Present and Future ICT Infrastructures for a Smarter Grid in Japan

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Yoshizumi Serizawa
Central Research Institute of Electric Power Industry
Outline

• Smarter Grid Concept in Japan
• Present and challenges of ICT Infrastructure in Japanese Grids
• Innovative ICT Infrastructures for a Smarter Grid
Smarter Grid Concept in Japan
Surroundings of Future Power Grid

- CO$_2$ reduction throughout power grid, 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
  - Growth not foreseen
  - Enhancement of energy-consciousness in consumers
  - Shift to electricity and intelligent/ICT society (digital society)

- Increase of aged power assets to be replaced
Requirements and Backgrounds toward a Smarter Grid

• More focused on the large penetration of distributed renewable energies, mostly photovoltaic (PV), 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
Concept of Next Generation Grid

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

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

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

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

4. **Develop asset management**
   - Sophisticate asset management and introduce advanced power system maintenance and devices
Roadmap of Next Generation Grid

<table>
<thead>
<tr>
<th>Near term</th>
<th>Mid term</th>
<th>Long term</th>
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<td>(2050)</td>
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1. Minimize blackout risk
2. Integrate supply/demand
3. Utilize DER
4. Develop asset management

Demand/Supply Integration
Autonomous Demand Area Power Systems (ADAPS)
Five Research Areas on Next Generation Grid

- **Low carbon emission generation**
- **Demand supply integration**
- **Customer gateway**
  - Demand/supply interface
- **EV/PHEV**
- **Smart meter**
- **Battery**
- **Distribution System (ADAPS)**
  - **Sensor/control**
- **New distribution equipment**
- **Customer gateway**
- **Sensor/control**
- **Electricity sensor/control**
- **High efficiency thermal**
- **Nuclear**
- **IGCC**
- **Hydro**

**ICT**
- Wide-area/high-speed control network
- Secure communications network for demand area
- Sensor network for asset management and operation

**ADAPS**
- ADAPS (Autonomous Demand Area Power System)
- Demand supply integrated control

**Bulk Power**
- Adequacy evaluation and analytical method of intermittent power
- Optimum role-sharing for fluctuation and excess power of PV

**DR**
- Evaluation of demand response (DR) effectiveness
- Development of DR integrated EMS (HEMS/BEMS)

**Apparatus**
- Next Generation insulation technology
- Current limiter
ICT Infrastructures for a Smarter Grid

- Internet/Public Telecommunication Network
- Demand Area Network (Distribution and customers)
- Operation and Maintenance Network
- Wide Area Monitoring, Protection & Control Network
- Corporate Business Intra/Extra-network

- Power Station
- Load Dispatch Center
- Control Center
- Service Center
- Customer
- Distribution Control Center
- Maintenance Center
- Corporate Business Intra/Extra-network
- DER
- Substation
- Customer
Present and Challenges of ICT Infrastructure in Japanese Grids
ICT Applications in Existing Grid

Generation (Large scale)
- Power planet operation
- Emergency Protection and Control
- EMS (Generation control in accordance with load)
- Market

Delivery (Transmission/distribution)
- Transmission/substation automation (SCADA)
- Distribution automation (SCADA, protection)
- Maintenance/AM/AM/FM

End use (Industrial/commercial/residential)
- Remote metering, load surveillance
- End use

Information flow
- Electricity flow

Electricity flow
- Delivery (Transmission/distribution)
- End use (Industrial/commercial/residential)
- ICT Applications in Existing Grid

Operation (SCADA/EMS)
- Emergency Protection and Control
- Power planet operation
- EMS (Generation control in accordance with load)
ICT Applications in Smarter Grid

**Smart Generation**
- (Centralized)
- Plant Emergency Control
- Plant Operation
- Plant Condition Monitoring

**Smart Delivery**
- (Transmission & Distribution)
- Load Dispatch and Transmission Operation (EMS/SCADA)
- Distribution Operation
- Transmission/Distribution/DER Condition Monitoring

**Smart End Use**
- (Industrial/Commercial/Residential)
- Customer Equipment/DER Protection
- Customer Interaction (Metering, Switching, Information, etc.)
- Customer Equipment/DER Condition Monitoring
- Appliance Monitoring/Control (BEMS, DR, HEMS, etc.)
- Customer Service (Security, etc.)

