Recent Trend of New Type Power Delivery System
and its Demonstrative Project in Japan

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Recently many such distributed generating systems as co-generation, photovoltaic, wind, fuel cells etc. are introduced into power distribution systems, and the power system must cope with the situation with distributed generators. Moreover, such industries as IT request reliable and high quality power to preserve their businesses, and some other electric energy based industries request less reliable but cheaper electricity. From these backgrounds, several new type power delivery systems are emerging where lots of distributed generators (DGs) can be connected and many benefits offered by DGs can be realized without affecting the existing power system. They are referred to various names. In U.S.A., Microgrid, Power Park and Virtual Utilities, etc. are proposed. In Europe, DISPOWER or Smart Grid is under developing. In Japan, FRIENDS and Demand Area Network System etc. are proposed and tested in real sites. In this paper, first, general concepts of such new type power delivery systems and new businesses expected to be created by using DGs are introduced. Then, recent research activities in this area in Japan are introduced so as to stimulate new business opportunities. In the later part of this paper, related NEDO’s demonstrative projects are introduced. NEDO is the largest public R&D management organization and promoting several projects regarding grid connecting issues on the power system. Those projects were planned to solve several problems on the power system where distributed renewable energy resources are installed.

Keywords: distribution system, distributed generator, power quality, Microgrid, FRIENDS

1. Introduction

In recent years, such distributed generators (DGs) as solar cells, gas engines or turbines, wind turbines, fuel cells etc. are installed and connected to power distribution systems. Although more than 200 benefits by connecting DGs to power systems are estimated in Ref. (1), normally, distribution systems are not designed to accept lots of DGs in demand side. Therefore, sometimes several problems are predicted by connecting DGs to power distribution systems. They are typically:
- Protection of distribution lines (islanding operation),
- Voltage and frequency fluctuations (power quality),
- Back-up reserves by existing large scale generators,
- Unbalanced load conditions by single phase generators,

To avoid the above problems and to attain the benefit of DGs, several kinds of new type power delivery systems have been proposed and developed in the world wide: for instance, Micro-grid, Power park, Virtual Utility, DISPOWER, Smart grid, Demand area network system, and FRIENDS, etc. These new type power delivery systems not only enable to connect lots of DGs to power systems but also creates many kinds of new business chances. From the above background, in Japan, to establish connecting DGs or renewable energy resources to power systems, several demonstrative national projects are under test in real sites.

In the following Chapters, authors survey and explain the new type power delivery systems, their demonstrative project in Japan, and the new business chances expected to be created through them. In Chapter 2, new business chances to be expected are introduced, and the enablers of the new businesses or new type power delivery systems proposed in world wide are briefly shown. In Chapter 3, national demonstrative project in Japan relating to them are presented.

2. New Paradigm of Power Delivery Systems

2.1 New Business Opportunities

The keywords for future power delivery system may be the following 3 words:
- IT (Information Technology)
- DG (Distributed Generator)
- CS (Customer Services)

In the above, “IT” and “DG” means two ways: that is, (i) IT controls power delivery system with DGs, and (ii) reliable power must be delivered to the IT industry by using DGs and other facilities. Therefore, in future power system, “customer services” with DG and IT may take an important role for power distribution companies. With DG and IT, the following new businesses might be expected relating to CS.

1) Customized Power Quality Services From our past experiences, black-out causes huge damage to the public. Especially the damage may be large for such new businesses as the ones based on IT as well as energy based industries, etc. To avoid the damage, “multiple power quality services” or “customized power quality services” are emerging.
where several qualities of electric power are supplied according to customer’s needs by using DGs, distributed energy storage systems (DESSs) and power electronics devices, etc. The issues to be developed to realize the customized power quality services are summarized as follows by NEDO’s investigating committee:

- Loss reduction of power electronics devices,
- Development of sophisticated inverter control system,
- Protective relaying system and high speed fault sensing,
- Control technologies of power delivery system with DGs,
- Reliable customized power quality supply system, etc.

So as to realize customized power quality services, several systems are proposed. One is so called “Power Park” and other example is QCC of FRIENDS (see Sec. 2.2 and Sec. 3.2).

(2) Customer Services through IT It can easily be predicted that innovative information technology may cause to change electric energy supply control system. By using information network to control power supply, the following new businesses may come out in near future.

