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Mitsubishi Electric

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Infrastructure Solutions for Realizing a Sustainable Society

MITSUBISHI ELECTRIC

Changes for the Better

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Mitsubishi Electric ADVANCE

Infrastructure Solutions for Realizing a Sustainable Society

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Technical Reports

Precis

Mitsubishi Electric Group, with its basic philosophy of solving social issues through business, has positioned the realization of a sustainable society as the foundation of its management. Infrastructure Business Area (IBA) recognizes challenges such as the circular economy, carbon neutrality, measures for labor shortage, measures for aging infrastructure, and the realization of a safe and secure society. IBA's ideal vision is to contribute to solving these challenges by stable operation of the world's critical infrastructure and achieving carbon neutrality while also contributing to national security in Japan and Asia.
In this paper, we introduce the development status of IBA's business, including environmental value management solutions for energy suppliers, solutions for power plants and transmission & distributions using digital data and digital energy platform, and DC high-speed circuit breaker for rolling stock.

Environmental Value Management Solusions for Energy Suppliers to Achieve Power Supply Decarbonization

Authors: *Mitsue Imahori*, Fumiya Morikawa*, Ikki Takada**

**Energy systems center*

Abstract

As society works to achieve carbon neutrality, initiatives such as the GreenHouse Gas (GHG) Protocol(1), Renewable Energy 100% (RE100)(2), and 24/7 Carbon-Free Energy (24/7 CFE)(3) are garnering attention, and there is rapidly rising demand among consumers for decarbonization. To meet this need, electricity retailers are diversifying their lineup of power plans with environmental value, and sales volumes are also increasing. As a result, electricity retailers are facing the challenge of increasingly complex operations relating to environmental value, such as linking renewable energy sources with consumers and managing non-fossil fuel energy certificates. In response to this situation, Mitsubishi Electric has developed BLEnDer CN for Supplier (hereinafter referred to as "CN for Supplier"), a cloud-based Software as a Service (SaaS) product equipped with functions to manage the environmental value of electric power. This service is part of the "BLEnDer"*1 series of products for the power market that enable comprehensive handling of electricity trading and supply and demand management. With CN for Supplier, we have begun providing services to help reduce the operational burden on electricity retailers and prevent human error, while supporting maximum utilization of the environmental value they possess.

1. Introduction

As efforts to achieve carbon neutrality accelerate globally, governments, companies, and other organizations are strengthening the steps they are taking while fulfilling their respective roles. For example, countries are strengthening regulations and introducing carbon taxes to curb greenhouse gas emissions, and in Japan too, companies are legally required to promote renewable energy adoption and reduce greenhouse gas emissions based on the Act on Sophisticated Methods of Energy Supply Structures (hereinafter referred to as the "Sophisticated Methods Act")*2 and the Act on Promotion of Global Warming Countermeasures (hereinafter referred to as the "Warming Countermeasures Act")*3. Furthermore, from an ESG management*4 perspective, the emphasis is on efforts to reduce environmental impact, and there is a need for decarbonization across the entire supply chain. Companies that fail to respond to this challenge may face not only a declining reputation among stakeholders but also risks such as loss of business opportunities and exclusion from markets. Thus, there is a growing recognition that achieving carbon neutrality is not just a responsibility to be fulfilled as a member of society, but also an imperative for companies to achieve sustainable growth.

Under these circumstances, environmental value derived from non-fossil energy is attracting attention as an important way to achieve carbon neutrality. For example, RE100 advocates the goal of "sourcing 100% of power used from renewable energy." One way to work toward this goal in Japan, where fossil fuel-based thermal power generation is the mainstream, is to claim that power is CO_2-free by adding environmental value procured from the non-fossil value trading market to the supplied power. In this way, companies can promote CO_2 emissions reduction across the entire supply chain by utilizing environmental value, and clearly demonstrate their proactive efforts toward decarbonization to stakeholders. Also, international standards and initiatives aimed at promoting adoption of renewable energy include the GHG Protocol, RE100, and

*1 Abbreviation for Bid Liaison and Energy Dispatcher.
*2 A law requiring suppliers of non-fossil energy to improve the ratio of non-fossil power sources in their supplied power.
*3 A law requiring businesses and local governments to reduce greenhouse gas emissions and promote global warming countermeasures.
*4 Management approach emphasizing the three elements of Environment, Social, and Governance.

24/7 CFE, and in the future, there is a possibility that hourly matching*5, supply in the same area, and supply from renewable energy sources with additionality*6 may be required. Against this backdrop, it will be important for electricity retailers to expand their lineup of power plans with environmental value and provide more flexible and diverse options to companies and environmentally-conscious low-voltage consumers.

Electricity retailers have come to play a role in providing environmental value through power plans with environmental value, and the nature of their operations is also undergoing significant changes from their previous situation. For example, to support the promotion of renewable energy use, electricity retailers need to engage in new operations such as: procuring environmental value required by companies and other consumers, appropriately allocating the procured environmental value according to factors such as consumer needs and the requirements of various environmental standards and institutional systems, managing inventory levels of environmental value to monitor continuous supply, and preparing external reports on supply results for consumers. At present, many electricity retailers do not have much data to manage, so they handle environmental value supply operations using spreadsheet software and similar tools. However, with the expansion of plans and increase in consumers, the amount of data to be handled is expected to increase rapidly in the future, making electricity retailers' operations increasingly complex and making it essential to establish systems that provide efficient operational support.