**Electricity & Information**
- Customer Interaction
- Protection
- Equipment/DER Condition
- Load Dispatch and Transmission
- Distribution Operation

**Smart Generation**
- (Distributed)

**E & I**
- Plant
- Emergency Control
- Plant Operation
- Plant Condition Monitoring

**Load Dispatch and Transmission Operation**
- (EMS/SCADA)
Power System Protection and Control
(Fault clearance, stabilizing, restoration)

*Present*

- Fault clearance and automatic reclosing
  - Applied technologies are different among bulk and local power systems; current differential scheme mostly implemented in bulk power system, limited in local power system
- Failure extension protection against instability, overload, frequency/voltage anomaly (SPS/SIPS)
  - Almost completely equipped for bulk power system, limited application to local system
- Restoration
  - Status monitoring after fault and manual operation
- ICT
  - System specific, legacy (PDH), high-speed transmission with ms-order delay, 10-ms to ms-order delay variation. Sampling synchronization with an accuracy of microseconds
  - Limited data linking and cooperative operation among protection and control systems, specialized for each system
Power System Protection and Control (Fault clearance, stabilizing, restoration)

<Challenges>

• Emergency protection and control for local and distribution grid resulting from the high penetration of PVs
  – Dependable local grid fault clearance (current differential, primary/backup coordination),
  – Disturbance monitoring and prediction for local grid
  – Advanced failure extension protection (wide-area coordination)
• IP-based relay communications
A Special Protection System

System-wide state information

Central Control Computer

SCADA Network

Legend

TE  Terminal Equip.
TT  Tripping Equip.

→  Processed result (Generator to be shed)

→  Shedding command
Power System Operation: EMS/SCADA
(Power plant, load dispatch, transmission grid)

<Present>
- Computer control system based on open and distributed architecture with some vendor specific technologies
- Transition form legacy serial channel to IP-based wide area/local communications network, operable in the order of a second
  - IP-based (MPLS) trunk networks and UDP-based SCADA protocol with reliability assurance scheme
- Proprietary application layer protocols and data definitions with some industry standards

<Challenges>
- Applicability of international standards such as IEC 61850
- Domestic standardization
- State monitoring to cope with the high penetration of PVs
Operation Network Architecture

Application Program and Data Model
- Operation and maintenance applications
- Object-oriented data models

Application-layer Protocol and Middleware
- IP-based protocol
- Reliability/QoS ensuring scheme (Redundant and prioritized transmission)

Transport Function
- UDP (User Datagram Protocol)/IP
- TCP (Transmission Control Protocol)/IP
- MPLS, Ethernet, etc.

Ex. Distributed Real-time computer Network Architecture (DRNA)
Distribution Automation Network

- Tap changing of main transformer
- LDC (Line voltage drop compensator), controlling sending voltage automatically according to feeder current
- Sending voltage is controlled by pre-set program

- SVR (Step voltage regulator) installed when distribution line is longer than about 5km.
- Tap ratio adjustment of pole mounted transformer by manual setting

Substation 6.6 kV distribution line

Communication for sensor and remote operation of section switches
Distribution Automation

<Present>
- Completely remote monitoring and control of MV section switches necessary for reliable power supply
- Section switches with sensors (voltage, current, power factor, fault status, etc.), voltage regulators (SVR/SVC) and computer control systems implemented
- Communications methods include private PLC, copper and fiber optic cables

<Challenges>
- Monitoring and control of MV-interconnected DER including substation-installed battery, looped feeder flow and voltage control
- High-speed detection and location of faulty sections
- Load and outage management of LV grid utilizing customer status information from smart meters
- Overload monitoring of pole-top transformers for maintenance
Metering and Customer Integration

<Present>
- HV customer load surveyed, metered, managed (off-line) via private communications. MV customers able to be metered
- Manually metered and switched LV customers. Remote metering and switching (smart metering) is under way with private communications of fiber optic through pole-top concentrators and wireless or PLC through customers
- Broadband telecom networks reach to residential customers

<Challenges>
- PV operation monitoring and output control on high penetration of PV
- Efficient installation of smart meters (cost, duration, private or telecom networks)
- Functional integration/separation and ownership of devices and operation
Customer Energy Management

<Present>
• EMS implemented for most HV customers
• Spontaneous energy saving activities by LV customers, with telecom and broadcast network

<Challenges>
• Automated DR for HV and MV customers
• Visualization of energy usage and load adjustment for LV customer
• PV output control when large installation of PV by using programmed control or third-party control
• Coordination with customer appliances and optimal operations (HP water heater, etc.) and storages (PHV/EV, etc.)
• Premises energy management
Facility Maintenance (Condition Monitoring, Diagnosis and Management)

- Surveillance and inspection
- Sensing (electric, electromagnetic, vibration, image, acoustic, etc.)
- Data upload/download (input/transmission/output)
- Field work support
- Remote monitoring
- Diagnosis and analysis
- Data processing and management, etc.

