The activities for flexible operations of NPPs in Korea

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1. Overview
2. The flexible operations in existing NPPs
3. The flexible operations in New Reactors
4. Challenges and Solutions
# Overview: Status of NPPs in Korea

### In operation
- **23 units**
  - **20,716 MW**

### Under construction
- **5 units**
  - **6,600 MW**

### Design Phase (4)
- APR1400 4 units

### Under Construction (5)
- OPR1000 1 unit
- APR1400 4 units

### Operation (23)
- OPR1000 11 units
  - 600MW WEC PWR(2)
  - 900MW WEC PWR(4)
  - 900MW French PWR(2)
- 600 MW PHWR (CANDU)(4)
1. Overview: Status of NPPs in Korea

- **APR1400**
  - 28 units
  - Construction: SUN 1&2, SKN 1&2, SKN 3&4, More
  - Operation: YGN 5&6, UCN 5&6, WSN2,3&4, UCN 3&4

- **Improved OPR1000**
  - 23 units
  - Construction: NGS Design for PHWR commenced

- **OPR1000**
  - 20 units
  - Construction: YGN 3&4

- **Non Turn-key**
  - 9 units
  - Construction: UCN 1&2, YGN 1&2, KORI 3&4

- **Turn-key**
  - 3 units
  - Construction: WSN1, KORI1, KORI2
  - NSSS Design for PWR commenced
  - UAE contract

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*Keplco E&C*
# Overview: Energy mix for Electricity Power

## Electricity generating capacity of South Korea

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>STATUS (2012.12.31)</th>
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<tbody>
<tr>
<td></td>
<td>Capacity (GW)</td>
<td>Portion (%)</td>
<td>Generators</td>
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<tr>
<td><strong>Nuclear</strong></td>
<td>20.716</td>
<td>25.32</td>
<td>23</td>
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<tr>
<td><strong>Steam Power Plant</strong></td>
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<tr>
<td>Coal (imported)</td>
<td>23.409</td>
<td>28.62</td>
<td>45</td>
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<tr>
<td>Coal (domestic)</td>
<td>1.125</td>
<td>1.38</td>
<td>6</td>
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<tr>
<td>Heavy Oil</td>
<td>3.950</td>
<td>4.83</td>
<td>16</td>
</tr>
<tr>
<td>L N G</td>
<td>0.887</td>
<td>1.08</td>
<td>4</td>
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<tr>
<td><strong>Sub-total</strong></td>
<td>29.371</td>
<td>35.90</td>
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<tr>
<td>Combined Cycle</td>
<td>19.799</td>
<td>24.20</td>
<td>148</td>
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<tr>
<td>Internal combustion</td>
<td>0.367</td>
<td>0.45</td>
<td>208</td>
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<tr>
<td><strong>Sub-total</strong></td>
<td>49.538</td>
<td>60.55</td>
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<tr>
<td>Group energy facility</td>
<td>2.768</td>
<td>3.38</td>
<td>44</td>
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<tr>
<td>Pumping-up power</td>
<td>4.700</td>
<td>5.75</td>
<td>16</td>
</tr>
<tr>
<td>Renewable (Hydro)</td>
<td>4.084 (1.746)</td>
<td>4.99</td>
<td>3,913 (239)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>81.806</td>
<td>100</td>
<td>4423</td>
</tr>
</tbody>
</table>

- Gross Electricity Production: 74.291 GW

Reference: the report issued by KPX (Aug. 20, 2013)
1. Overview: Flexible operations of NPPs in Korea

Flexible Operations of Nuclear Power Plants in Korea

- In Korea, the generating units such as hydro, fossil, and pumping-up power operate flexibly to balance generation and demand of electricity.

- All of existing nuclear power plants (NPPs) have been operated in base-load mode at steady full power, as higher as possible, to meet the electricity demand.

- A flexible operation of NPPs such as load following, frequency control, and low power operation has not been a concern for operating plants in Korea because we have been suffered from the electricity shortages for many years.
Flexible Operations of Nuclear Power Plants in Korea

- The generators of NPPs are not assigned in balancing generation with demand of electricity, and also not designated as generators for load frequency control (LFC).