Mitsubishi Electric is deploying the BLEnDer series of products for the power market. In this paper, section 2 describes the nature of the operations of electricity retailers, and section 3 discusses CN for Supplier, an SaaS product in our BLEnDer series designed for electricity retailers that supply power plans with environmental value, including the product's development background, functions, and features.

2. Electricity Retailer Operations

Figure 1 shows the operational flow of an electricity retailer with regard to environmental value. Operations are broadly divided into: creating and managing power plans with environmental value, collecting information on power supply and demand volumes, allocating environmental value, purchasing and managing non-fossil fuel energy certificates, managing environmental value inventory, and external reporting of supply results.

(1) Creating and managing power plans with environmental value

Master data—such as sources of procured environmental value (renewable energy sources, non-fossil fuel energy certificates, etc.), power plans with environmental value, and consumers—is registered in the customer information system. This information is transcribed to spreadsheet software or a similar tool, and linkage information is created that shows the relationships between sources of environmental value and consumers for each plan.

(2) Collecting information on power supply and demand volumes

Data on planned generation, measured generation, planned demand, and measured demand is output from the supply and demand management system and transcribed to spreadsheet software or a similar tool. If we consider, in particular, the possibilities that 24/7 CFE may be realized and that the non-fossil fuel energy certificate system may follow international standards in the future, the allocation units for environmental value are likely to become finer grained, increasing the amount of data to be taken in.

(3) Allocating environmental value

Allocation targets and allocation amounts of environmental value are calculated manually based on linkage information that shows relationships between sources of environmental value and consumers, and supply and demand data. For example, to achieve 24/7 CFE, it is necessary to allocate environmental value in hourly units without excess or shortage.

(4) Purchasing and managing non-fossil fuel energy certificates

Information on non-fossil fuel energy certificates purchased from the renewable energy value trading market and the market for achieving the obligations under the Sophisticated Methods Act is manually transcribed into spreadsheet software and other applications. It is necessary to ascertain the types and required quantities of environmental value that match consumer needs and procure them with the appropriate timing.

*5 Matching renewable energy-derived power generation with consumption.
*6 Effect of promoting the addition of new renewable energy sources.

