Smart Power Grid Case Study in Jeju Test Bed for Key Technology and Construction Procedure

Woohyun Hwang, Ja-hee Kim, Sunghwan Bae, Kyo-Sang Ahn
KEPCO, SNUT
Korea

SUMMARY

Transmission and distribution network consists of T&D facilities and lines, which are supervised and operated with SCADA and DAS to restore faults if occur. With economic growth, transmission and distribution network expands and its operational methods become more complicated, posing constraints to diagnosis, fault prediction and efficient operation only with automation system. Furthermore, demand for renewable energy generation and electric vehicle charging devices increases with the efforts to cut carbon dioxide emissions and curb global warming. Power grid is increasingly linked with large-volume power storage devices. Therefore, this paper defines the smart grid-based key intelligent technology developed to prevent faults with the convergence of T&D facilities and ICT, introduces a phase-by-phase implementation plan, and presents cases in Jeju test bed.

KEYWORDS

Smart Grid, Renewable energy, Demand management, Losses minimize, Global Warming, Load Balance, Process, Jeju test bed, Renewable

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1. Introduction

The increase of new and renewable energy sources, such as photovoltaic and wind power, and new types of demand, such as electric vehicles and electric homes, undermines the stable operation of T&D network. The current operation system based on work units makes it difficult to prevent faults occurring due to outworn facilities and to promptly respond to natural disasters. Such functional limitation prolongs the restoration time. In order to implement the key technologies necessary to make power facilities exposed to expansive regions and natural environment more intelligent and integrate and link separately-operating system, procedures for step-by-step execution and cases in Jeju test bed are presented here to strengthen smart grid system establishment and operation.

2. Main Discussion

2.1 Composition and operational system characteristics of T&D network

The power grid is composed of transmission and distribution facilities, substations, and operational system. Their main function is to provide high quality electric power stably by raising capacity factor and reducing power loss. Most facilities are exposed to natural environment and, consequently, to stiffening, aging, softening effects and natural disasters, and these conditions may well cause faults. To prevent and respond to faults, SCADA, DAS and AMR are used to monitor remotely and isolate faults.

![T&D Facilities and Operating System](image)

Transmission facilities include transmission towers, suspension fitting and insulators, lines; substation facilities are power transformers, switchgear, and auxiliary installation. Electric power in ultra high voltage such as 154kV, 345kV, and 765kV is transported from power plants to substations, which is then sent to consumers through distribution lines. Transmission facilities often break down and cause temporary power failure due to ice and snow, strong wind, insulator damage; close access of heavy industrial equipment at nearby construction sites; or birds getting in vicinity of the facilities.

![Transmission facilities and SAIDI](image)

<table>
<thead>
<tr>
<th>Line length (c-km)</th>
<th>Tower (Thousand)</th>
<th>Insulators (Thousand)</th>
<th>Substation (Units)</th>
<th>SAIDI (Min./Household)</th>
</tr>
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<tbody>
<tr>
<td>30,676</td>
<td>40,811</td>
<td>9,098</td>
<td>731</td>
<td>1.6</td>
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</table>

Poles, suspension fitting and insulators, and cables constitute distribution lines; distribution transformers, protective devices and switchgears make up distribution network. Distribution network is also vulnerable to aging and environmental disasters. Distribution facilities suffer power faults resulting from birds and trees, and when faults occur, industrial production and daily lives are directly affected.
Table 2. Distribution facilities and SAIDI

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<th>Line length (c-km)</th>
<th>Pole (Thousand)</th>
<th>Transformers (Thousand)</th>
<th>SAIDI (Min./Household)</th>
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<td>428,259</td>
<td>8,343</td>
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<td>13.55</td>
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T&D facilities and load facilities are not concentrated and installed over a vast region are monitored, controlled and metered with SCADA, DAS, and AMR. SCADA is capable of minimizing power supply interruption if a fault occurs on facilities through regular metering with devices installed transmission lines or substations. DAS can remotely isolate the fault section and reduce breakout time with the input on voltage and current provided from switchgears and devices installed on distribution lines.

2.2 Changes in grid operation
Until recently, the operation of power grid consisted of generation, transmission and distribution, and consumption. Electric power has been generated from nuclear, thermal and hydro power plants. T&D facilities did not require significant changes because they were built with reserve margins taken into consideration from the initial stage. Additional distribution facilities were built to meet the demand from urban and industrial development. In five to 10 years, however, nations around the world will be obliged to reduce their carbon dioxide emissions while growth rates of the power industry are expected to go down to around two percent. Under this circumstances combined with oil price hikes and environmental pollution, photovoltaic, wind, biomass power generation, and demand management through electric vehicle charging system, intelligent home appliances, and large-volume batteries are expected to become more popular. With the accelerating development of network technology including the Internet and smart phones, power grid and IT have to be converged to offer convenient use of environment-friendly power sources and reasonable power prices for consumers, and loss reduction, better capacity factor and work efficiency for utilities. The supplementary system has to enable prevention and prompt restoration of faults caused by environmental disasters or facility aging.

