Optimizing Power Supply Stability through ICT Utilization in Power Systems

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1. Introduction

Electricity is an essential energy for daily life and industry, and sound operation of power systems for electricity supply to consumers is directly related to stable supply of electricity. To operate a power system in a sound state, the following requirements must be satisfied: (i) match the amount of electricity generated with demand constantly (supply-and-demand balance), (ii) maintain power quality such as frequency and voltage (quality maintenance), (iii) promptly locate and isolate a fault section of the power grid (fault clearance), and (iv) maintain continuation of power supply to sound areas that are not affected by the fault (security of the electricity supply). Various ICT-based systems are in operation to satisfy these requirements concerning power systems.

In the meantime, to achieve carbon neutrality by 2050, it will be increasingly necessary to promote renewable energy and utilization of facilities and equipment that demand electricity such as electric vehicles (EVs). The utilization of ICT will be a crucial factor in achieving the goal.

Considering the background, this paper describes the usage of ICT in power systems currently in operation as well as the future vision of such usage of ICT and expectations for it.

2. Utilizing ICT for power systems

This section focuses on the utilization of ICT for stabilizing electric power supply. So it describes the following systems and technologies as representative examples in the following sub-sections: a “transmission line protection relay system” in subsection 2.1 and an “online pre-calculating system stabilizing controller (OPCSSC)” in subsection 2.2, which are responsible for adjustment of supply and demand to maintain the supply-and-demand balance during normal times in subsection 2.3; control of output for non-firm power sources to achieve both effective use of transmission and substation facilities and stable power supply and quality control on the consumer side in subsection 2.4; and a "distribution feeder automation system” in subsection 2.5.

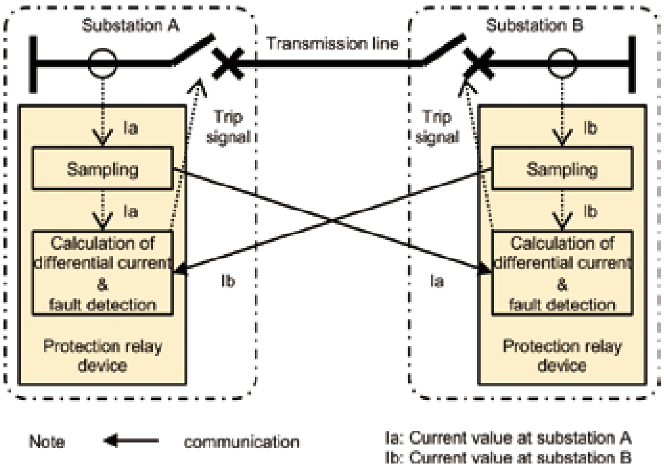
Smart meter systems also utilize various types of communications. However, this paper focuses on power supply stability. So please refer to other literature for communications for smart meter systems, if necessary.

2.1 Transmission line protection relay system

A transmission line protection relay system—consisting of a main protection relay and a back-up protection relay—eliminates short circuits or earth faults that occur on transmission lines. The main protection relay uses communication/transmission for sampled values of current and voltage, and pulse-code-modulation (PCM) current differential relays are used as the main protection relays in 500 and 275 kV bulk power systems.

The basic configuration and operation of the PCM current differential relay is shown in Figure 1. Protection-relay devices are installed at substations located at both ends of the transmission line to be protected, and sampled values of the current flowing in each phase of the transmission line are constantly transmitted to the other end of the line. The protection relay devices calculate the difference of current by using the current values sampled at its own end and those transmitted from the other end. In the case where the difference exceeds the setting criteria, they judge that a fault has occurred on the transmission line, and dispatch trip signals to the circuit breaker to isolate the fault section.

Figure 1: Configuration of PCM current differential relay system



Communication systems used for the PCM current differential relays must have low latency (i.e., 5 ms for 50 Hz power systems and 4 ms for 60 Hz power systems) and high reliability (i.e., system-wide failure rate to operate of 1.0×10^{-7})[1]. To meet those requirements, microwave radio[2] and optical ground wires (OPGW)[3] are used as communication media, which are connected by dedicated multiplex equipment (CR-MUX). Microwave radio has two key features as a communication technology for the PCM current differential relays: (i) ease of assuring low-latency transmission because the transmitting and receiving points are connected over the shortest possible distance and (ii) reliability even in the event of large-scale disasters because physical media are not used (only robust towers are used)[4].