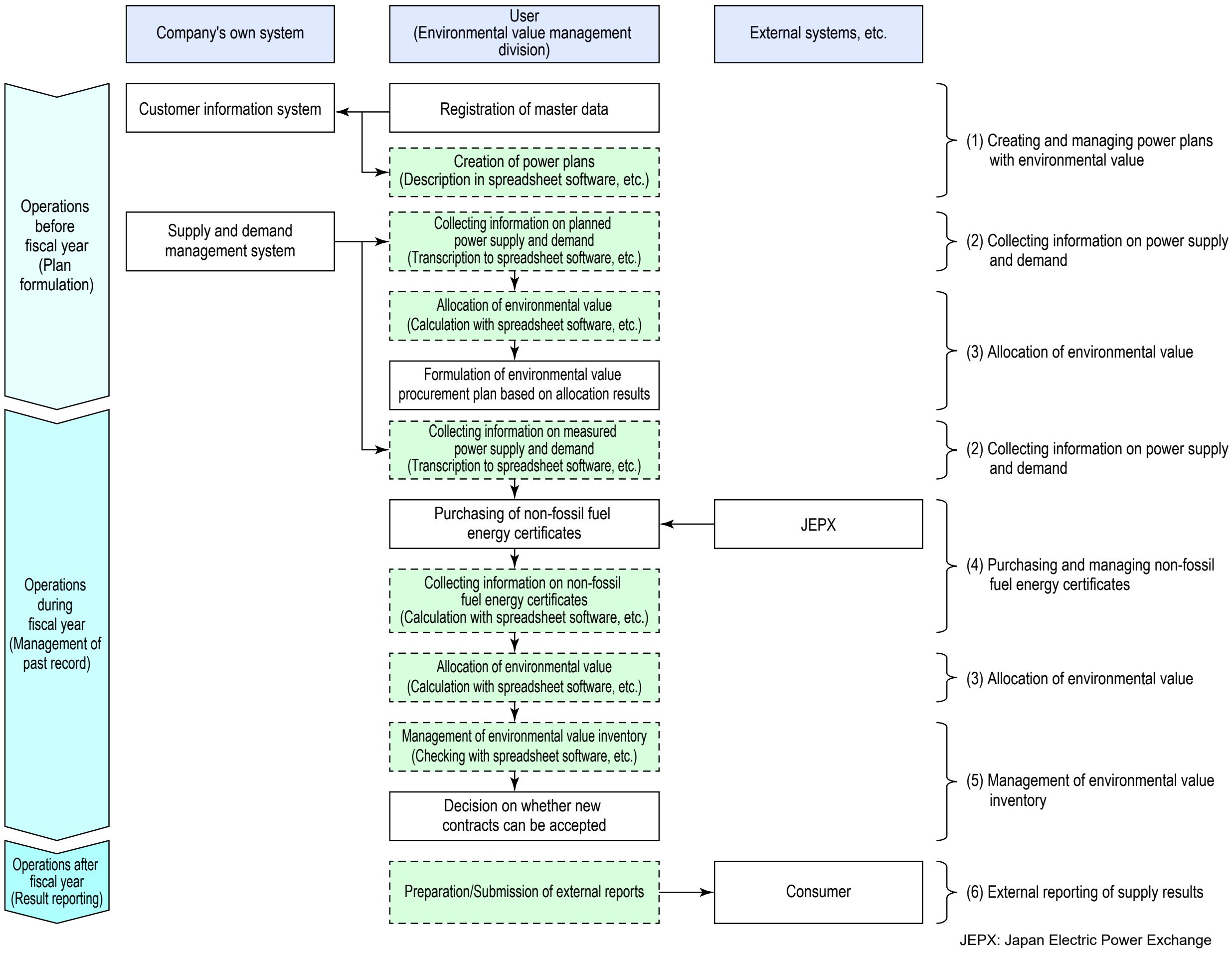

Fig. 1 Operational flow of environmental value management

(5) Managing environmental value inventory

To check for excess or shortage of procured environmental value, it is necessary to manually calculate inventory quantities using spreadsheet software and other tools.

(6) External reporting of supply results

Data necessary for external reporting is collected, and reports are prepared based on that data. Allocation results are reported to consumers. Other information is also reported, such as the non-fossil ratio of supplied power under the Sophisticated Methods Act, and greenhouse gas emissions under the Warming Countermeasures Act.

3. CN for Supplier

As interest in environmental value increases and the number of consumers grows, the types of environmental value that are in demand are also increasing. As a result, linkage information is increasing, and the burden of manually creating and managing plans is expected to increase significantly. Furthermore, manual data transcription and allocation calculations are not realistic for gathering power supply and demand data and allocating environmental value in fine-grained units.

This section describes the development background, functions, and features of CN for Supplier, developed by Mitsubishi Electric to support these electricity retailer operations.

3.1 Functions and service composition

Figure 2 shows the functions of CN for Supplier, together with related SaaS products. CN for Supplier operates in conjunction with our services for electricity utilities—BLEnDer BG (power supply and demand management service), BLEnDer DEP (Digital Energy Platform), and BLEnDer ICE (battery-powered wireless terminals for sensor networks)—and is provided as an environmental value management SaaS.

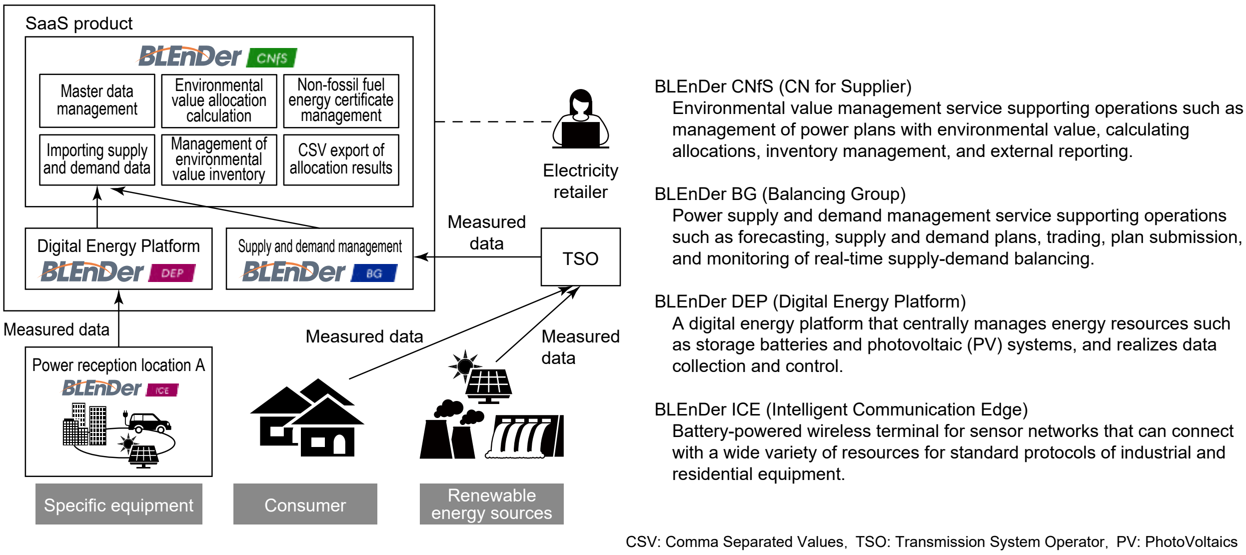

Fig. 2 Composition of environmental value management SaaS provided by Mitsubishi Electric

(1) Master data management function

This function centrally manages master data such as contracted consumer information, information on power plans with environmental value, and renewable energy sources. It also manages linkage information showing the relationship between the sources of procured environmental value and consumers for each plan. When attributes are set, such as renewable energy type, area, and additionality for plans and environmental value sources, respectively, linkage information that connects items with the same attributes is automatically created, and this can reduce the burden of manual matching work.

(2) Import function for supply and demand data

For users who have BLEnDer BG, we provide a function that automatically links planned generation, measured generation, planned demand, and measured demand in 30-minute units from BLEnDer BG. For users who do not have BLEnDer BG, on the other hand, we provide a tool that converts linked supply and demand data in CSV format from the supply and demand management system they have into the format for CN for Supplier.