Facility maintenance and management

Power apparatus

Sensors

Maintenance personnel

IEEE PES
Facility Maintenance (Condition Monitoring, Diagnosis and Management)

<Present>
- Manual surveillance and inspection
- Online monitoring of customer monitoring on sensing and neighboring inn requires sensors and inks

<Challenges>
- Sensor network able to be added on to aged assets while energized
- Ad-hoc system to be installed or removed (initial failure, worn-out failure, etc.) when necessary
- Plug-and-play scheme for automatic setting of sensors and information processing procedure
- Field works assistance
Market Communications

<Present>
• Internet-based virtual private network (VPN)

<Challenges>
• Standardized protocol and data modeling
Innovative ICT Infrastructures for a Smarter Grid
ICT Infrastructure for a Smarter Grid

1. Minimize blackout risk
2. Integrate supply/demand
3. Utilize DER
4. Develop asset management

- Efficient energy supply & utilization
  - Demand Area Secure Communications Network
- Resilient and self-healing power system
  - Wide Area and High Speed Control Network
- Optimal facility management
  - Sensor Networks for Facility Maintenance and Operation
Scope of ICT Infrastructure

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

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

- **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.
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

- Precise simultaneous sampling
- Intelligent modular device
Decentralized Modular Device Network

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

- High-speed L2 Network
  - Integrated Device
    - Measuring Module
    - Processing Module
    - Control Module
    - Communication Module

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

- Stability Assessment Device
  - Monitoring Module
  - Processing Module
  - Control Module
  - Communication Module

- 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
- Primary protection (2 terminals)
- Primary protection (3 terminals)
- Backup protection
- Stability monitoring and control
- 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)

Device #2

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

Device #3

- 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

L2 network (Data transmission, time synchronization)

- Traffic load
- Delay, delay variation
- Packet loss

Node #1

- Analog input (AI)
- Digital input (DI)
- Digital output (DO)

Node #2

- Analog input (AI)
- Digital input (DI)
- Digital output (DO)

Node #3

- Analog input (AI)
- Digital input (DI)
- Digital output (DO)

Node #4

- Analog input (AI)
- Digital input (DI)
- Digital output (DO)
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

Smart Grid Server

PON Head end

Existing PON service station

Smart Grid Base Station

TRX

Customer Gateway

Customer Gateway

Mobile

Maintenance Worker

PON Terminal

PON Terminal

PON Terminal

Existing PON customers

Smart grid device installations using radio-on-fiber technique
ADAPS Configuration

Substation 1

Customers

P/Q control

Communication Network (L2, mobile agents, etc.)

Operation & Control System

P/Q control

Substation 2

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
Demand/Supply Integration

- HV/EHV System
- Substation

Reduce reverse flow

ADAPS

Level flow

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

Control load and energy storage according to PV power output

Controller

PV

Storage

Time

kW

Residential Customer

Hot Water Supply

HVAC

Others
Customer Gateway Structure
Sensor Network for Facility Maintenance and Operation

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

Facility Maintenance (Patrol, inspection, monitoring, diagnosis)

Facility Operation (SCADA/EMS)

IP-based Network

Control Center

Maintenance Center

Weather

Lightning

Environment

OPGW

Wireless sensor network
Plug-and-Play and Ad Hoc schemes

- Speedy installation and removal of field sensor networks
- Reduce maintenance of the monitoring and diagnosis system itself

**<Ordinary state>**
- Oil temperature
- Oil level
- Current, etc.

Conventional sensing, surveillance and inspection

**<Intensive monitoring>**
- Audible noise
- Vibration
- Electromagnetic noise
- Temperature, etc.

Source probing

Intensive monitoring

Intensive data

Detecting pre-fault sign

Identify faulty parts
Repair or replacement

Trend analysis
Sensor Network 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
Sensor Network Architecture

Applications:
- Asset management, diagnosis, inspection, supervision, preventive maintenance, condition base maintenance, corrective maintenance, fault location

Facility maintenance sensor network

DRA-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)

Plug and play for attachment/detachment of sensors (Network coordination scheme)

Power equipment, sensors, workers
Conclusion
Concluding Remarks

• Japanese smarter grid concept
  – To cope with the large penetration of PVs associated with optimal demand/supply integration
• Present ICT infrastructure and challenges
  – Almost automated power delivery grids with existing legacy technologies
  – Backward smart metering and customer integration (AMI)
• Focused ICT networks for a smarter grid
  – Ethernet-based decentralized modular device network for wide area monitoring, protection and control
  – Demand area secure communications network accommodating modular mandatory/optional applications in customer gateways
  – Sensor network for facility maintenance and operation based on ad-hoc and plug-and-play schemes
• Another issue
  – Review the applicability of international standards and standardization activities
Thank you for your attention. Comments, questions?

Yoshizumi Serizawa
E-mail: seri@criepi.denken.or.jp