Marketing
- Automated metering services
- Load survey
- Real time pricing and automated billing services
- Optimal facility management services
- Home security & home automation
- Premises security & services
- Home automation systems & services
- Home energy management services

Information services
- Information services of power system maintenance
- Local meteorological information services
- Advertisement of company & virtual shop
- Digital phone, visual phone, internet, cable TV, etc.

(3) Co-generation System Such DGs as gas engine, gas turbine or fuel cells etc. show 70–80% efficiency if we use heat simultaneously. Therefore, especially in Europe, cogeneration system is commonly used for DGs. In north Europe, thermal energy is efficiently consumed as an energy for building heating in winter time. In Japan, though we must consume more heat than use so as to obtain necessary electricity, 1kW co-generation gas engine system recently is developed for the home with floor heating system.

(4) Virtual Power Plant or Virtual Utility In one enterprise or in one country, large number of small scale emergency generators exist. If we can operate and control these emergency generators combined with DGs in normal condition, the collected power of these small generators may be the one as large as a large scale power generating station, and can contribute to power systems control. Therefore, when a number of DGs are integrated and controlled from one control center, the system is sometimes called as “virtual power plant”. If existing DGs spread to wide area, generated power of each DG must be sold to different transmission operators. In this case, the owner of DGs can control DG’s output so as to receive the largest profit by selling their power. Such a system is called “virtual utility” because the power is sold to different transmission operators.

(5) Other Business Opportunities After a severe disaster, continued energy supply is exceptionally important. Especially after an earthquake, we have had serious experiences in Japan or in many Asian countries. A reliable power supply service is important for the areas where severe disaster is normally prospected. Other opportunity is an intelligent demand side management (DSM) through IT and energy conservation services. Home DSM through IT may be a new business opportunities for an Energy Service Company.

2.2 New type Power Delivery System To integrate DGs into power system and to realize the above new business opportunities by utilizing DGs, IT, and power delivery system where many DGs can be connected, several concepts and ideas are proposed in world wide. Among them, Microgrid, Power park, Smart grids and FRIENDS, etc. are briefly introduced below.

(1) Micro-grid The concept of Micro-grid is shown in Fig. 1. As shown in Fig. 1, a lot of DGs (several kinds of power sources) are connected to the power distribution lines combined with several loads. The system has a connection to power system at one point. Normally, Micro-grid is operated through connecting itself to the power system, and behaves as “good citizen” for power system by controlling DGs and loads within Micro-grid. If black-out occurs in the power system, Micro-grid disconnects the power system, and starts islanding operation with its own load and DGs. Therefore, reliable (uninterruptible) power supply is expected within the micro-grid.

(2) Power park To supply customized power qualities, several ideas are proposed. Power park is the one which realize the customized power quality supply. Many demonstrative projects of power park are proposed in U.S.A. but they are not yet realized caused by regulatory issues. Among them, a part of Custom Power Park is really designed and installed for industrial loads. The concept of “Custom Power Park

Fig. 1. Conceptual diagram of Micro-grid

Fig. 2. Concept of custom power park
(3) Smart grids

Smart grids is the vision of Europe’s electricity network in 2020 and beyond. The keywords of Smart grids are as follows:

- Flexible: responding to the changes and challenges ahead.
- Accessible: granting connection access to all network users.
- Reliable: improving security and quality of supply.
- Economic: providing best value by innovation and competition.

The concept of smart grids is shown in Fig. 3. The basic concept of Smart grids is to harmonize the conventional generating station and distributed renewable energy generating facilities installed at demand side, etc. Therefore, power system’s control by advanced information systems takes an important role. Smart grids try to provide toolbox of technical solutions, standard interfaces, open access and harmonization of regulatory and commercial.

(4) FRIENDS

FRIENDS (Flexible, Reliable and Intelligent Energy Delivery System) provides a concept for desirable and suitable power distribution system where many DGs are allocated. Through DGs, DESSs, DSM, power electronics technologies, high-level communication technologies, and distributed intelligent facilities, and so on, FRIENDS aims to attain the following functions.

- Flexibility in reconfiguration of the system.
- Reliability in power supply.
- Customized power quality services.
- Load leveling and energy conservation.
- Efficient demand side management through IT.