✓ Negative aspects of flexible operation of NPPs:
  - Technical difficulty, complexity of operation, safety of NPP

- The existing rules and regulations are not requiring flexible operations of NPPs

- Government’s decision is a prerequisite for the flexible operation of NPPs.
1. Overview: Flexible operations of NPPs in Korea

- Types of Flexible Operations under consideration and done in Korea

  - Daily Load Following Operation
  - Frequency Control Operation
  - Extended Reduced Power Operation
  - Abrupt Load Change Operation
2. The flexible operations in the existing NPPs

Flexible Operation Capability in the existing NPPs in Korea

- Daily load following Operation
  
  ✓ Most of NPPs in Korea have a capability of daily load following operation with limited operator actions (Manual Operation of Boron & CEAs)
  
  - Korean type Fleet: OPR1000(12), APR1400(4)
  
  - CANDU type(4), WH(4), Framatome type(2)

- Frequency Control Operation
  
  ✓ A few design changes in most of NPPs would have a capability of Local Frequency Control.
  
  ✓ CANDU NPPs can be operated without design changes (Normal Mode: reactor follow turbine)

- Extended reduced power operation: Feasible if necessary

- Abrupt Load Change Operation: Possible as design bases events
2. The flexible operations in the existing NPPs

- Daily Load Follow Operation Experience in OPR1000 NPP

- Load Following Capabilities of OPR1000 (12 units)
  - Load change capabilities
    - Daily load cycle with typical 100-50-100(%), 14-2-6-2(hr) pattern up to 90% EOC
    - Load change capability was demonstrated during initial startup test.
2. The flexible operations in the existing NPPs

- Daily Load Following Operation Experience in OPR1000 NPP

✓ Control Systems:

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<tr>
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<tbody>
<tr>
<td>RRS</td>
<td>Automatic</td>
</tr>
<tr>
<td>PPCS</td>
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<td>PLCS</td>
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<tr>
<td>FWCS-1</td>
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<td>FWCS-2</td>
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<tr>
<td>SBCS</td>
<td>Automatic</td>
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</table>

✓ Operators:

- Turbine load decrease/increase
- Boration/dilution
- Insertion/withdrawl of Part Strength Control Element Assemblies (PSCEAs) to maintain the Axial Offset

Figure 1. Reactor power change

Figure 2. Turbine power change
2. The flexible operations in the existing NPPs

- Frequency Control Capabilities of the NPPs in Korea
  - CANDU NPPs(4) can be operated in frequency control mode without big design changes (Normal Mode: reactor follows turbine)
  - A few design change in most of the Korean NPPs would have a capability of Frequency Control even if Frequency control capability was not a design basis.

- The Capabilities of Frequency Control in OPR1000 (Evaluation)
  - Primary regulation (local frequency control)
    - Requirement: No control rod movement
    - Capability: ±2.5% power
    - Modification of Reactor Regulating System (RRS) is required.
    - Within current Tech. Spec. LCO band (cold-leg temperature)
  - Secondary regulation (remote frequency control)
    - Capability: ±5% power
    - Limited due to Power Dependent Insertion Limit (PDIL) and power distribution control
2. The flexible operations in the existing NPPs

- **Extended Reduced Power Operation Capabilities of the NPPs in Korea**
  - Experiences on an extended reduced power operation in Korea
    - Operating experiences in OPR1000 plants (Korea)
      - During initial startup testing, tests are performed at different power plateaus (20, 50, 80, and 100% power). The tests are generally done for some period of time, e.g., days, and weeks (2 or 3), but not for months.
      - The operations have demonstrated that the plant can be operated in the stable, controllable, and safe condition at the reduced power levels.
    - Operating experience of ELPO in Kori 1 (Korea)
      - Kori unit 1 experienced a reduced power operation at 85% power to reduce the corrosion in steam generator tubes for 2 years.
  - The NPPs in Korea can be operated in an extended reduced power operation, if necessary.
2. The flexible operations in the existing NPPs

- Abrupt Load Change Operation Capabilities of the NPPs in Korea

- Abrupt Load Changes:
  - Load rejection at any power level
  - Turbine generator runback to house load
  - Turbine trip without Reactor trip
  - Turbine power step change of ± 10% (1%) power at the high(low) power
  - Turbine power ramp change of ± 5%(1%)/minute at the high(low) power
  - Loss of one out-of-operating Feedwater pumps at any power
2. The flexible operations in the existing NPPs

