CRIEPI’s Research on Smart Grid, \textcolor{red}{TIPS}

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Outline

- Overview of Smart Grid Projects in East Asian Countries
- Scope for Next-generation Grid: TIPS
  - Triple I (Intelligent, Interactive and Integrated) Power System
  - ADAPS
    - Autonomous Demand Area Power System
- ICT Infrastructure for TIPS
Overview of Smart Grid Projects in East Asian Countries
Smart Grid Project in China

Strong and reliable, economical and highly efficient, clean and environmental, open and transparent, friendly and interactive

More focused on Transmission Grids to meet rapidly growing demands

- FACTS, UHV AC/DC
- Advanced real time dispatching and three dimension visualized monitoring system
- WAMS with over 700 PMUs
- Unified data platform, digital substation, fiber optic trunk networks, etc.

Distribution Grids and Customers

- Distribution automation and management system
- AMR (fiber/230 MHz radio/GPRS, RS485/PLC/radio)
- DG applications, energy storage using NAS and Redox Flow batteries,
- DSM, etc.

Smart Grid Project in Taiwan

Enhance power grid safe and reliable, improve generating & dispatching efficiency, upgrade user’s service quality, and integrate distributed energy resources

Transmission Grids
- Wide area monitoring & control
- Demand responsive resources integration
- Automated asset condition assessment and fault location, etc.

Distribution Grids and Customers
- Feeder automation (PLC), distribution SCADA
- Substation automation
- Remote monitoring of fault indicator
- Integrated VQC
- Feeder or area peak load management
- Equipment condition monitoring
- Micro grid management involving DER and PHEV(BEV)
- AMR using GPRS, AMI

Smart Grid Project in Korea

The next generation electric power system which optimizes power system efficiency by convolution of conventional power grid system and IT technology – bi-directional communication and distributed computing system

- **Generation**
  - Renewables
  - High efficiency generation

- **Transmission and Distribution**
  - Energy storage
  - Optimal operation
  - Self-healing

- **Demand Side – Customer**
  - Smart metering
  - Demand response
  - Demand side energy efficiency

- **Power IT**
  - EMS, IT-based FACTS, transmission network monitoring and operation, advanced SAS, intelligent DAS, active power facility monitoring, consumer portal, broadband PLC, power semiconductor, microgrid, etc.

Source: Jong-keun Park, “Demand Response Programs in Korea,” ICEE 2009 Keynote Speech, Shenyang, China

Source: “Center for Power IT National Program (CPIT)”
Smart Grid Projects in Japan

Background

- More focused on the large penetration of DERs for CO₂ reduction
- Comprehensive optimization of power grids and consumers with respect to CO₂ emission, social cost, and power supply reliability and quality
- Long experience on renewable energy integrations and microgrids
- Already almost automated power delivery grids
- Smart metering and customer integration (AMI) are behind
Smart Grid Projects in Japan

Current projects

- **TIPS (Intelligent, Interactive and Integrated Power System)**, CRIEPI
- **Smart Power Network**, Tokyo Tech, TEPCO and vendors
- **Ubiquitous Power Grid**, Univ. Tokyo, NEC
- Microgrids in islands
- Advanced power system simulator associated with large penetration of PVs
- New Mexico project
- etc.
Scope for Next-generation Grid: TIPS
Future of Power Grids

**CO$_2$ Reduction throughout Grids (from Generation to End Use)**
- Large penetration of unstable renewable energy source (Targeted value of PV in 2010: 4.8GW, 2030: 53 GW)
- Increase of inflexible generation (IGCC etc.)
- Increase of uncertainty in supply/demand control

**Demand change**
- Enhancement of energy-conscious in consumers
- Shift to electricity and Intelligent/ICT society (digital society)

**Increase of aged grid apparatus to be replaced**
Requirements of Next-generation Grid

**TIPS** - Triple I (Intelligent, Interactive and Integrated) Power System

1. **Integrate supply/demand**
   - Enable conservation and efficient utilization of energy with integration of demand and supply

2. **Utilize DER**
   - Enable large penetration and effective utilization of distributed energy resources

3. **Minimize blackout risk**
   - Minimize the risk of large blackout with secure and stable operation of resilient and self-healing system

4. **Develop asset management**
   - Sophisticate asset management and introduce advanced power system maintenance and devices
Road Map of TIPS

<table>
<thead>
<tr>
<th>Short term</th>
<th>Mid term</th>
<th>Long term</th>
</tr>
</thead>
</table>