The concept of FRIENDS is shown in Fig. 4. An important point of the concept is that so-called “Power Quality Control Center (QCC)” is introduced to realize customized power quality services. QCC not only produces various qualities of power but also flexibly changes system configuration through switching operation of static switches for reliable and economic power supply. Of course, DGs and DESSs are installed in QCC for attaining high supply reliability, energy conservation, and load leveling, etc. Fig. 5 shows an example of conceptual system configuration of FRIENDS. QCCs are allocated in underground spaces of large buildings or public streets. The details of FRIENDS can be found in Ref. (6).

(5) Demand area network system

Demand area network system is a system which tries to accept to connect lots of DGs by making loop network in the conventional power distribution system. Brief explanations of the proposals are shown in Sec. 3.2.

3. Demonstrative Projects in Japan

The New Energy and Industrial Technology Development Organization (NEDO) is Japan’s largest public R&D management organization for promoting the development of advanced industrial, environmental, new energy and energy conservation technologies. One of the important objectives of NEDO’s R&D is solving problems that arise when distributed and renewable resources are connected to power grids. These issues arise because the power output from most renewable energy resources fluctuates with weather conditions and connecting them to traditional power grids may create power quality issues. Therefore, the development of energy management systems, energy storage applications and forecasting methods is important for resolving connection issues. In this section, several projects promoted for the purpose mentioned above by NEDO are introduced.

3.1 Regional Power Grid Projects

The Demonstrative Project of Regional Power Grids with Various New Energies, being undertaken from FY2003-FY2007, encompasses three related projects. Those sub-projects are following.

- Demonstrative Project of Regional Power Grids with Various New Energies at Expo 2005 Aichi and Central Japan...
Airport City (Aichi Project)
- Regional Power Grid with Renewable Energy Resources:
  A Demonstrative Project in Hachinohe City (Hachinohe Project)

In the Aichi Project, a power supply system utilizing fuel cells, photovoltaic cells and a battery storage system was constructed. All power supply system equipped with inverter. A block diagram of the supply system for the project is shown in Fig. 6.

The fuel cells adopted for the system include two molten carbonate fuel cells (MCFCs), with capacities of 270 kW and 300 kW, one 25 kW solid oxide fuel cell (SOFC) and four 200 kW phosphoric acid fuel cells (PAFCs). Fuel for these fuel cells is mainly city gas. However, some of the fuel for the MCFCs is supplied by a methane fermentation system and a gasification system which are converting methane gas from food waste, wooden waste and PET bottles.

The total capacity of the installed PV systems is 330 kW, and the adopted cell types include multi-crystalline silicon, amorphous silicon and a single crystalline silicon bifacial type. A Natrium-Sulfur battery is used to store energy within the supply system and it plays an important role in matching supply and demand in this system.

At first, this demonstrative power plant was installed at the site of The 2005 World Exposition, Aichi, Japan (EXPO 2005) and operated from December 2004 to September 2005. During the demonstration period, a total of 3,716 MWh of electricity was supplied by the power plant to two major pavilions. Moreover, after the period of Expo 2005 (in September 2005), the potential for independent operation with only inverter-equipped power sources was examined. In this independent operation test, it was confirmed that the operating voltage and frequency were stable.

After EXPO 2005, the power plant (Fig. 7) was relocated to a site in Tokoname City near Chubu International Airport and demonstrative operation was restarted in August 2006.

Operation of the Kyotango Project system commenced in the middle of FY2005. The energy supply facilities and demand sites of this project are connected to a utility grid and are integrated by a control system applying commercial communication system. The energy supply system functions as a “virtual micro-grid”.

The main facility of the system is a biogas plant, which is shown in Fig. 8. In the plant, five gas engines with a total capacity of 400 kW were installed together with a 250 kW MCFC and a 100 kW lead-acid battery. In remote locations, two PV systems and one 50 kW small wind turbine were also installed. The power generation equipment and end-user demand are managed by remote monitoring and control as shown in Fig. 9. The system is managed not by a state-of-the-art information network system, but by conventional information networks, such as ISDN or ADSL, because this system was constructed not in city area but in rural area where infrastructure of communication system is not well covered.