(3) Function for calculating environmental value allocation

This function allocates environmental value to consumers based on CN for Supplier's proprietary logic. When allocating, the function considers the contract details of power plans with environmental value, planned and measured volumes for generation and demand, and the attributes of procured environmental value. Allocation processing can perform matching in units as short as 30 minutes.

(4) Function for management of non-fossil fuel energy certificates

This function manages information on non-fossil fuel energy certificates purchased from the renewable energy value trading market and the market for achieving the obligations under the Sophisticated Methods Act.

(5) Environmental value inventory management function

This function calculates power generation and environmental value equivalent[*7] for each Feed-In Tariff (FIT) and non-FIT power source owned by the electricity retailer's power generation division, the amount of environmental value procured by the retail division, and the environmental value allocation amount for each consumer and power source after environmental value allocation calculation. It provides screens where calculation results can be confirmed in various units such as by power source or by consumer, and in annual, monthly, or 30-minute units.

(6) Function for CSV export of allocation results

This function outputs data necessary for preparing reports for external reporting, such as environmental value allocation results, in a CSV file.

*7 The amount of environmental value derived from non-fossil power sources, calculated based on generation.

3.2 Features

Mitsubishi Electric provides various products aimed at solving challenges pertaining to the power market, and by linking these products with each other, we can achieve more effective operational support. The features of CN for Supplier are as follows.

(1) Improved operational efficiency and optimization of environmental value procurement through automatic linkage of supply and demand data

BLEnDer BG handles power management, while CN for Supplier handles environmental value management. Data linkage between these two functions enables procurement of environmental value based on demand forecast data, thus making it possible to avoid excess or shortage in environmental value procurement. Furthermore, data linkage is automated, so this can also prevent human error such as data input mistakes.

(2) Simplification of monitoring of the past record of environmental value supply by providing a screen to check allocation results

A screen is provided where environmental value allocation results for each power source and consumer can be visually confirmed. Figure 3 shows a screen that displays allocation results for consumers who have contracted for matching plans in 30-minute units. At this screen, it is easy to confirm the supply capacity type of environmental value allocated to each consumer and whether there is any excess or shortage in supply, in both annual and 30-minute units.

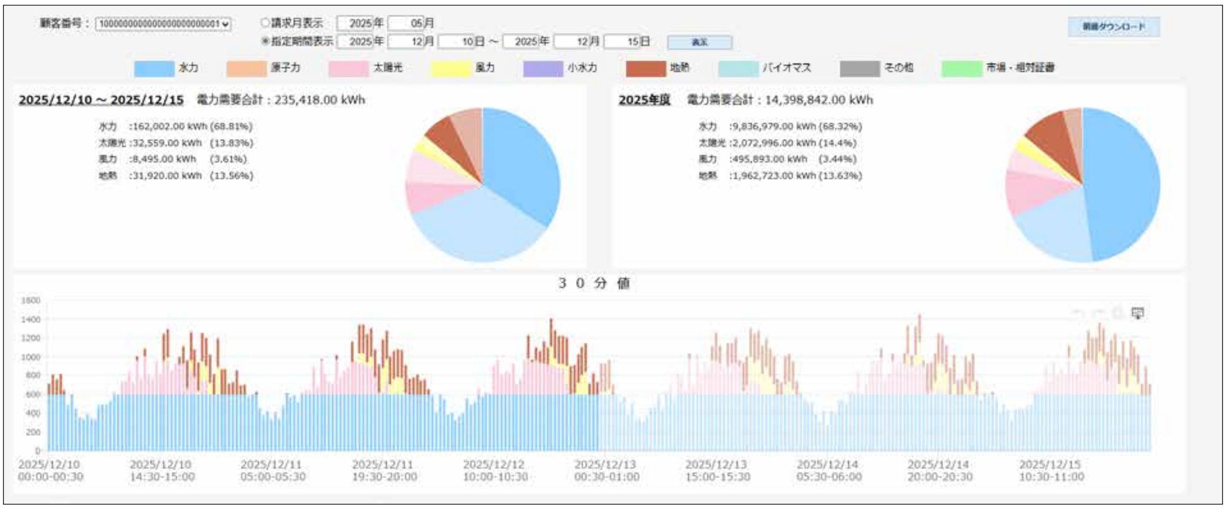

Fig. 3 Screen for checking environmental value allocation results

(3) Dealing with the requirement for realizing real-time matching

Supply and demand data is linked from BLEnDer BG in 30-minute units, and based on this data, matching is performed with environmental value equivalents in 30-minute units. Going forward, requirements of the GHG Protocol, RE100, and other initiatives may include matching in hourly units. CN for Supplier has already realized this idea. We have also introduced a system that collects consumption data for each piece of equipment via BLEnDer DEP, from BLEnDer ICE installed for each piece of power consuming equipment within a location. This enables matching in equipment units.

