A Trend Survey on Smart Grid Technology Development

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Abstract

Smart grid is a brand new industrial evolution of the 21st century. It has many new facilities and functionalities for making the existing electrical grid intelligent. Smart grid will make our daily life changed totally with smart vehicles, electricity usage monitoring, smart appliances, and smart phones. It has self-monitored power generation system, intelligent transmission and distribution infrastructures, and advanced metering infrastructures for efficient and effective power grid. The existing one way functionality will be changed to directional communication. Many changes will be shown to the public from the state of art. This paper presents a recent trend of smart grid technology development and introduces its key concepts in detail.

Keywords*: Smart Grid, Intelligent Electrical Grid, AMI, ICT, EMS*

1. Introduction

Industrial development and fossil energy consumption causes to maximize the CO_2 emissions contribute to global warming. The Earth has been enduring growing indigenous capacity loss by causing extreme weather events such as floods, torrential rains, typhoons, and desertification. Recent development trends reduce fundamentally carbon dioxide emissions in order to combat this global warming, and they are willing to adopt renewable energy technologies such as hydroelectric system, tidal power, wind power, solar power generation, in particular convergence of information technology to the existing electricity grid. Smart grid technology can make multifunctional power providers and consumers to communicate each other, and optimize energy efficiency by exchanging real-time information in both directions. Whereas the existing electrical grid has one way direction as a power supply chain from the power plant, transmission, distribution and sales, but the smart grid has bidirectional exchange that optimizes energy efficiency by power suppliers and customers [1-5].

Table 1. Comparison of the traditional grid and smart grid

Item	***Traditional Grid***	***Smart Grid***
Control System	Analog	Digital
Power Generation	Centered	Distributed
Power Transmission / Distribution	One way	Two way (bidirectional)
Failure Detection	Manual Monitoring	Self-Monitoring
Failure Control	Manual Restoration	Self-healing
Control Type	Limited control	Pervasive control

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Metering	Limited	Real-time
Pricing	Actually Fixed Pricing	Real-time Pricing

The traditional power grid structure is very vulnerable to equipment failures and power outages because of the centralized power generation and one-way distribution to the consumer. In particular, the power generation amount in accordance with the surging difficult fashion in response to the peak demand time under limitations of power plant capacities, it is almost impossible to predict power usage in real time. The current power grid structure has a bid difficulty in communication with a consumer and it is a very closed industrial and centered architecture. Consequently, this paper introduces the smart grid technology and surveys its trends for the future research works and industrial development.

2. The Concept of Smart Grid

Smart grid is the next generation intelligent electrical grid which is designed to optimize energy efficiency by exchanging real-time information in both directions, suppliers and customers by combining communication technology (ICT) to the existing power grid. Key components of the smart grid include renewable energy, advanced energy storage systems (ESS), electric vehicles, power charging stations, advanced metering infrastructure (AMI), peak-time demand response (DR), and energy management systems (EMS). Smart grid technologies can be applied throughout the power supply chain as below [1-7]:

- Wide are monitoring and control: progress and monitor real-time power system status and performance in a wide range of power transmission and control
- Information and Communication Technology (ICT) integration: leverage and communications networks and related equipment, computing, system control software for the efficient operation and management of power grid
- Renewable Energy and Distributed Generation Integration: Integration and control systems of renewable energy and distributed generation
- Advanced Transmission: improve transmission efficiency and reduced additional investment
- Distribution Network Management: Improve sensing and automation of power outages and recovery times reduced by maintaining voltage and asset management
- AMI: based on power measurement and control resources of the consumer, improving energy efficiency through the two-way data communication network, and operating energy efficiency and reliability
- Electric Vehicle Charging Infrastructure: a smoothly operating G2V (Grid-to-Vehicle) and V2G (Vehicle-to-Grid) according to the power grid load level
- Customer systems: industrial, commercial, energy management systems, energy storage, smart appliances, distributed generation sources utilized to manage the power consumption of the household sector customers