Fig. 6. Diagram of supply system in Aichi project

Fig. 7. EXPO 2005 power plant

Fig. 8. Kyotango city biogas plant

Fig. 9. Overview of Kyotango project
In the Hachinohe Project, a private distribution line measuring more than five kilometers was installed for constructing typical micro-grid system. A diagram of the complete system, from the sewage plant to the city hall, is shown in Fig. 10. The private distribution line was constructed to transmit electricity, primarily generated by the gas engine system. At the sewage plant shown in Fig. 11, three 170 kW gas engines and a 50 kW PV system have been installed. To support the creation of digestion gas by the sewage plant, a wood waste steam boiler was also installed due to a shortage of thermal heat to safeguard the bacteria.

Between the sewage plant and city office, four schools and a water supply authority office are connected to the private distribution line as demands. At the school sites, renewable energy resources (PV systems and small wind turbines) are used to create a power supply that fluctuates according to weather conditions in order to prove the micro-grid’s control system’s capabilities to match demand and supply. The system commenced operation during the middle of FY2005.

3.2 Network Technology Projects

In the Demonstrative Project on New Power Network Systems (FY2004-FY2007), network technologies for future distribution systems are being developed. This project includes two experimental sub-projects and one research sub-project shown below.

- The Demonstrative Project on Power Network Technology
- The Demonstrative Project on Power Supply Systems by Service Level
- Comprehensive Investigation into New Power Network Technology

In the first experimental sub-project named the Demonstrative Project on Power Network Technology, equipment that can control the voltage and power flow to distribution feeders by compensating reactive power and coordinating active power is being developed and improved.

In this project, new test equipment was installed on a test distribution network (Fig. 12) constructed at the Akagi Test Center of the Central Research Institute of Electric Power Industry (CRIEPI). This equipment includes a static var compensator (SVC), a step voltage regulator (SVR) and loop balance controllers (LBCs). The SVC and SVR are sometimes applied on an actual utility network. However, in this project, the effects of integrated control of these equipments are being examined for managing line voltage when disturbed by distributed generators.

LBCs are a new type of equipment that can control the power flow between two distribution feeders by means of a back-to-back (BTB) type inverter. In this project, two types of LBCs are being developed. The first type is a 500 kVA mini-prototype with a transformer; the second type is a new concept 1000 kVA model without a transformer. Because LBCs are expected to be installed on electric poles, as shown in Fig. 13, it is very important that the weight of LBCs is light. Therefore, the second LBC did not adopt a transformer to reduce its weight.

The second sub-project is the Demonstrative Project on
In this project, the electricity supply system shown in Fig. 14 was constructed. In this system, two 350 kW gas engine generators, one 250 kW MCFC and various types of compensating equipment were installed in control system area shown in Fig. 15. The compensating equipment includes an integrated power quality back-up system that supplies high quality power to “A” class consumers and “B1” class consumers, for whom interruptions and voltage drops are compensated for by a UPS back-up system. For “A” consumers, the wave pattern is guaranteed, whereas for “B1” consumers it is not. In the case of “B2” and “B3” class consumers, only short-term voltage drops are compensated by a series compensator.

The equipment is being tested using dummy loads in FY2006. In FY2007, the equipment will be connected to meet actual demand, such as for a university or Sendai City facility, and demonstrative operation will be started. Moreover, BTB equipment will be added to the system and then applied to create an artificial voltage drop for testing the function of the compensating equipment.

In the “Comprehensive Investigation into New Power Network Technology” sub-project, impacts of introduction of network voltage compensating equipments and power supply systems by power quality service level to actual power system are being surveyed.

### 3.3 Outline of Other Projects

Adding to the projects mentioned above, NEDO is promoting “the Wind Power Stabilization Technology Development Project” for demonstrating battery system installed at a wind farm for reducing influence to system frequency from FY2003. Also, in FY2006, NEDO has just started the project “Verification of Grid Stabilization with Large-scale PV Power Generation Systems” in which output from a large-scale PV power station is to be managed through the use of batteries for stabilizing voltage of power system. Both of the above projects were designed to identify methods to reduce the negative impacts of renewable energy.

When a cluster of distributed power sources are installed, there is a possibility for interference and malfunction of the islanding prevention equipment. Also it becomes difficult to manage line voltage within operational standard by too much inflow from clustered PV systems. To solve such problem, NEDO is promoting “the Demonstrative Project on Grid-interconnection of Clustered Photovoltaic Power Generation Systems”.

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