4. Conclusion

This paper has described CN for Supplier provided by Mitsubishi Electric. CN for Supplier is an SaaS product that supports the environmental value supply operations that electricity retailers are newly taking on. More specifically, the SaaS based on CN for Supplier provides functions to support operations such as: creating and managing power plans with environmental value, collecting information on power supply and demand, allocating environmental value, purchasing and managing non-fossil fuel energy certificates, managing environmental value inventory, and external reporting of supply results. In this way, it is expected that we can flexibly respond to diverse consumer needs while achieving greater operational efficiency and business growth for electricity retailers.

Going forward, our direction will be to aim for expansion of products that can be adopted not only by electricity retailers, but also by power generators that own renewable energy sources and all businesses that need emissions management. This will further promote decarbonization across the entire supply chain and contribute to achieving carbon neutrality.

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Digital Energy Platform for Transmission and Distribution

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**Energy systems center*

Abstract

Mitsubishi Electric provides Enterprise Resource Planning systems such as the wheeling fee calculation package (BLEnDer TS*1) for Transmission System Operators (TSO), and thereby contributes to the smooth execution of transmission and distribution operations(1). On the other hand, transmission and distribution operations require operational improvements for the next generation, such as responding to revenue caps*2, expanding renewable energy, and improving service levels. To address these challenges in transmission and distribution operations, we are developing a digital energy platform for TSOs (hereinafter referred to as a “digital energy platform for transmission and distribution”) aimed at service delivery, rather than providing products based on conventional from-scratch development.

1. Introduction

The Japanese transmission and distribution domain has undergone various institutional and operational reforms since the start of power retail liberalization in 2000, including the liberalization of high-voltage consumers in 2004, expansion to low-voltage consumers in 2016, and legal separation of transmission and distribution divisions in 2020. As a result of repeated additions to existing operations, as well as system modifications and expansions, operations and systems have become complex and bloated, and are now reaching their limits in keeping up with large-scale institutional changes such as distributed energy resource support, next-generation central load dispatching instruction support, simultaneous markets, and transition to nodal systems*3. Meanwhile, the method of setting wheeling fees has changed from rate-of-return regulation*4 to revenue cap regulation, and the recent impact of labor shortages has caused resource shortages in planning, development, and maintenance for both operations and systems, and there is a need for fundamental efficiency improvements and cost reduction initiatives.

This paper provides an overview of the development of our digital energy platform for transmission and distribution, our new initiative to transition from conventional product delivery (selling products) based on from-scratch development and package development, to service delivery (selling services) based on new solutions that combine global solutions with our own expertise.

2. Digital Energy Platform for Transmission and Distribution

The digital energy platform for transmission and distribution provides new services with three basic concepts: fit to standard, one-stop service delivery, and development of an ecosystem platform. The solution concepts are shown in Fig 1.

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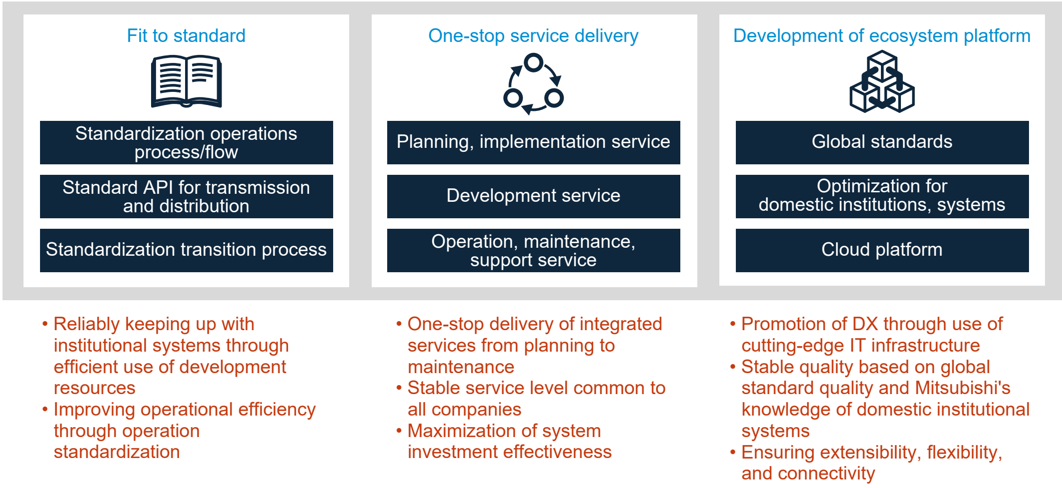
*1 One of the BLEnDer series of packaged software products, developed by Mitsubishi Electric, for the power market to comprehensively address electricity trading and supply-demand control.

*2 A mechanism whereby TSOs set wheeling fees based on business plans approved by the national government as “revenue caps,” and achieve cost efficiency while securing necessary investments within that scope.

*3 A market-driven congestion management method that sets different prices at each location (node) reflecting transmission network congestion and constraints, and awards contracts starting from the lowest-priced power sources in the power market.

*4 A pricing method that determines services by adding appropriate profit (appropriate business compensation) to the supply cost. The method is applied to rates of highly public service businesses for which stable supply is essential, such as electricity, gas, and water rates.