Through highly developed technology of control and communications, smart grid based on the existing electrical network can improve the stability of electrical power system by integrating and exploiting renewable energy such as wind power and rays of the sun of which the generation is inconstant and by stably moving and dispersing it. In order to improve the inefficiency that the previous electrical system with the center concentration and one way control manner had, smart grid utilizes the electrical system in a distributed way. This distributed manner that can independently control electrical power depending on scale collects real-time electrical usage information through the sensor and smart-meter equipped to the electrical system. Distributed power supply is what utilizes small-scale electrical generation technology located in the vicinity, and it can reduce the amount of electrical leak and is expected to reduce the cost for it with increased reliability.

Electricity suppliers and consumers can actively manage the supply of electricity as smart grid can flexibly help the cost of it. Electricity Suppliers can flexibly set the cost of electricity and control the supply through smart grid. Electricity Consumers can check the real-time cost of electricity they are charged, which enables them to efficiently use electricity.

Table 2. Key Technologies of smart grid

Technical Area	*Hardware*	*Software*
Wide Area Monitoring and Control	PMU(Phasor Measurement Units) and various sensors	SCADA(Supervisory Control and Data Acquisition), WAMS(Wide-Area Monitoring System), WAAPCA(Wide-Area Adaptive Protection Control and Automation), WASA(Wide-Area Situational Awareness)
ICT Integration	PLC, WiMAX, LTE, Router, Switch, Gateway, Servers, etc.	ERP(Enterprise Resource Planning), CIS(Customer Information System)
Renewable Energy and Distributed Generation Integration	Power generation control devices, Storage Devices	EMS(Energy Management System), GIS(Geographic Information System)
Advanced Transmission	Superconductor, FACTS, HVDC	Network Security Analysis, Automatic Recovery Systems
Distribution Network Management	Remote control, Distributed generation, Storage, transformers, Sensors, Cable sensors	DMS(Distribution Management System), OMS(Outage Management System), WMS(Worker Management System)
AMI	Smart meters, in-home displays, servers,	MDMS(Meter Data Management System), IHD Integration System
Electric Vehicle Charging Infrastructure	Charging infrastructure, Battery, inverters	Energy, Billing, Intelligent software for G2V and V2G
Customer System	Smart appliances, routers, In-home displays, building automation systems	Energy Dashboards, energy management systems, energy management for applications, Demand Response applications

Smart grid can decrease the amount of both the total energy consumption and peak demand by changing the pattern of electricity with Demand Response, and this makes it possible that consumers can efficiently use the electrical grid by themselves. It allows the structure change of the electrical industry through its real-time cost signals, and electricity consumers can manage the amount of electricity usage according to the real-time cost provided by the electrical company, and furthermore they can save or supply electricity. Consumers can perform not only the role of consumers but suppliers of the distributed electricity with the structure of electrical industry expected to be transferring from supplier-centered to consumer-centered, electrical companies in the world point large-scale consumers as the most dangerous competitors against their electricity-supply business in the next ten years.

3. The Present Condition of the Development of Smart Grid

3.1. Technology Development by Promoted Fields [8]

Smart electricity transmission system, smart power equipment, smart power communication network are included in IEGT. In order to realize smart grid, development of communication which integrates the traditional electrical technology and strategies that can commercialize this in the real system are required.

Smart consumer technology refers to the technology of which the goals are to optimize the consumption of electricity by the information of supply and demand of electrical power and improve

the efficiency of electrical grid such as AMI (Advanced Metering Infrastructure), EMS (Energy Management System), Bi-directional Communication Network Technology, etc.

Smart Transmission Technology refers to the technology that improves the efficiency of the electrical grid and reduces the amount of green gas by linking the electrical grid to electrical vehicles such as recharging infra technology, V2G technology, part-material technology, etc.

Smart New and Renewable Energy Technology refers to the technology that connects new and renewable power supply with the existing electrical grid by utilizing various kinds of new and renewable energy that helps us overcome the technological barrier that impedes the supply of generated electrical power such as Micro Grid, ESS (Energy Storage System), Electric Power Quality Compensation, Electric Power Transaction Infra Technology, etc.