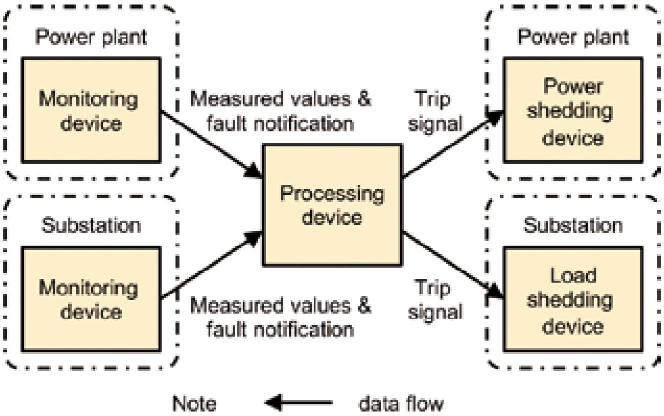
2.2 Online pre-calculation system stabilizing controller

Online pre-calculation system stabilizing controllers (OPSSCs) are operated for purposes such as maintenance of frequency during severe accidents, and they play a role in preventing fault cascading[5]. During the large-scale power outages that occurred in recent years, they also operated to prevent blackouts from occurring[6].

Figure 2 shows a basic configuration of OPSSC —[7]. The processing device constantly receives measured values related to power flows at important points within the power system, and it repeatedly identifies circuit breakers to be tripped for all patterns related to transmission route faults in a bulk power system, loss of generation, etc. at regular intervals. In the event of a fault causing a system disturbance, the relevant monitoring devices notify the fault occurrence to the processing device, which then sends trip signals to the power/load shedding devices responsible for the control target at that time. The power/load shedding devices receiving the trip signals, they trip the designated circuit breakers.

The transmissions of fault notifications and trip signals necessitates ICT that achieves low latency and high reliability; therefore, as in the case of PCM current differential relays, microwave radio, OPGW, etc. are used as the communication media.

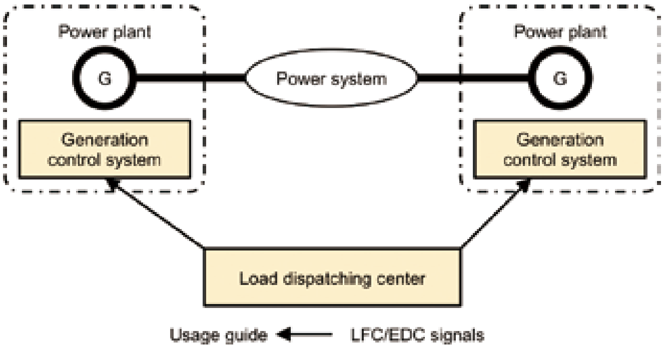
■ **Figure 2: A basic configuration of OPSSC**



2.3 Supply and demand balance control

To maintain the balance between power supply and demand, the output of generators and other equipment is controlled by "load frequency control" (LFC) and "economic load dispatching control" (EDC). Figure 3 illustrates the basic configuration of the system used for LFC and EDC. The load dispatching center system receives measured values such as output and current flow and status values such as breaker open/close status from power plants, etc., and it sends control signals for LFC and EDC to the target power plants every few seconds and every few minutes, respectively. Since the communication used for LFC and EDC (especially in the case of the LFC command) requires low latency and high reliability, microwave-radio and OPGW are mainly used for the transmission path.