API: Application Programming Interface, DX: Digital Transformation

Fig. 1 Solution concepts

2.1 Fit to standard

Wheeling operations—one type of transmission and distribution operations— are carried out according to general provisions (such as wheeling service general provisions) created by each TSO based on the wheeling service system established by the Ministry of Economy, Trade and Industry. Therefore, basic concepts such as fee calculation formulas are uniform across all companies. On the other hand, differences in actual operational processes/flows occur among companies due to differences in interpretation of general provisions, region-specific conditions (such as the presence or absence of remote islands), historical operation practices, and differences in existing overall system configurations. Furthermore, individual company requirements (add-on development) arise in system development, resulting in issues with development scale escalation and lead time prolongation. Therefore, the digital energy platform for transmission and distribution aims to reduce individual company requirements and optimize development scale through fit to standard.

The aim of fit to standard is simple processes/flows that conform to domestic institutional systems and enable operational standardization among TSOs by incorporating the following four points:

(1) Knowledge gained from operation of current wheeling system, etc.

(2) Issues faced by TSOs (specifics examined by TSOs and Mitsubishi Electric in current operations with the aim of issue resolution)

(3) Standard processes/flows and operational (data) models in global solutions

(4) Measures for the next generation of transmission and distribution operations

By utilizing these standard processes/flows, it is possible not only to reduce the volume of development through reduction of the add-on development mentioned earlier, but also to provide systems that meet transmission and distribution operation requirements without the need for TSOs to examine operational requirements from scratch, and to improve lead times to system introduction. Table 1 shows the applicable scope of standardized operational processes/flows for wheeling operations.

Table 1 shows the applicable scope of standardized operational processes/flows for wheeling operations

Operational domain	Scenario name
Customer information management	Contract management between consumers and generators (new contracts, modification)
	Contract management between consumers and generators (contract termination)
	Retailer management
	Temporary contract management (exceeding period)
	Temporary contract management (less than 1 year)
	Contract power management (actual quantity system)
	Contract power management (consultation system)
	Private power generation supplementation record management
Meter management and reading	Meter replacement
	Automatic meter reading
	On-site meter reading
Energy data management	Energy data calculation
	Energy data agreement
	Partial supply energy data allocation
	Generated energy data allocation (for transmission service charge)
	Generated energy data allocation (for imbalance)
	Overall contract power factor calculation
	Imbalance calculation
	Restriction/suspension total time calculation
	Supply halt or suspension period calculation
	Economic output control settlement basic data preparation
	Imbalance charge basic data preparation
	Balancing power charge basic data preparation
	Renewable energy voluntary wholesale supply energy data calculation
	Inter-operator settlement P0
Power delivery	Delivery of 30 mins. of power
	Confirmed usage notification
	Energy data notification after generation allocation
	Monitoring of real-time supply-demand balancing
	Power data utilization

Operational domain	Scenario name
Fee calculation	Transmission service charge calculation (for consumers and generators)
	Ancillary fee calculation
	Imbalance fee calculation
	Balancing power fee calculation (for BSP)
	Balancing power fee calculation (for TSO)
	Inter-operator settlement
	Renewable energy specified wholesale supply fee calculation
	Renewable energy voluntary wholesale supply fee calculation
	Renewable energy purchased received/delivered power fee calculation
	Last resort supply fee calculation
	Settlement amount registration
	Difference settlement and correction recalculation for retroactive transfer, etc.
	Fee exception correction recalculation
	Unit price revision
	Fee calculation hold (individual designation)
Billing, money received	Money received (direct debit)
	Money received (credit card)
	Money received (convenience store)
	Money received (bank transfer)
	Return
	Notification (account payment request)
	Notification (bill payment request)
	Overpayment management
	Demand for payment
	Demand for payment (LR)
	Overdue interest
	Deposit (deposit recording)
	Daily closing processing
	Fee collection outsourcing
	Temporary payment procedures
	Refund (bank transfer)
	Deposit (return, payment appropriation)
	Payment management
Statistics	Statistics, reports for internal use
	Statistics, reports for regulatory authorities
	Statistics, reports for neutral bodies
	Operation quality statistics
Inquiries	Search for common information

BSP: Balancing Service Provider, LR: Last Resort

2.2 One-stop service delivery

We will shift direction to the next generation regarding our method of providing value as well. Currently, we provide value through a product delivery (selling things) approach where we customize and develop add-ons for package products such as the wheeling fee calculation package (BLEnDer TS) to meet individual company requirements and realize solutions, and deliver the result to the customer environment. Providing packages has development benefits such as reduced development volume and costs due to common development elements, in comparison to from-scratch development by a single company. However, with the product delivery format, new and modified development is possible when requirements such as institutional response have been determined, but it is difficult to discover the latent needs of TSOs and create new value. Therefore, Mitsubishi Electric is shifting from the conventional product delivery format to an approach that provides one-stop delivery of services (selling services) ranging from planning to maintenance. Services are broadly divided into four types: system consulting/implement service, system development service, system operation service, and system technical support service. Stable operations and new value creation are realized by cycling through these four services. Figure 2 shows the service concept for one-stop services, and Fig. 3 shows the effects of one-stop services on each phase.