1. Integrate supply/demand
2. Utilize DER
3. Minimize blackout risk
4. Develop asset management
5 Research Areas on TIPS

- Low carbon emission generation
- Demand supply integration
- Customer gateway (Demand/supply interface)
- EV/PHEV
- Smart meter
- Battery
- Distribution System (ADAPS)
- Nuclear
- High efficiency thermal

- Secure communications network for demand area
- ADAPS (Autonomous Demand Area Power System)
- Demand supply integrated control
- Adequacy evaluation and analytical method of intermittent power
- Optimum role-sharing for fluctuation and excess power of PV
- Evaluation of demand response (DR) effectiveness
- Development of DR integrated EMS (HEMS/BEMS)
- Next Generation insulation technology
- Current limiter
Research Items (1), 2008-2010

- **ICT infrastructure**
  - Secure communications network for demand area
  - Wide area and high-speed networks for monitoring, protection and control
  - Sensor networks for facility maintenance and operation
- **ADAPS operation and control under demand/supply integration**
  - Load and storage control techniques according to PV power output
  - Demand/supply integration control techniques in grid emergency
  - Utilization techniques of DG and ADAPS developed
- **Bulk Power System Operation under large penetration of DER**
  - Evaluation of regulation capability of bulk power system and distribution system
  - Generation adequacy assessment method
  - Long-term power system simulation method
Research Items (2), 2008-2010

- Evaluation of Demand Response (DR)
  - Evaluation method of DR program
  - Feasibility of DR program in Japan
  - Energy management system for DR

- Power Apparatus
  - 6.6 kV current limiter using superconductivity
  - Solid insulation mold transformer
  - Hybrid gas insulated bus
ADAPS (Autonomous Demand Area Power System) – Preceding and Current Projects –
Schematic Configuration of ADAPS

Supply & Demand Interface
to support customer demands and operate emergency DER shedding

Loop Power Controller
to control power flow and voltage of distribution line

Section switch with fault sensor

Substation 1

Customers

P/Q control

Communication Network (L2, mobile agents, etc.)

Substation 2

Section switch with fault sensor

Operation & Control System
ADAPS: Accomplishment to date

Penetration Capacity of DER (percentage to feeder capacity)

- Large (100%)
- Middle (50%)
- Small

Penetration Area of DER

- Local Area
- Wide Area

Technologies developed applicable to this region

- Locally concentrated
- Dispersed and small
- Wide and middle
- Wide and Large (PV: 53 GW)
ADAPS: Accomplishment to date

✓ Centralized Voltage Control

In addition to SVC (STATCOM)
ADAPS: New project undertaken

Penetration Area of DER

Penetration Capacity of DER (percentage to feeder capacity)

- Large (100%)
- Middle (50%)
- Small

Locally concentrated

Dispersed and small

Technologies to be developed applicable to this region

(Wide and middle)

(PV: 53 GW)
Problem in large penetration

Reverse power flow

Distribution Substation

LPC
Demand/Supply Integration

- Information
  - Power system
  - Load profile
  - Weather forecast, etc.

HV/EHV System

Substation

Controller

ADAPS

PV

Storage

Time

kW

Residential Customer

Hot Water Supply

HVAC

Others
Demand/Supply Integration

- HV/EHV System
- Substation
- Reduce reverse flow
- ADAPS
- Level flow
- Controller
- PV
- Storage
- Hot Water Supply
- HVAC
- Others
- Residential Customer

Information
- Power system
- Load profile
- Weather forecast, etc.

Control load and energy storage according to PV power output

Information
- Power system
- Load profile
- Weather forecast, etc.

Reduce reverse flow
ICT Infrastructure for TIPS
ICT infrastructure to achieve objectives of TIPS

1. Integration of demand and supply sides
2. Integration of distributed generations
3. Minimize the risk of large blackout
4. Advance asset management

- Efficient energy supply & utilization
- Resilient and self-healing power system
- Optimal facility management
- Sensor Networks for Facility Maintenance and Operation
- Demand Area Secure Communication Network
- Wide Area and High Speed Control Network
Centralized Gen. (Low Carbon Emission, High Efficiency)

Sensor Networks for Facility Maintenance and Operation

Transmission Grid

Wide Area and High Speed Control Network

IGCC

High Efficiency Plant

ADAPS

Distributed Gen. (PV, WT)

Distribution Grid (ADAPS)

Battery

Demand Area Secure Communication Network

End Use (High Efficiency, More Electrification)