2.3 Smart grid Key technology
Four technical factors required to build the conventional power grid smart are: 1) intelligent T&D network enabling system operational flexibility, 2) capability to use diverse distributed power sources, 3) automatic shift of power demand in different seasons and day/night time considering the characteristics of each power source, and 4) optimization of power consumption.
2.3.1 Intelligent power facility
The integral part of the power generation and supply is the power grid. Accordingly, it is quintessential to maintain power grid without faults and promptly recover for stable power supply. From this perspective, it is important to make the power grid smarter, and such efforts are mainly involved in T&D facilities and operation system: transmission towers, suspension fittings and cables for facilities; power transformers, switchgears and protective devices for substations; and distribution transformers, switchgears, cable and protective device for distribution.

2.3.2 Automatic connection with distributed power sources for stable operation
If renewable energy sources such as photovoltaic, wind and biomass are fed into the grid simultaneously and taken away from it, a delay in protection coordination can cause a wide area blackout. Therefore, automatic connection with distributed power sources and its monitoring have to be put in place for stable system operation in preparation for the nationwide use of distributed power sources and power storage devices when commercialized.

2.3.3 Automatic management of power demand
With simultaneous use of power according to life patterns, divergence in power generation and consumption occurs. That is, during day time, most industrial and business facilities are in operation, and generation volume goes up; during night time, the volume sharply goes down because industrial and business facilities are idle. It is important that by narrowing such difference, construction costs and operational expenses of power plants should be saved. With bigger difference between day and night, power facility costs increase, pushing up electricity prices and undermining industrial competitiveness and public welfare. Therefore, such day/night power demand gap should be managed using renewable energy generation and large-volume batteries.

2.3.4 Optimization of power consumption
Electricity is consumed mostly in public facilities, commercial buildings, industrial facilities and homes. Considering that electric power is used simultaneously with production, key technology is to make an appropriate use of electricity at a necessary time. As households account for 20% of power consumption, it is logical to make industrial and business facilities intelligent first. Individual households can optimize their power consumption depending on weather conditions with the help of overall monitoring and operation device which links photovoltaic, wind and power storage devices with load.
2.3.5 Interface device
The external devices connected to the operating power grid are mostly load facilities, and power
generation or storage devices are very limited. When renewable energy generation facilities, batteries
and storage devices, new, intelligent power consuming equipment such as electric vehicle and
electricity homes are more widely used in the future, stable operation of the power network will be
greatly affected. Too much or little output, or electricity quality should be controlled and managed
with systematic response in order to avoid influencing the existing grid operation.

2.3.6 Application program
A smart grid is capable of monitoring facilities connected to the grid with sensors and operating them
with switchgear. The data collected with sensors are used to analyze the states of distribution lines,
power transformers, transmission lines leveraging on data mining technique, and help efficiently
operate them. Load imbalance of each facility can be identified and evened up; T&D loss can be
minimized close to a theoretical figure. Also, aging can be analyzed in accordance with long-term
changes in order to predict fault occurring and reduce fault time. Damages and interruptions caused by
a fault in a device can be calculated, which allows a prompt response and restoration following set
procedures. Devices trying to connect to the power grid can be sensed with P&P interface and such
connections are automatically approved or rejected, and the scale of the power sources connected can
be computed for an optimized operation and realignment of T&D system. Depending on the data
collected, electricity quality can be monitored to maintain rated voltage, and harmonics and other
noise can be cut off to elongate equipment life and prevent erroneous operation. When the amount of
renewable energy sources rises, the smart grid enables optimized operating conventional power
sources, reducing thermal power generation and carbon dioxide emissions significantly.

2.3.7 Integrated operation system for smart grid
SCADA and DAS are operated by utilities. The generation facilities of renewable energy such as solar
or wind power and large-capacity power storage devices, electric vehicle charging infrastructure, and
home or industrial EMS are managed by their respective owners. This makes data sharing and
management in connection with the grid difficult. With smart grid implementation, the Power Grid
Operation and Management System (PGOMS) is necessary to integrate and operate all system
connected to the power grid. The PGOMS can run in link with the conventional grid operation system,
which means that minimum investment on the PGOMS promises an integrated operation of all
transmission, substation, and distribution networks.