■ **Figure 3: Basic configuration of the system for balancing supply and demand**



2.4 Curtailing the output from non-firm connected power supplies

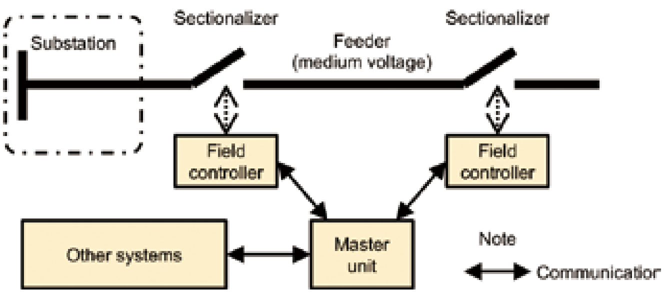
Non-firm connection is a method of connecting the power supply with the upper limit of the available capacity of transmission and substation facilities, and the output of the power supply is controlled according to the available capacity. Specifically, this control is achieved by transmitting the upper-output-limit schedule for each 30-minute time frame as a percentage of the generator's rating in advance via communication. In some cases, the upper output limit value in the 30-minute frame during operation is changed on demand according to the situation.

Two different systems are operated for this output curtailment, and the one chosen depends on the voltage level with which the power supply is interconnected. For power supplies connected to medium- and low-voltage (less than 66 kV) grids, a system based on the Internet and HTTP is used. As for this system, a server is installed on the side of the distribution system operator, and the output-upper-limit schedule is periodically obtained from the generator side via HTTP and Internet VPN. On the contrary, for power supplies connected to high-voltage (66 kV or higher) grids, the output-upper-limit schedule is distributed by cyclic digital transfer (CDT) via a dedicated communication network. Via the dedicated network, commands can be issued at any time, so output can be controlled in real time according to the actual supply and demand of the day.

2.5 Feeder automation system

A feeder automation system in Japan is mainly for medium-voltage feeders (6.6 kV), and they are responsible for distribution grid switching, regulating voltage, and quick restoration of sound sections by isolating a trouble section[8]. This system is almost 100% adopted in Japan, where it is contributing to optimizing voltage and shortening power-outage times. Figure 4 illustrates the basic configuration of a feeder automation system. The system consists of a master unit which is responsible for monitoring and control as well as fault location, isolation, and service restoration, and field controllers. Some of the field controllers are responsible for control of sectionalizer and measurement of current and voltage, and others are used to monitor and control voltage-control equipment (e.g. a step voltage regulator) installed on the medium-voltage feeders. The master unit is also linked to other system such as distribution management systems and control and protection systems for transmission power systems. For communication between the master unit and field controllers, power line communication, metal cables, and optical cables are used as dedicated communication paths. Whichever is used, they are basically mounted to distribution poles and laid along medium-voltage feeders.

■ **Figure 4: Basic configuration of feeder automation system**



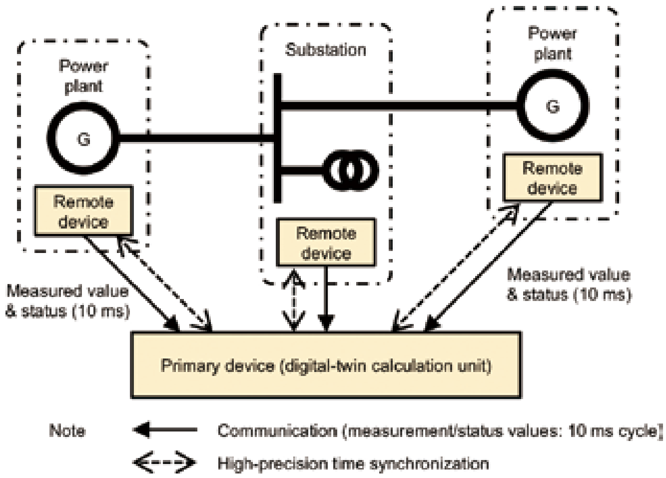
3. Future vision of utilizing ICT in power systems

Four future visions of the use of ICT that are considered to differ significantly from the conventional use of ICT in power systems are described in this section.

3.1 Utilization of ICT for digital twins

Utilizing ICT is essential to create a digital twin. As for the "real-time smart digital twin" (RSDT) proposed by the Central Research Institute of Electric Power Industry as one kind of digital twin, as shown in Figure 5, remote devices installed in power plants and substations synchronize their times with high precision and transmit measured values with time stamp to the primary device at 10 ms intervals. The primary device ascertains the degree of system stability in a few minutes according to the received values measured at the same time, and it could perform preventive control, as necessary[9].