New Power Device

Information

Sensor/Controller

Electricity
Scope of ICT Infrastructure

- **Demand Area Secure Communication Network** for distribution and DER management, smart metering, demand response, customer access, energy management, and premises communication

- **Wide Area and High Speed Control Network** for power system monitoring, adaptive protection and emergency control to prevent large blackout and localize disruption

- **Sensor Network for Facility Maintenance and Operation** based on DRNA (Distributed Real-time computer Network Architecture) and field network technologies and the concept of Plug-and-Play
Demand Area Secure Communications Network

- Media-integrated (wireless and/or wired) structure
- IP-based communication protocols and data management
- Security measures for embedded and easily accessible equipment
- Customer gateway
Media-integrated structure

Existing Passive Optical Network (PON, FTTx)

Smart grid service station

Existing PON service station

Smart Grid Server

PON Head end

Star Coupler

Smart Grid Base Station

TRX

Customer Gateway

PON Terminal

Customer Gateway

Mobile Maintenance Worker

Smart grid device installations using radio-on-fiber technique

Existing PON customers
Customer Gateway

Functional Modules

- Metering
  - Not only for billing but also for ESCO, security service or DR
  - ANSI C12/19,22, IEC 62056
- Interface to ADAPS
  - PV systems and other equipment may be controlled by an ADAPS controller for energy balance and for safety reasons
- Interface to DR and other services
  - Providing status information of appliances for DR provider or ESCO provider
- Home appliances control
  - Coordinating controls to appliances from different service and system
Security Measures

- Power company
  - Authentication Server
  - FW
  - Distribution automation
  - FW
  - Private Network
    - Loop Power Controller
    - Section switch
    - Pole-top transformer
    - LV controller
  - DER
  - FW
  - Customer gateway
  - FW
  - Appliance
- Service provider
- Mobile
- Public Network

- Private Network
- Public Network

Device authentication
Encrypted communication
Wide Area and High Speed Control Network

- Ethernet-based network with extremely high reliability and low latency for data exchange and time synchronization
- Intelligent device with modular functions (monitoring, processing, control, communication)

Flexible and scalable to various schemes of monitoring, protection and control, and to power system configurations
Decentralized Modular Device Network

- Control Device
  - Measuring Module
  - Processing Module
  - Control Module
  - Communication Module

- Integrated Device
  - Measuring Module
  - Processing Module
  - Control Module
  - Communication Module

- Measuring Device
  - Measuring Module
  - Processing Module
  - Control Module
  - Communication Module

- High-speed L2 Network

Sampling timing or time synchronization
Wide-area/high-speed network and time synchronization

- Due to delay constraints, L2 (layer-2 or Ethernet) switches and native Ethernet frames can be applied. IP or MPLS routers are not appropriate.

- To avoid the influence of other traffics and communication disruptions (at least 50 ms) due to rerouting, two separate L2-switched networks dedicated for the system are implemented.

- To accommodate wide-area VLANs (virtual LANs) for various applications or groups of applications efficiently, a layered VLAN scheme is introduced.

- To achieve time synchronization with an accuracy less than 1 µs among terminals for wide-area applications, a proprietary device-embedded mechanism and the IEEE 1588 (Precision Time Protocol) mechanism external to devices are applied.
Experimental Prototype Network

**Device #1**

- PQVF measurement
- Backup protection
- Stability monitoring and control

**Device #2**

- PQVF measurement
- Primary protection for 2 terminals
- Stability monitoring and control

**Device #3**

- Primary protection for 3 terminals
- Primary protection for 3 terminals
- Stability monitoring and control

**Device #4**

- Primary protection for 3 terminals
- Backup protection
- Stability monitoring and control

**HMI (PC)**

- Setting applications
- Monitoring of application functions, system operation, transmission data, device status
- Traffic load
- Delay, delay variation
- Packet loss

**L2 network**

(Data transmission, time synchronization)

- Data format conversion (analog, digital)
- Sampling synch.
- Time synch. (time stamp)
- Instantaneous value
- Effective value
- Phasor
- State transition
- Trip, control
- Analog input (AI)
- Digital input (DI)
- Digital output (DO)

**Node #1**

- L12
- L23
- L24
- L34

**Node #2**

- G1

**Node #3**

- G1

**Node #4**

- G1

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Sensor Network for Facility Maintenance and Operation

- **Facility Maintenance** (Patrol, inspection, monitoring, diagnosis)
- **Facility Operation** (SCADA/EMS)

- **Plug-and-Play and Ad Hoc schemes**
  - Wired/wireless sensor and access network for field information collection
  - Wide area and premises networks (DRNA-based)
  - Data exchange and management
Scope of architecture

Two-layered network configuration:
- Field sensor network to acquire the sensing data
- IP-based wide area network to provide them to many applications including statistical analysis and asset management

Technologies for field sensor network include wireless ad hoc network, broadband communication, and plug-and-play device.