Smart Electric Power Service Technology refers to the technology that enables various businesses such as consumer-response, smart electric power transaction by developing a number of electric rate systems and installing consumer-electric power transaction system that improves the efficiency of the electrical grid such as RTP, DR, echnology for Electrical Power Transaction, etc.

3.2. Advanced Metering Infrastructure [9]

Unlike the general communications network, AMI composed of smart meter that transfers the information of consumer electric usage and the like and the network system that transfers information which smart meter creates enables the exchange of information between consumers and suppliers via Open Architecture, a kind of protocol and the standard that connects the linked information regardless of manufactories.

This is the core technology that allows innovation of smart grid as the new electric meter for the next generation that provides consumers with information about the real time rate of electric power. Electric power suppliers can also find it advantageous in that it helps them monitor the real-time rate and information of electric power and respond to emergencies more quickly.

AMI provides the reduction of electric rate, efficient consumption and supply reliability by transferring real time rate signals, energy usage information, remote-monitoring on the electrical equipment and control signals and providing the interface that reflects the needs of consumers.

Smart meter is a kind of gate way that enables consumers and suppliers to communicate with each other, and AMI's based system that transfers the real time consumption or patterns' quantification and rate information.

The network system consists of Application Layer that utilizes and analyzes the total power usage of various consumers and Transport Layer that provides the analyzed information to the consumers. However, standard technology has not been established yet despite the demand for various communications networks between consumers and suppliers in order to realize the functions of AMI smoothly.

Table 3. Communication network for AMI infrastructure

Network	***Contents***	***Features***
RF Mesh Network	. Communications technology that sends information by connecting various peers through wireless frequency	. the scalability is as good as the internet . it is difficult to handle emergency situations as its update frequency is long.
3G Network	. Communication Protocol between Smart Sync and AT&T . People use the 3G Network at home, and Gate Ways and suppliers use the existing public network.	. low cost . the public network is not suitable for AMI
WiMAX	. Communications technology that offers high-speed and wide-area wireless information to the assigned wireless frequency ranges.	. its update frequency is short, thus comparably stable. . the rate is high, and it has yet to be proven due to the lack of usage so far.

HAN (Home Area Network) refers to the network or communication protocol that connects gate ways like smart meter with small electric apparatus. It generally refers to the close area communications network that at first intensively gathers the response of demand from electric apparatus and then connects or transfers them after integration. This considers ZigBee which realizes long-life batteries, low rate of update frequency and high stability or PLC (Power Line Communication) which can utilize the voice call, data, internet, etc. at a high speed via electric wires.

3.3. Demand Response Technology

Demand Response (DR) refers to RTP(Real Time Pricing) based on different values commensurate with daily time period or changing the general pattern of electric use by consumers' response so as to the consumption of electric use when the rate hikes or the reliability of the system decreases. RTP is an extended version that takes the consumers' aspect into account on top of the previous electric market concept which only focused on the aspect of supply. Electric power offers final customers the rate of wholesale markets and the situations of linked rate change according to the changes of fuel and electric power supply situations. RTP is a rate system that induces consumers to reduce the amount of electric usage or change the time to use it in the hope of taking economic advantages based on the signals of changing rates provided by electric power companies [10].

In contrast to the fixed rate system or clocking rate system that charges consumers based on the amount of electric power usage with pre-determined electric rate (won/kWh), RTP is a rate system in which the rate charged to consumers is commensurate with daily time period. Although RTP has a higher variability compared with the fixed rate system, both suppliers and consumers can take benefits from it if consumers use electricity economically.