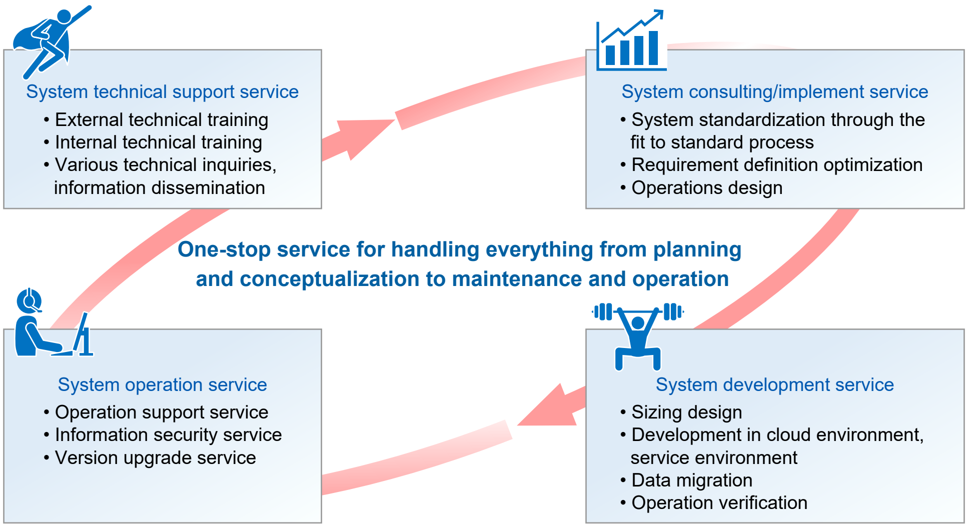


Fig. 2 One-stop service

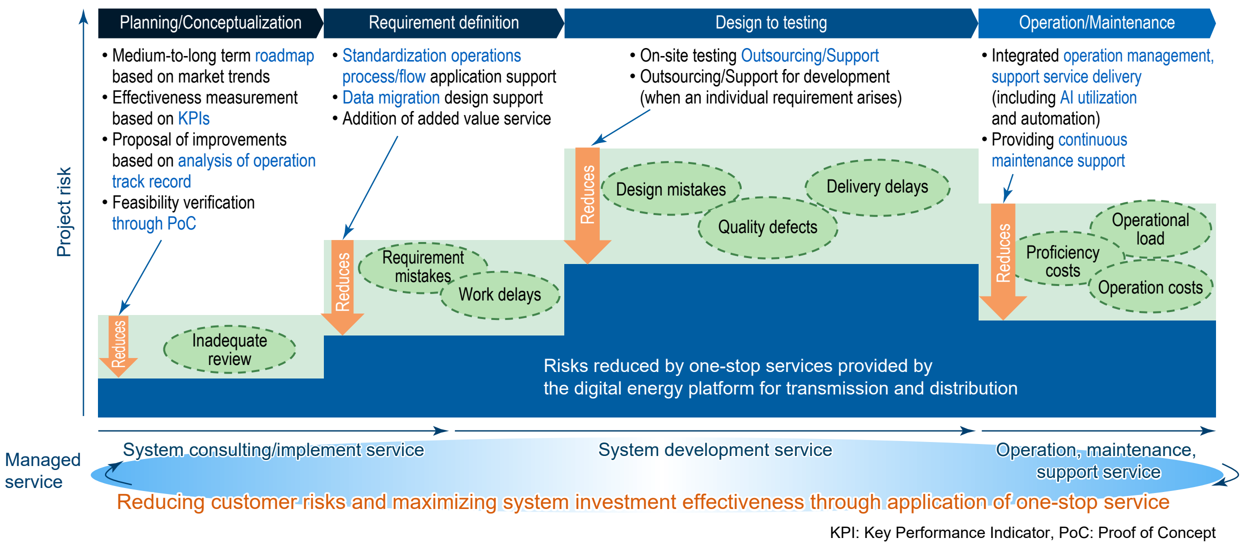


Fig. 3 Effects of one-stop services on each phase

2.2.1 System consulting/implement service

Mitsubishi Electric examines new needs and creates value based on information from various national committees and the Organization for Cross-regional Coordination of Transmission Operators, JAPAN (OCCTO), as well as operational issues analyzed concerning the system operation service. We create development roadmaps and formulate plans for service delivery. Based on the roadmap, we provide TSOs with operation improvement and system implementation policy proposals that maximize the effectiveness of system investment.

2.2.2 System development service

This service supports system construction for requirements confirmed through the system consulting/implement service. Upon request, we also undertake system construction contracts for individual company requirements. This includes user education and environment setup to make services ready for use.

2.2.3 System operation service

This is a service to support stable operation of the provided systems and services. Through system monitoring, fault response, regular maintenance, performance optimization, and other steps, we minimize system downtime and ensure operational continuity. Furthermore, by analyzing operations and identifying issues based on information (such as logs) obtained during maintenance and operation, we deploy insights in system consulting/implement service, and connect to creation of new value.

2.2.4 System technical support service

We provide technical products that contribute to improving the efficiency of operations and in-house development, such as Digital Adoption Platform (DAP), no-code/low-code tools, and process mining, as well as various types of support including design guidelines, learning content, and educational training for using various services.

2.3 Development of an ecosystem platform

We are developing an ecosystem platform as a foundation for providing the fit to standard and one-stop services described in sections 2.1 and 2.2. The digital energy platform for transmission and distribution is composed of three layers: an application service layer that provides various operational functions, a managed service layer that serves as the foundation for providing one-stop service, and the IT service base layer that serves as the technical foundation of the application service layer and the managed service layer. Figure 4 shows the platform's three-layer structure.