- **Abrupt Load Change Operation**

- **Load Rejection at 100%**

### Reactor power

- **Time, seconds**
- **Reactor Power, %**

### Turbine power

- **Time, seconds**
- **TBN Power, MWt**
2. The flexible operations in the existing NPPs

- **Abrupt Load Change Operation**

- **House Load Operation (~4 hours)**

![Graphs showing reactor and turbine power changes](image-url)
2. The flexible operations in the existing NPPs

- **Abrupt Load Change Operation**

  ✓ Turbine power step change (step : 95 ↔ 85%, ramp : 85 ↔ 70%)

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**Reactor power**

**Turbine power**

![Graphs showing reactor and turbine power changes](image-url)
3. The Flexible Operations in New Reactors

- Flexible Operations in New Reactors

  ✔ New Reactors in Korea

**APR1400**

- Advanced Power Reactor 1400
- Power: 1,400 MWe
- Life Time: 60 years
- Const. : 54 months
- Seismic: 0.3g

**APR+**

- Advanced Power Reactor plus
- Power: 1,500 MWe
- Life Time: 60 years
- Const. : 36 months
- Seismic: 0.3g
3. The Flexible Operations in New Reactors

- Flexible Operations in New Reactor (APR+, APR1400)
  - Flexible Operations capabilities for new reactors under development
    - Daily Load Following Operation
    - Frequency Control Operation
    - Extended Reduced Power Operation
    - Abrupt Load Change Operation
3. The Flexible Operations in New Reactors

The Studies for Daily Load Following Operation in APR+

- **Constraints**
  - Operator burden to control
  - Limit of CEA insertion duration
  - Limit of CEA lifetime

- **Studies to Improve Load Follow Capability**
  - Constant T-avg program
  - Application of Model Predictive Controller (MPC)
  - Operator aids system for soluble boron control
  - More insertion duration of control rods
  - Control Element Drive Mechanism (CEDM) life extension
3. The Flexible Operations in New Reactors

- The Studies for Daily Load Following Operation in APR+

  - Constant T-avg program
    - Purpose: To reduce reactivity to be compensated
    - Result: Constant T-avg from at 75% power
    - Too high S/G pressure for Constant T-avg program from at 50% power

![Graph showing temperature vs power for Constant T-avg and Sliding T-avg programs.]
3. The Flexible Operations in New Reactors

- The Studies for Daily Load Following Operation in APR+

- Model Predictive Controller
  - Automatic control of power and power shape
    - Regulating banks and PSCEAs are automatically controlled
    - Inputs for T-avg, T-ref, power distribution, control rod positions, and fuel burnup
    - Conventional RRS and MPC control PRDS mode
    - Mode switch between RRS mode and PRDS mode

PRDS (Power Regulation & Distribution Control System) : Control system including MPC controller
3. The Flexible Operations in New Reactors

The Studies for Daily Load Following Operation in APR+

- Operator Aids System for Soluble Boron Control

  - Automatic boron control is difficult due to time delay
  - Operator Aids system to predict plant behavior and proper boron control

Operator Aids System for Soluble Boron Control

- System Model
- Core Model
- Dynamic Calculation of Boron Concentration
- Boron Control Logic
- Operator Interface
3. The Flexible Operations in New Reactors

The Studies for Daily Load Following Operation in APR+

- More Insertion Duration of Control Rods
  
  **Limitation**
  
  - Duration of control rod Insertion (more than about 30%) is limited by current Technical Specification (TS) long term steady state insertion limit
    - 14 EFPD (Effective Full Power Day) per 365 EFPD
  
  - Load follow scenario requires about 120 EFPD per 365 EFPD for continuous load follow operation

**Extension of TS Long-Term Steady State Insertion Limit**

- Feasible with burnup distribution calculation with control rod insertion scenario during load follow operation and related safety analyses
3. The Flexible Operations in New Reactors

- The Studies for Daily Load Following Operation in APR+
  
  - CEDM Life Extension
    
    - Current life time of CEDM: 100,000 feet
    - Test is undergoing with new CEDM design
      - Expected life time is expected about 200,000 ~ 300,000 feet

