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

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Background

- ROK is island system after separation from DPRK system in 1948
  - Needs the electricity co-operative 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
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>

- **ROK**: Existing Tie Line
- **JP**: Future planning Tie Line

- **Weak Tie Line (110/220kV)**
- **Undersea cable (DC)**
- **Under discussion**
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-RELIABILITY) 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)
(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
(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)
(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 $)

<table>
<thead>
<tr>
<th>Year</th>
<th>Independent (I/L cost)</th>
<th>Interconnected (I/L cost)</th>
<th>G/F cost</th>
<th>Fuel cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td>3,595</td>
<td>9,660</td>
<td>13,254</td>
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<td></td>
<td>168</td>
<td></td>
<td>2,052</td>
<td>10,103</td>
<td>12,323</td>
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<td></td>
<td>Changes</td>
<td></td>
<td></td>
<td></td>
<td>-7.0%</td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td>7,268</td>
<td>9,785</td>
<td>17,053</td>
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<td></td>
<td>234</td>
<td></td>
<td>5,156</td>
<td>9,898</td>
<td>15,288</td>
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<td>Changes</td>
<td></td>
<td></td>
<td></td>
<td>-10.4%</td>
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<tr>
<td>2020</td>
<td></td>
<td></td>
<td>10,895</td>
<td>10,022</td>
<td>20,918</td>
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<tr>
<td></td>
<td>298</td>
<td></td>
<td>7,462</td>
<td>10,831</td>
<td>18,591</td>
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<td></td>
<td>Changes</td>
<td></td>
<td></td>
<td></td>
<td>-11.1%</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<tbody>
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<td></td>
<td>IDP</td>
<td>ITP</td>
<td>Change</td>
<td>IDP</td>
<td>ITP</td>
<td>Change</td>
<td>IDP</td>
<td>ITP</td>
<td>Change</td>
</tr>
<tr>
<td>ROK</td>
<td>52.03</td>
<td>51.30</td>
<td>-1.4%</td>
<td>46.00</td>
<td>47.37</td>
<td>3.0%</td>
<td>51.31</td>
<td>51.27</td>
<td>-0.1%</td>
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<tr>
<td>DPRK</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>RFE</td>
<td>6.61</td>
<td>9.19</td>
<td>39.1%</td>
<td>7.64</td>
<td>10.03</td>
<td>31.3%</td>
<td>8.13</td>
<td>9.12</td>
<td>12.1%</td>
</tr>
<tr>
<td>ES</td>
<td>23.50</td>
<td>23.65</td>
<td>0.6%</td>
<td>28.18</td>
<td>30.30</td>
<td>7.5%</td>
<td>34.29</td>
<td>38.72</td>
<td>12.9%</td>
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<tr>
<td>Total</td>
<td>82.14</td>
<td>84.15</td>
<td>2.4%</td>
<td>81.83</td>
<td>87.70</td>
<td>7.2%</td>
<td>93.73</td>
<td>99.11</td>
<td>5.7%</td>
</tr>
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</table>

*) IDP : Independent Power System, ITP : Interconnected Power System
### Marketability Analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>Results</th>
</tr>
</thead>
</table>
| 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>

Deregulation

- Regulation and Incentive (ex: Green power)
- Competition, Market
- Enhancement deregulation
- Transmission Right

GHG/Environ.

- Cheap Fuel cost
- Refuse NRE, DSM, IRP
- Negative for Environment
- Enhancement interconnection
- Positive for NRE

Reliability/PQ

- Free Market
- Economic viewpoint
- Enhancement interconnection

Interconnection

Economics

- Trade of GHG Diffusion
- Positive for environment
**<Conclusions for feasible power exchange>**

**Summary for “ROK-DPRK-RF” interconnection scenarios**

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

RFE Vladivostok
(50Hz 500kV AC)

DPRK AC SYSTEM

CHEONGJIN

DPRK AC SYSTEM

GAESUNG
(60Hz 345kV AC)

PYONGYANG or
Border of ROK-DPRK

ROK AC SYSTEM

BTB

Border of RF-DPRK

BTB

Border of ROK-DPRK

RFE Vladivostok
50Hz AC

DPRK AC 60Hz

ROK AC 60Hz

KEDO NP ?
<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 ?