![Figure 3. Integrated operational system and connection devices](image-url)
2.3.8 Enterprise system and smart grid
Utility business involves numerous customer data, T&D facilities and independent power supply interface of consumers, with all of these being integrated and operated. Utilities operate large-scale systems for asset management, marketing and operation, such as customer information system (CIS) and distribution information system (DIS), which are all linked. In particular, integration of charging rates and CIS for recharging an electric vehicle allows a uniform electricity billing. For distribution facilities, the linkage of intelligent parts and DIS enables to predict, restore and reduce similar hitches and failures in accordance with the life of the facilities. Considering the integration of utility system and system operational system cost heavily, data linkage of different systems would be an appropriate approach to take in making operation smarter.

2.4 Procedures of smart grid-based T&D network establishment
First, the smart grid makes the power grid more intelligent and optimizes the T&D facilities and operation system. If external devices are connected to the grid, they are arranged and aligned to respond to system conditions. Second, when distributed power sources or storage devices are connected, they are analyzed and interpreted by interface device to decide whether they are allowed to connect. The interface device works for determining the connection of countless external resources because if the main device has to play this role, it will expand the system size or impose too much load, causing speed to slow down. Third, the smart grid links the grid with data collected from monitoring and controlling in order for optimized operation and prediction and prevention of faults. Lastly, the smart grid maintains the balance of energy sources and consumption to even up system loads and minimize loss, allowing demand management and optimized consumption.

<table>
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<th>1st phase</th>
<th>2nd phase</th>
<th>3rd phase</th>
<th>4th phase</th>
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<td>Intelligent power grid</td>
<td>P&amp;P</td>
<td>Monitoring/controlling</td>
<td>Demand control</td>
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<td>Enhanced efficiency</td>
<td>On/Off</td>
<td>Prediction response</td>
<td>Optimized consumption</td>
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<tr>
<td>Improved quality</td>
<td>DG stabilization</td>
<td>Fault prediction</td>
<td>Load balancing</td>
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<tr>
<td>Increased capacity</td>
<td>Fault prediction</td>
<td>Prompt restoration</td>
<td>Loss minimization</td>
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Figure 4. Integrated smart grid operation system

2.5 Application of SPG in Jeju Test Bed
Smart Power Grid means the device necessary to make T&D system more intelligent, which includes ball sensors, intelligent electronic device, and lightning position and tracking system. In the distribution lines, two-way reclosures and intelligent switchgears are installed and tested in preparation to the integration of renewable energy sources into the distribution system. The equipments put in place on site are connected via optical and zig bee communications network and linked to each operation system. The collected data are saved on the database and operated in PGOMS.

Figure 5. Intelligent power grid composition and demonstration devices
Intelligent transmission technology is being developed on 154kV Jocheon-Seongsan Transmission line and Jocheon and Seongsan substations. To expand transmission volume, ball sensors, meteorological observation sensors, and monitoring/diagnostic system are installed; a transmission volume computing program is being developed. At the time of the completion of the first phase last May, ball sensors, and IED for transmission lines, GIS, and M.tr are completely installed and are in operation based on IEC61850. The second phase project was launched in June 2011, during which two sets of ball sensors and distribution line IED will have been installed and human machine interface will be developed.

For intelligent distribution, intelligent switchgear, FRTU, circuit breaker, lightening positioning and tracking system, and controlling intelligent system are installed and being operated on four distribution lines of Seongsan substation for fault prediction and automatic restoration of distribution facilities. In the second demonstration phase, reactive power controller, remote voltage monitoring device, transformer monitoring devices will be installed and applied programs will be developed. Reactive power controller will be designed and tested to balance out and compensate active and reactive power as renewable energy sources are integrated into the distribution system.

Also, at the point of voltage drop on the distribution line, a device designed to remotely monitor the state of voltage real time will be installed to raise or reduce voltage. Sensors will be installed inside the transformers to monitor load and aging states; they are all linked with PGOMS to store data and carry out trend analysis to predict and diagnose aging. PGOMS will utilize fundamental smart grid technologies capable of power facility condition monitoring and fault prediction and response, raising reliance 30% and capacity factor 10% through fault prevention from the contact of external materials. For the monitoring and diagnosis of main transformers and GIS, GAS pressure and PD are identified to reduce faults; digital relay and optic cable are leveraged to make compact switchboards and save construction costs. With greater fault prevention and higher stability in distribution system, faults decrease by 20%, and with decreased distribution line loss, capacity factor will increase at least 10%.