    - Area of Design Change
      - Design Change for CEDM Latches & Drive Shaft
      - Design Change for CEDM Coil Assembly
      - Material Change for CEDM Latches & Drive Shaft
The Studies for Extended Reduced Power Operation in APR1400

**Motivation**

- Extended operation in a reduced power level can be an option for countries:
  - To reduce an excessive seasonal power by a reduced power operation
  - To avoid outage time in an extremely cold or hot weather with 18 month fuel cycle

**Issues**

- **GL 84-21**: Potential safety issues with increased power peaking after return to full power due to burnup distribution change
  - Low power operation increase fuel burnup at upper part of the core ⇒ power peaking at core bottom
  - Operation with control rod insertion decreases fuel burnup at near the control rod ⇒ power peaking near control rod insertion
- Equipment performance during ERPO such as excessive wear and vibration
3. The Flexible Operations in New Reactors

- Power pattern for Extended reduced power operation

- Extended Reduced Power Operation with full power operation in-between (Typical)
3. The Flexible Operations in New Reactors

- The Studies for Extended Reduced Power Operation in APR1400
  - Preliminary Results

  ✓ Operating Strategy
    - PSCEA insertion strategy during ERPO is required to reduce power peaking

  ✓ Safety Evaluation and Equipment Performance
    - No major impact on safety analyses and equipment performance ⇒ ERPO is Feasible

  ✓ Other areas of study
    - Method for Tech. Spec. surveillance at reduced power
    - Operating strategies during ERPO and at return to full power
    - Fuel performance with increased resident time
4. **Challenges and Solutions in Korea**

- **Review of Current Situation**
  - **Dispute about load follow operation & Frequency Control**
    - **Positive**
      - Needed for grid stability (considering the renewable energy)
      - Required to increase nuclear participation in electricity
    - **Negative**
      - No need for NPPs
      - Technically difficult and less margin
  - **Utility Company**: Selling price of electricity should be increased considering load follow operation. (Economic benefit)
  - **Government’s decision** is a prerequisite for the flexible operation of NPPs.
4. Challenges and Solutions in Korea

- **Daily Load Cycling**
  - Daily load cycling is licensed
  - Technical Limit
    - Tech. Spec. Long Term PDIL violation with continuous operation
  - Others
    - CRDM wear: replace if needed
    - Operator’s difficulty: Difficulty will decrease with experiences
    - Limited Boron dilution capability at EOC
      - Compromise: Operation until (80%) of Cycle of life
    - Limited AO control capability at EOC
      - Compromise: Operation until (80%) of Cycle of life
4. Challenges and Solutions in Korea

- Local Frequency Control
  - Local Frequency Control is not Licensed
    - But, current design can accommodate the Design Transient of local frequency control.
    - Justification for fuel integrity is feasible (for small & fast power change)

- Technical Limit
  - No outstanding technical limit
  - Simple modification in rod control system is needed to minimize the control rod motion
4. **Challenges and Solutions in Korea**

- **Remote Frequency Control**
  - Remote Frequency Control is not Licensed
  - Technical Limit
    - Not feasible
      - CRDM wear
      - Fuel Integrity
      - Power shape control
      - Violate transient PDIL and long term PDIL
    - ±5% may be possible but CRDM wear and long term insertion limit should be resolved.
First Step toward Local Frequency Control

- Technically feasible with small control system modification
- No major licensing issue is expected.
- Preferred than load cycling because the NPP’s Spinning Reserve Capability (SRC) is not good: Fossil plant has better SRC.
- No side effects in liquid waste and CRDM wear
- Easy to persuade the opponent of load follow operation
4. Challenges and **Solutions** in Korea

- **Local Frequency Control**
  - Suggested for 2014 government R&D project
  - If accepted, detailed proposal for application
    - Pre-understanding between Dispatcher, KHNP, and Licensing body
  - Expected Licensing Steps
    - Get license for 2~3% local frequency control for one unit
    - Plant modification
    - Droop setting for smaller local frequency control
    - Plant test with 1~2 months
    - Evaluation and get approval for higher capability
The Bright Future of the Global Nuclear Industry,
Together we can make it happen!

Thank you!

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