■ **Figure 5: Illustration of communication relationship in RSDT (transmission of measurement and status values only)**



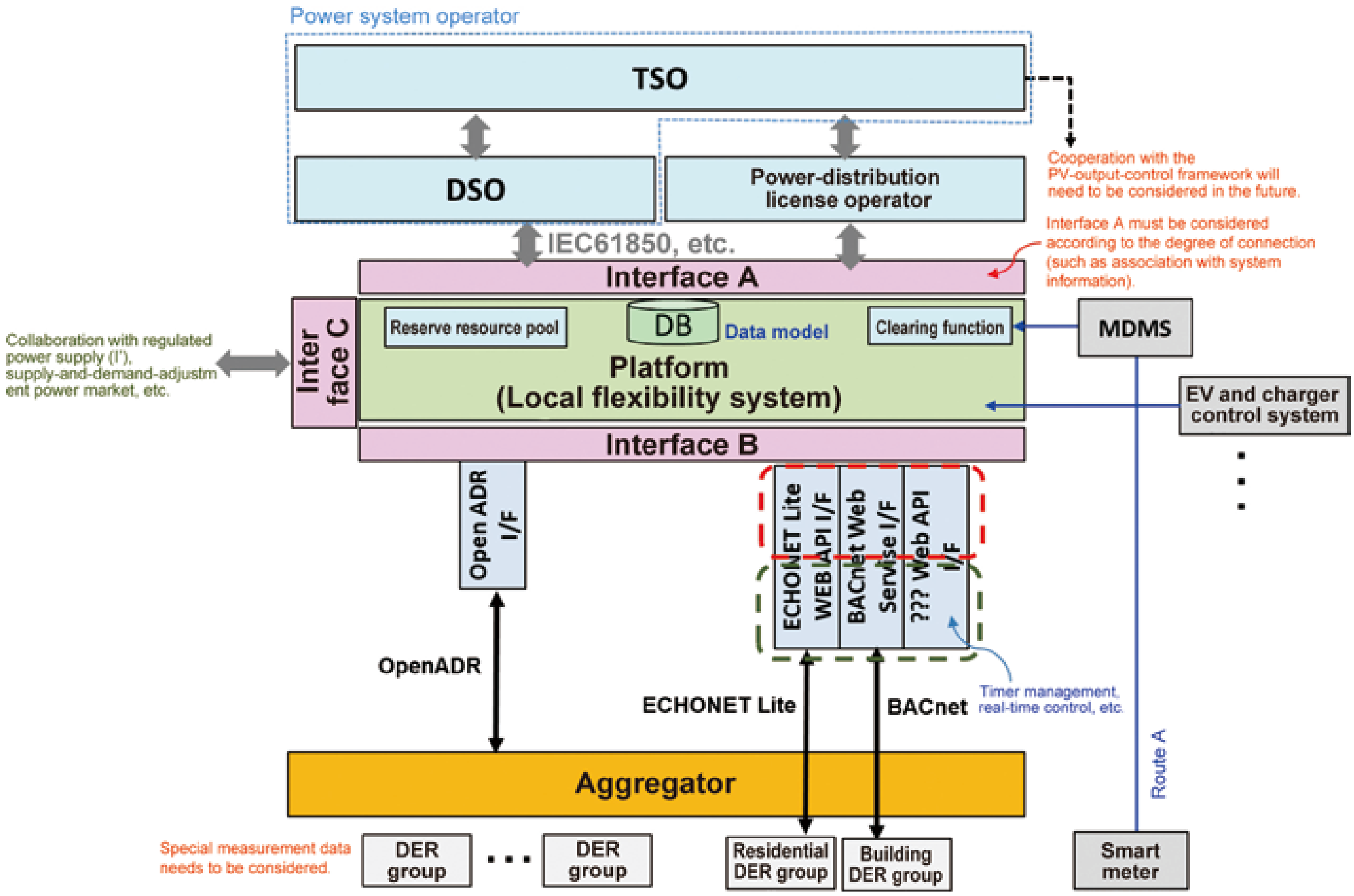
3.2 Cooperation between power system and EVs

EVs are one of the major changes in future electricity usage compared to today's one. Numerous projects are already conducting field trials to utilize the charging and discharging functions of EV storage batteries as a service for operation of power systems[10]. These field trials include transmitting control setpoints to EVs to supply services for replacement reserve for feed-in-tariff. In the future, the utilization of telematics data is anticipated to foster a synergy between the power system and EVs, serving as a key component of a broader range of services tailored to EVs.