In the market of electricity, the first step of consumers' participation is Demand Response, and once it becomes vitalized, consumers can change the forms and patterns of consumption according to the changing rate of the electric market. In order to vitalize Demand Response, first the price function of the market should be effective, and second, the rate signals should be comparably detailed and automatic. In the circumstance where the electric market is not formed, the rate system provided by only suppliers cannot efficiently induce Demand Response. Moreover, smart grid that allows consumers to choose a rate according to the real time pricing cannot efficiently operate. If Demand Response is vitalized, electric companies can provide electricity with lower cost and consumers may reduce the demand for electricity during the expensive time periods and instead increase the demand during the cheaper time periods. Distribution of electric usage during the peak time according to Demand Response can be even more efficient than power plants which use fossil fuels.

Through smart grid system, consumers who have small power systems such as plug-ins or batteries will be able to actively participate in the electric power transaction. They also can be active about purchasing electricity generated by various kinds of new and renewable energy like green electricity. Demand Response is a kind of technology or system that reduces the amount of electric usage by contract or on people's will. In 2030, 7 ~ 8% reduction of electric demand is expected as smart grid is expanded.

3.4 Distributed Development

Distributed Development as smart grid sets limits only to the development by renewable energy though it refers to Micro Grid, a kind of development in the vicinity of consumption sites by utilizing renewable energy or existing fossil fuels. Its cost of connecting electric power is cheap as it is developed near and is eco-friendly as it usually uses new and renewable energy. The biggest problem that the new and renewable energy has is about the intermittent generation of electric power and control of the electric flow between a number of Micro Grids and consumers needs. The intermittent generation of electric power can be overcome by generating various kinds of new and renewable energy or utilizing electricity saving technology [11].

EMS (Energy Management System) is a system that operates and manages the power system. Increases of distributed development will change the existing centralized EMS system to local-distributed EMS system. In the system of smart grid, Distributed EMS that can manage and sustain information by local area is needed. Center EMS performs a collective role by gathering information of local EMS. By controlling the load and distributed electric power through the optimized algorism,

centered EMS offers quality electric energy service with the minimum gas emission, minimum operation cost and acceleration of the quality of electric power. It also offers additional service that includes the collective energy management portal function such as real time load management, electric power transaction, etc.

3.5 Electric Vehicles [12]

Refer to the eco-friendly vehicles operated only by the power of batteries, which reduces the amount of gas emission and fuel consumption. This kind of vehicle is operated by electric motors instead of gasoline ones. While the efficiency of gasoline vehicle is around 20%, that of electric one is 70 to 80%. In order to promote the electric vehicle, technology of battery, electric motors, battery systems, and Smart Charging System must be preceded.

In order to commercialize PHEV (Plug-in Hybrid Electric Vehicle) for the next generation, the role of smart grid as an energy infra will be reinforced. Though researches on technology of fast charging battery which takes 10 to 15 minutes are being conducted, it still takes a longer time than the gasoline vehicle that only takes 3 to 5 minutes, and the price is more expensive. If a massive number of vehicles are recharged much at the same time, it could have effects on smart grid. Simultaneous Centralization problem may be prevented via wireless communication between electric vehicles and smart grid, yet it is still on the research stage. If plenty of electric vehicles are supplied to people in the future, the effects similar to having rechargeable mass batteries installed in the local areas will occur, and this can contribute to the distribution of peak electric power. Plug-in Electric Vehicles may be recharged during the low cost time period and supply electricity to smart grid.

3.6 Electric Power Storage System

ESS is a system that increases the efficiency by saving a mass amount of electric power generated during a low-demand period in the storage connected to electric grid and supplying it during the highest demand period. Composed of battery, BMS (Battery Management System), PCS (Power Conditioning System), PMS(Power Management System), it can be linked with distributed resources in electric grid in various ways, ensures stability of the output of new and renewable energy, and provide Load Leveling Peak Shaving Ancillary Service. Due to a lot of limits by environmental pollution, low-life, low efficiency, many different researches on storage systems are being actively promoted [3, 11].

4. Korea Industrial Trends and Prospects of Smart Grid [13]

Domestic electric network shows high efficiency with stable systems compared with other countries, and introduction of smart grid to our country is a bit different from the one promoted so as to change old electric networks in the U.S.

