Present and Future ICT Infrastructures for a Smarter Grid in Japan

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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

• CO₂ 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 CO$_2$ reduction
• Comprehensive optimization of power grids and consumers with respect to CO$_2$ 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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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)
- Nuclear
- High efficiency thermal
- IGCC
- Hydro

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

**ICT**

**ADAPS**

- 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

**Bulk Power**

**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

Corporate Business Intra/Extra-network

Wide Area Monitoring, Protection & Control Network

Operation and Maintenance Network

Demand Area Network (Distribution and customers)

Internet/Public Telecommunication Network
Present and Challenges of ICT Infrastructure in Japanese Grids
ICT Applications in Existing Grid

**Generation** (Large scale)

**Delivery** (Transmission/distribution)

**End use** (Industrial/commercial/residential)

- **Emergency Protection and Control**
  - Power planet operation
  - EMS (Generation control in accordance with load)
  - Transmission/substation automation (SCADA)
  - Distribution automation (SCADA, protection)

- **Operation (SCADA/EMS)**
- **Maintenance/AM/AM/FM**
- **Market**
- **Remote metering, load surveillance**

**Electricity flow**

**Information flow**
ICT Applications in Smarter Grid

Smart Generation
(Centralized)

Smart Delivery
(Transmission & Distribution)

Smart End Use
(Industrial/Commercial/Residential)

- Plant Emergency Control
- Power System Protection & Control
- Feeder Protection
- Customer Equipment/DER Protection

- Load Dispatch and Transmission Operation (EMS/SCADA)
- Distribution Operation
- Customer Interaction (Metering, Switching, Information, etc.)
- Customer Equipment/DER Condition Monitoring

- Appliance Monitoring/Control (BEMS, DR, HEMS, etc.)
- Customer Service (Security, etc.)

- Plant Operation
- Transmission/Distribution/DER Condition Monitoring

- Plant Condition Monitoring
- Market

- E & I

- Electricity & Information
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

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.

Sensors

Power apparatus

Maintenance personnel

Facility maintenance and management

Surveillance and inspection
Sensing (electric, electromagnetic, vibration, image, acoustic, etc.)
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

Resilient and self-healing power system
- Wide Area and High Speed Control Network

Efficient energy supply & utilization
- Demand Area Secure Communications Network

Optimal facility management
- Sensor Networks for Facility Maintenance and Operation
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)

New Power Device

Distribution Grid (ADAPS)

Demand Area Secure Communications Network

Battery

End Use (High efficiency, more electrification)

Evolutionary Power Plant

Information

Electricity

Sensor/Controller

Sensor Networks for Facility Maintenance and Operation

Centralized Gen. (Low Carbon Emission, High Efficiency)

Distributed Gen. (PV, WT)

New Power Device

End Use (High efficiency, more electrification)
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

- **High Speed Control Network**: Precise simultaneous sampling
- **Intelligent modular device**
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

- Stability Assessment Device
  - Monitoring 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

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

Device #1
- PQVF measurement
- Primary protection for 2 terminals
- Stability monitoring and control

Device #2
- PQVF measurement
- Primary protection for 3 terminals
- Stability monitoring and control

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

Device #4
- Primary protection for 3 terminals
- Backup protection
- Stability monitoring and control

Node #1
- Analog input (AI)
- Phasor
- Instantaneous value

Node #2
- Digital input (DI)
- State transition
- Effective value

Node #3
- Digital output (DO)
- Trip, control

Node #4
- Communications
- Data format conversion (analog, digital)
- Sampling synch.
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

Mobile Maintenance Worker

Customer Gateway

Smart grid device installations using radio-on-fiber technique

PON Terminal

PON Terminal

PON Terminal

Existing PON customers
ADAPS Configuration

Substation 1

Communication Network (L2, mobile agents, etc.)

Customers

P/Q control

Operation & Control System

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 2
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

Hot Water Supply

HVAC

Others

Residential Customer

Time

kW
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
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>

Conventional sensing, surveillance and inspection

- Oil temperature
- Oil level
- Current, etc.

Detecting pre-fault sign

<Intensive monitoring>

Intensive monitoring

- Audible noise
- Vibration
- Electromagnetic noise
- Temperature, etc.

Source probing

Intensive data

Trend analysis

Identify faulty parts
Repair or replacement
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

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)

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

Network & Security Management Function
- Device management
- Performance management
- Security management, etc.

Adaptation Function
- IP-based application-layer protocol
- Platform
- Reliability/QoS ensuring middleware

Application Program and Information Model
- Power system O&M applications
- Object-oriented power system information models

Transport Function
- UDP, TCP/IP/Ethernet, etc.

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?

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