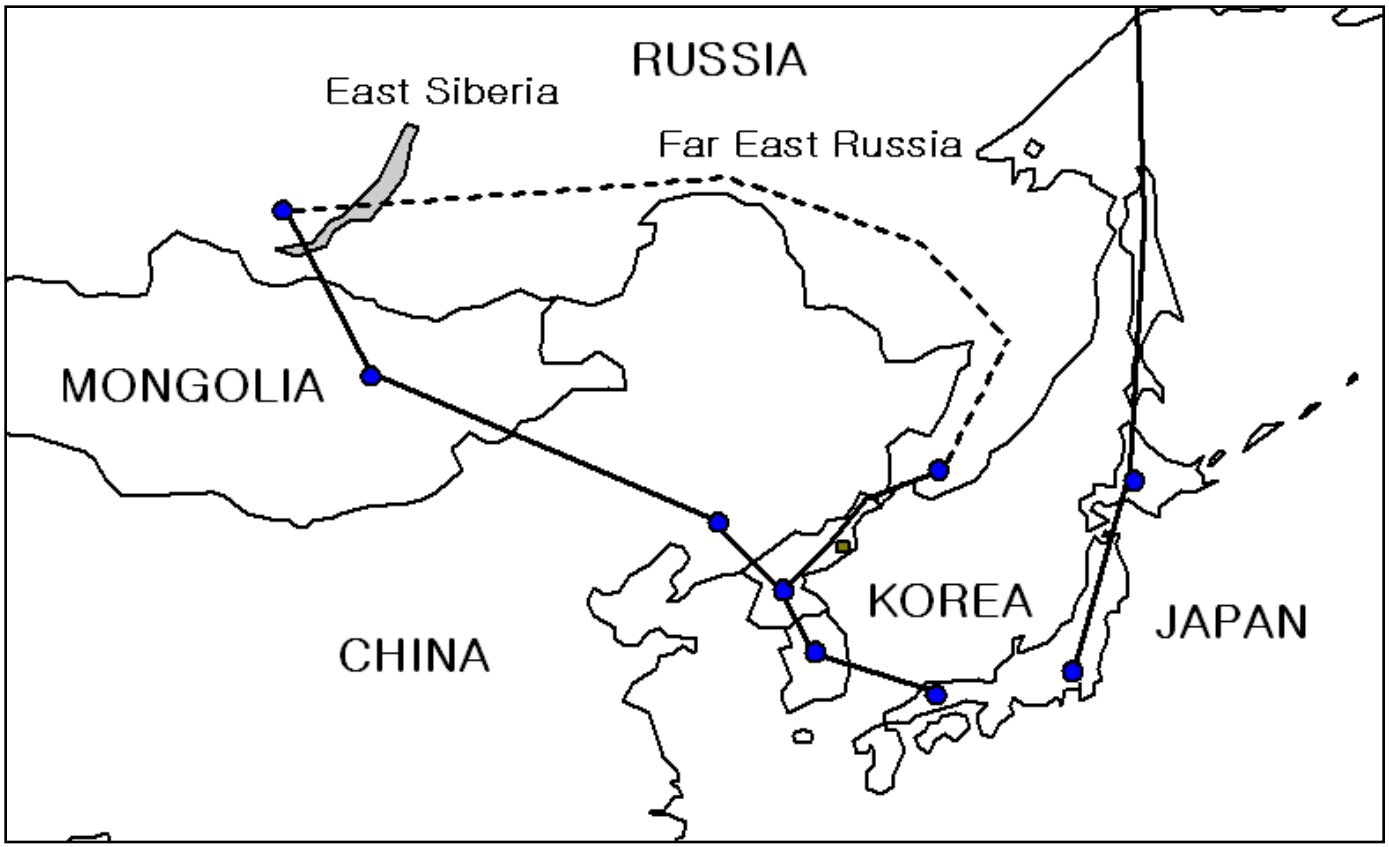
- **Proposal for "ROK-DPRK-RF" interconnection**
  - **Overview of interconnection**
    - 3 Terminal PTP-HVDC system is suitable for interconnection
    - Converter stations are located at Vladivostok, Pyung Yang and Seoul
    - BTB–HVDC is not available due to weak power system of DPRK
  - **System configuration**
    - DC ±500kV, Multi-Terminal HVDC system
    - VSC type HVDC system is more appropriate for interconnection
    - Two-Bipole DC transmission
  - **Feasible exchange power**
    - Feasible exchange power taking account of technical and economic constraints is 3GW to 4GW
    - 3GW to 4GW is allowable from the viewpoint of energy security (About 5% of power demand in 2017)

<Future Prospects : Interconnection Scenario>



<Future prospect : Final Goal>

will be expected commencement of NEAREST in near future



<Issues on NEAREST>

- **Transmission planning & pricing**
  - Planning : Capacity, Voltage, AC/DC, System design
  - Pricing : Fixed or Negotiated pricing
  - Institutional considerations
- **Generation tracking and electricity market**
  - Creation of international electricity market
  - Electricity and CO2 trading (Green market)
- **Reliability standards**
  - Analysis the interconnected system security (short-term)
  - **Evaluation the generation/load adequacy (short and long-term)**
- **Market power & International negotiation**
- **Political & Financial considerations**
  - **Intra political & financial factor (Deregulation)**
  - **Inter political & financial factor (Interconnection)**

<To be determined topics for NEAREST>

- Specific items to be studied (Partially studied)
  - Countries and locations (S/S) for power interconnection
  - Whether construct the generation plant or not ?
  - Overview of interconnection line route ?
  - AC or DC interconnection ?
  - Voltage grade(kV) and interconnection capacity(MW) ?
  - Strength of interconnection S/S in terms of power transmission
- Economic & Market viewpoints (Partially studied)
  - Free volume of electricity in future ?
  - Power exchange tariffs including transmission pricing ?
  - Overall legal and management framework ?