Korea has invested 253.2 billion won in the electricity industry since 2005 and promoted technology development selected as electric power 10 assignments in order to promote new growth power. The government has set up stage based promoting plans of which the goal is to install a national smart grid by 2030 through gathering smart grid road maps. According to the Ministry of Knowledge and Economics, smart grid national road maps, our domestic smart grid market will have been expanded into 73.9 billion dollars' worth market by 2030, and is expected to make profits of 49.2 billion dollars' worth in exportation to foreign countries.

- Stage 1 (2010~2012): Provides the new technology by installing and operating testing sites.
- Stage 2 (2013~2020): Consumers' intellectualization complete and expanding the wide areas.
- Stage 3 (2021~2030): Complete to make the whole land under smart grid structure.

In order to promote related technology as well as industrialization, testing sites were constructed in Jeju Island and base infra investment has been made since July 2009. By 2013, 239.5 million dollars will be invested into total five fields (Smart Network, Smart Consumers, Smart Transportation, Smart New and Renewable Energy, Smart Electric Power Service).

Table 4. Key projects of Jeju island smart grid practice Area

Field	*Contents*	*Leading Company*
Smart Consumer	. Conducts electric usage change by using smart meters in home and business	SKT, KT, LG Electronics, KEPCO
Smart Transportation	. Develops charging infrastructure for electric vehicles . Batteries for EV	KEPCO, SK Energy GS Caltex
Smart Renewable Energy	. Shares residue of renewable energy . ESS and Micro Grid technology	KEPCO, Hyundai Heavy Industry, POSCO
Smart Electric Power Market	. Bi-directional power distribution . Automatic restoration from power failures or disrupts . . Integrated control solution for smart grid and digital power transmission network	KEPCO, KPX
Smart Electric Network	. Consumer-oriented pricing policy . Time-related and/or quality-based pricing . Power usage consulting	KEPCO

Smart Electricity Transmission Monitoring and Operating System

The current Electric Transmission network has limits in that it can respond to accidents only for limited time, chances of being stopped at any time, accidents of transmission equipment that we cannot instantly cope with. In order to overcome these problems people are developing Smart Electric Management Operating System that can prepare for grid accidents and natural disasters, using the maximum potential of Transmission equipment with IT technology.

Transmission System Based on Digital Technology

KEPCO aims to create fusion synergy technology of electric power technology with IT and take national advantages in the field of smart grid by installing a digital-based automatic transmission system combined with individual IED.

Smart Supply of Electricity System

Installation of Smart Supply of Electricity System would make the industry possible to step into the abroad as it will guarantee the reliability of electric power supply as well as the technology of making electricity supply equipment and reliability evaluation techniques.

Active Telematics & Electric Equipment for Eco-Monitoring

Several researches are trying to install an automatic system that checks the state of operation in real time and help operators take proper precautions by sending them information in advance.

5. Conclusions

World-wide energy policies are being converted into demand management-oriented ones, rather than increasing supply. Korea has a more powerful propulsion is required, with energy demand policy organized at the national level. Stable power supply is an important factor in Korea's economic growth, the power crisis, now is a very important issue. Rapid adoption of the introduction of smart grids can lead to changes in power consumption style. US Grid 2030 regarding the smart grid is a long-term project of participating companies and the government and the people. Korea should also establish such a long-term vision, and should carry out the project scientifically and efficiently built a concrete implementation phase.

These days AMI has been installed around 3% nationally. It is necessary to mandate the installation of the AMI, or spread through support such as subsidies. Development of the consumer aspects such as

essential DR and consumer portals in the smart grid is necessary. Liberalization of the electricity market is essential for the development of smart grids. Through active participation of local companies market will be active and competitive, and finally will create a favorable environment for secure smart grid realization. The technological standardization of power infrastructure and IT infrastructure must be conducted in order to achieve the smart grid's goals. In a well-built smart grid, many products will be derived and consumed from the power industry field, and global warming problem will be solved, and also companies will have good business opportunities.

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