3. Conclusion
With the intelligent power grid, fault prevention and prompt restoration become possible, which improves capacity factor and stability of power supply. Also, renewable energy sources fed into the power grid are more easily operated, and a constant, high quality power supply becomes attainable. High-volume storage device and independent power supply device can help do without additional power generation or investment in T&D facilities. With minimized power loss and system operation optimization, carbon dioxide emissions can be cut, while heavy investment is required. For future power industry advancement, a smart grid implementation project has to focus on key technology to make the power grid smarter, and be executed in a phase-by-phase manner. Considering heavy investment is required, continued study and research efforts have to be made on system formation and operation system in order to reduce investment costs.
BIBLIOGRAPHY


Short Bio-data of Main Author

Woohyun Hwang

1983 B.S Degree in Electric Engineering, Chungang University
2000 Masters Degree in Hanyang University (Master of Distribution Automation)
2009 Ph.D in Seoul National University Science and Technology (Data Mining)
1986~ General Manager, Smart Grid Construction and Test Team, Korea Electric Power Corporation
Status and Future Direction of HTS Power Application in KEPCO

K. W. Jeong, B. S. Moon, S. K. Park
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1. Introduction

Why Superconductor? Solution for environmental problems

Maldives’ cabinet underwater meeting (’09.10)
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  - HVDC
  - Electric Vehicle
  - Electrical Energy House
HTS Technology in KEPCO

SOLUTION

Large Capacity & Low loss + Eco-friendly

HTS applications
2. DAPAS Project

**DAPAS**: Development of Advanced Power System by Applied Superconductivity technologies

- Develop HTS Power equipments using superconductor wires (KEPCO, KERI, LS cable, SeoNam etc.)
- Project period: 2004 ~ 2011

**HTS Cable**
- 22.9kV 50MVA, send electrical energy 15 times more than conventional cable.
- Core technology of 22.9kV 150MVA, 154kV 1GVA HTS cable are developed

**FCL**
- The world top class 22.9kV 3kA SFCL was developed.
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**2G Wire**
- The World top class manufacturing technology
- manufactured with half price less and twice faster

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- Core components of 5MW superconductor motor were developed.
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Layout of HTS cable and SFCL in Icheon S/S
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◆ New project of HTS application in KEPCO grid.
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  ✓ Total budget: \ 75.4 bil ($68 mil)

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- Guem-ahk C/S in Jeju Island

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✓ Tres Amigas Super Station project will carry forward with DC 80kV HTS cable
Direction for new project

Real grid application expansion in phase

Required Technologies
- Longer cable (Cooling system development)
- Downsizing (Cryogenic Insulation development)

Expanding Base
- Collaboration (Industry-Academy-R&D)
- Domestic (wire, cooling systems)
Layout of Hanlim test bed

- Hanlim
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- New Town in Jeju
  - Anduk
    - 154kV Hanlim-Anduk T/L
    - 154kV AC HTS (~1km, 2014)

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154kV, 1GVA, 30m HTS cable system
6. Tres Amigas Super Station Project

- **Tres Amigas Super Station (TASS)**
  - Connecting 3 different power systems
  - Using HVDC inverters, energy storage, and HTS cables

- KEPCO, LS cable formed a consortium (2010)
  - KEPCO: Engineering
  - LS Cable: manufacturing and installation

- TASS project is under negotiation
7. Plans and expectations

- **Short-range metro-centric grid**
  - Environmentally friendly,
  - High efficiency of power transmission
  - Better power quality.

- **Entering overseas HTS project**
  - Package of HTS applications and engineering technology with manufacturers
8. Conclusion

- Since KEPCO had selected ‘8 Green Technologies’, HTS applications are developed through many projects.
- In DAPAS project, superconducting wires, HTS cable, SFCL, motor and more products have been developed.
- Through GENI project, 22.9kV HTS cables and SFCL are installed and operated in Icheon substation.
- To develop transmission class of HTS cable, AC 154kV and DC 80kV HTS cables are plan to design and manufacturing. These cables will be demonstrated in Jeju Island by 2014. And 154kV 1 GVA HTS cable is on testing in Gochang Power Test Center.
- HTS application technology will make KEPCO advance the leading overseas markets for new revenue-generating, set the HTS technology standard to take the technology leadership, contribute to green growth by building Eco-friendly grid with high power quality, and reduce power costs.
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22.9kV SFCL

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Offset manhole

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### HTS Applications

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<tr>
<th>Year</th>
<th>22.9kV HTSC</th>
<th>154kV HTSC</th>
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<td></td>
<td>DC 80kV HTSC</td>
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<td>’15</td>
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<td>345kV SFCL</td>
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<td>Longer HTSC (above 3km)</td>
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8. Conclusion

- Since KEPCO had selected '8 Green Technologies', HTS applications are developed through many projects.
- In DAPAS project, superconducting wires, HTS cable, SFCL, motor and more products have been developed.
- Through GENI project, 22.9kV HTS cables and SFCL are installed and operated in Icheon substation.
- To develop transmission class of HTS cable, AC 154kV and DC 80kV HTS cables are plan to design and manufacturing. These cables will be demonstrated in Jeju Island by 2014. And 154kV 1 GVA HTS cable is on testing in Gochang Power Test Center.
- HTS application technology will make KEPCO advance the leading overseas markets for new revenue-generating, set the HTS technology standard to take the technology leadership, contribute to green growth by building Eco-friendly grid with high power quality, and reduce power costs.