Technologies for IP-based wide area network include DRNA (Distributed Real-time computer Network Architecture) and plug-and-play data management.

IEC 61850 data modeling for maintenance and diagnosis
Applications:
- Asset management, diagnosis, inspection, supervision, preventive maintenance, condition base maintenance, corrective maintenance, fault location

Facility maintenance sensor network
- DRNA-based wide area network
  - Assemble of field data at each substation
  - Conversion to common information model
  - Response to requests from applications

Field sensor network
- Acquisition of sensing data or tagged data of apparatus in fields (Ad hoc network technology)
- Delivering data to maintenance personnel or communications (Broadband access technology)

Power equipment, sensors, workers
## Roadmap

<table>
<thead>
<tr>
<th>Network</th>
<th>FY 2008 - 2010</th>
<th>FY 2011 -</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demand Area Secure Communications Network</strong></td>
<td>• Survey and conceptual design of protocols and security measures</td>
<td>• Application to ADAPS and supply/demand integration, demonstration test</td>
</tr>
<tr>
<td></td>
<td>• Design and cost/performance evaluation of access networks</td>
<td>• HEMS/BEMS network design</td>
</tr>
<tr>
<td></td>
<td>• Customer gateway prototype</td>
<td></td>
</tr>
<tr>
<td><strong>Wide Area and High Speed Control Network</strong></td>
<td>• Design and prototype evaluation of scalable wide-area Ethernet, time</td>
<td>• Verification by using power system simulator and field test</td>
</tr>
<tr>
<td></td>
<td>synchronization schemes, and modular devices</td>
<td>• Coordination with ADAPS control systems</td>
</tr>
<tr>
<td><strong>Sensor Networks for Facility Maintenance and Operation</strong></td>
<td>• Conceptual design of sensor network for facility maintenance for plug-and-play and ad-hoc schemes</td>
<td>• Coordination of substation sensor networks and wide-area IP networks</td>
</tr>
<tr>
<td></td>
<td>• Method for designing substation wireless/wired sensor networks</td>
<td>• Extension to power plants and others</td>
</tr>
<tr>
<td></td>
<td>• Upgrading DRNA middleware and IP network design</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion
TIPS to support CO$_2$ reduction and stable power supply

Energy Saving

Low-Carbon Emission Generation

Shift to Electricity

TIPS - Triple I (Intelligent, Interactive and Integrated) Power System
Thank you for your attention. Comments, questions?

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Japanese typical distribution system

Proper supply voltage range for customer is regulated within 101 +/- 6V in 100V system and 202 +/- 20V in 200V system by Japanese electrical utility’s law.

SVR (Step voltage regulator); installed when D.L. length more than about 5km.

Tap changing of main transformer
LDC (Line voltage drop compensator); controlling sending voltage automatically according to feeder current.
Program control; sending voltage is programmed beforehand.

Substation 6.6kV distribution line

Communication for sensor and remote operation of SWs
Testing and Demonstration Site

Akagi Testing Center
Testing and Demonstration Site

**Distributed power generations in a site**

- **150kW rotating type generator** (simulates WP, Co-generation)
- **20kW Inverter type generator** (simulates PV, FC, etc.)
- **4 to 5 kW power conditioner** for PV power generation

**Composition of distributed power generators**

<table>
<thead>
<tr>
<th>Category</th>
<th>Power</th>
<th>Units</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotating generator</td>
<td>150kW</td>
<td>6 units</td>
<td>600kW</td>
</tr>
<tr>
<td>PV system</td>
<td>5kW etc.</td>
<td>16 units</td>
<td>80kW</td>
</tr>
<tr>
<td>Simulated FC, PV, Storage battery</td>
<td>20kW</td>
<td>12 units</td>
<td>240kW</td>
</tr>
<tr>
<td></td>
<td>100kW</td>
<td>3 units</td>
<td>300kW</td>
</tr>
<tr>
<td>MGT</td>
<td>30kW</td>
<td>1 unit</td>
<td>30kW</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>1250kW</strong></td>
</tr>
</tbody>
</table>

**Whole configuration of the test facility**