3.3 Utilization of flexibility

Alongside the synergy between power systems and EVs outlined in the previous section, there is increasing focus on power system operations – such as congestion management and voltage regulation – that capitalize on the flexibility provided by distributed energy resources (DERs), including controllable loads, to adapt power output or demand.[11]. When utilizing flexibility, power system operators and aggregators exchange data related to

■ **Figure 6: Platform for utilizing flexibility (cited from reference[11])**



service transactions and operations of DERs through a platform such as that shown in Figure 6.

3.4 Collection of equipment-maintenance data

To stabilize power supply, it is necessary to maintain not only the operation and protection of the power system as described above but also the soundness of facilities such as transformers and transmission lines. Until now, the soundness of facilities has basically been maintained through periodic inspections; however, in the future, methods that actively utilize ICT for appropriate inspections and repairs while monitoring the condition of facilities are expected to become mainstream[12]. That is, in addition to temperature, liquid level, vibration, and other data that are widely used in other fields, data characteristic of the electric-power field (such as partial discharge) is expected to be collected through the Internet of Things (IoT) and other means, and the state of the system will be analyzed by using AI and other methods.

4. Expectations for ICT

Expectations for ICT are described hereafter from the perspective of realizing the above-described future vision of ICT utilization and enabling the stable power supply in the future.

4.1 Ensuring openness through international standards

As for coordination with EVs and utilization of flexibility, parties outside of the electric-power sector are involved in the operations of the power system. And as for ICT used in such environments, "openness" is expected to be ensured. One way to ensure openness is to create international standards for coordination between the electric-power field and other fields. That standardization should be led by the International Electrotechnical Commission (IEC), which creates international standards for electric power-related communications. For example, regarding IEC 61850, the international standard for communications for monitoring and controlling power systems, the IEC has published a technical report for communications related to the sector coupling between power systems and thermal energy systems. In addition, another document for "power to gas" (P2G) technology is under development.

4.2 Expanding the scope of wireless communications

Wireless communications are already used in the PCM current differential relays for transmission line protection and smart meters. In addition, it is anticipated that its application in collecting facility-maintenance data will increase. At that time, it is expected that the power supply for wireless-communication terminals will also become wireless or independent. Moreover, the applications of wireless communication in fields such as protection and control are expected to simplify removal of communication cables and testing at substations.

4.3 Utilization of all-photonic communication network

To create digital twins, it is necessary to implement high-speed broadband communications. As one of the communication networks to meet that need, the "all-photonic communication network" is expected to be used in combination with high-speed wireless communication. It has already been presented by NTT in the form of their concept known as the "Innovative Optical and Wireless Network" (IOWN), and domestic and international companies are participating in the IOWN forum[13]. It is hoped that IOWN technologies will contribute to the realization of digital twins.

4.4 Assuring cybersecurity

Assuring cybersecurity is required in all fields. The design of cybersecurity measures for ICT in power systems should ensure the uninterrupted continuity of power system operations. For example, if communication is cut off immediately when a security certificate expires, the power system may be unable to operate, and a large-scale power outage may occur. For that reason, it is expected that an appropriate security policy—tailored to the characteristics of the electric-power sector—will be established, and that power systems will be operated in accordance with the policy.

5. Conclusion

This article has described how various ICTs are utilized in power systems and contribute to stable power supply. It also outlines future visions for ICT utilization in power systems, including digital twins, EV integration, flexibility use, and facility maintenance data collection, along with the expected role of ICT in achieving these visions.

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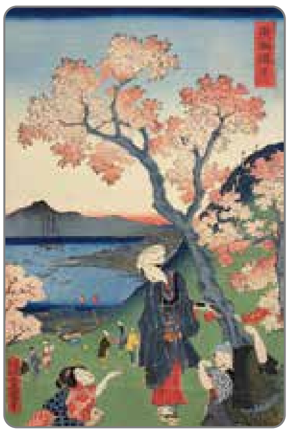

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Utagawa Toyokuni(III) (1786-1864)

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