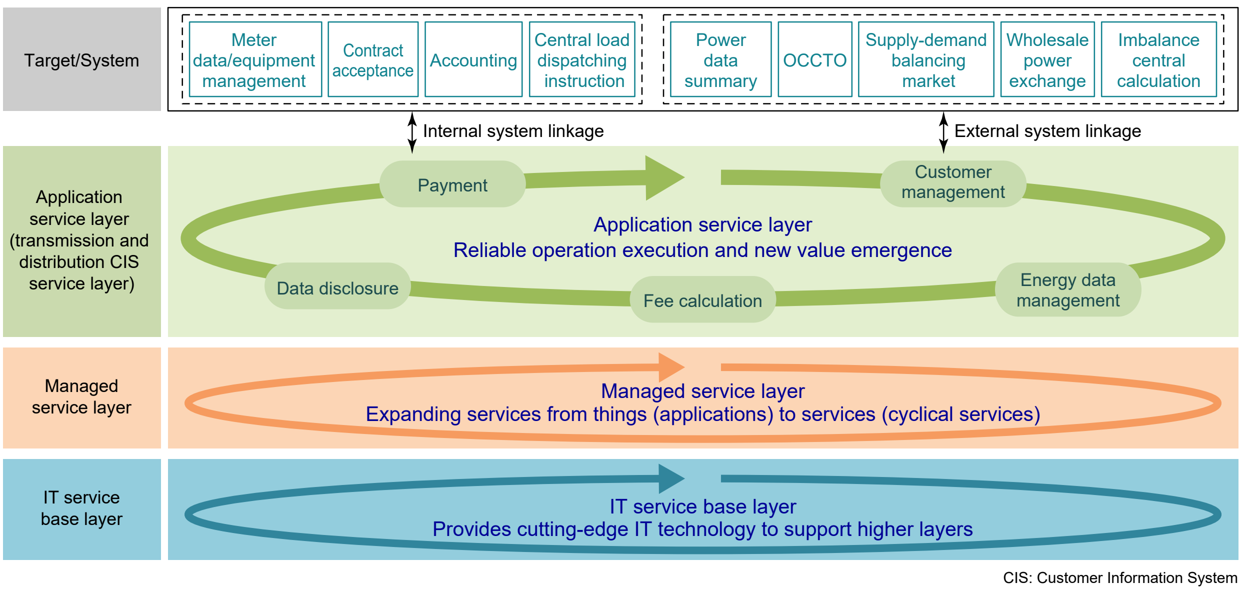


Fig. 4 Platform three-layer structure

Furthermore, the digital energy platform for transmission and distribution actively adopts global solutions in these service layers. In the recent evolution of IT technology, global IT service investment has been focused on the cloud and Software as a Service (SaaS), resulting in accelerated progress, and it is inefficient from both a management perspective and in terms of cost-effectiveness to achieve everything through in-house development. Therefore, it is necessary to provide value that previously could not be independently realized, by combining multiple solutions through alliances and other means. For the wheeling operations domain that is our current focus, we provide new value while holding down development costs and shortening development lead times. This is achieved by utilizing the latest IT technology of global solutions combined with the technology and knowledge gained from our current operations.

In the future, we aim to provide a service foundation for creating new businesses for TSOs by integrating and realizing visualization and sophisticated analysis of various types of operational information from TSOs, including information obtained from grid-related systems such as Distributed Energy Resource Management Systems (DERMS) and Supervisory Control and Data Acquisition (SCADA) systems.

3. Conclusion

This paper has described the three concepts of the digital energy platform for transmission and distribution: fit to standard, one-stop service delivery, and development of an ecosystem platform. Through the digital energy platform for transmission and distribution, we hope to provide an environment enabling creation of new value while realizing stable transmission and distribution operations, and contribute to implementing the next-generation transformation of transmission and distribution operations.

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Performance Evaluation of Newly Developed EIS/IIS Utilizing Digital Signal Processing

Authors: *Ryuki Tanaka*, Ryo Konishi*, Tetsushi Azuma**, Makoto Sasano**, Cheol Ho Pyeon****

Energy Systems Center, ** Advanced Technology R&D Center, * Kyoto University*

Abstract

Nuclear power generation is garnering attention as a way to realize a carbon-neutral society, and against that backdrop Mitsubishi Electric is developing new models of nuclear instrumentation equipment for Pressurized Water Reactors (PWR) that actively incorporate digital signal processing technology as a new approach, aiming for the sustainable development of nuclear power business in the future.

For the Ex-core Instrumentation System (EIS), signal processing with analog circuits has been the mainstream choice in order to apply specific processing methods to signals from neutron detectors. Amid that trend, we have achieved digitalization, which is rare, even globally.

For the In-core Instrumentation System (IIS), we have developed a signal processing unit compatible with Self Powered Neutron Detectors (SPND), which have not been previously applied in domestic PWRs, and confirmed that the specified performance can be achieved.

1. Introduction

Due to increasing demand for decarbonized power sources in recent years, global expectations have risen for construction of advanced nuclear reactors, particularly small modular reactor (SMR), for nuclear power plant. Mitsubishi Electric is participating in development of the SMR-300 small modular reactor by the US company Holtec International, and is in charge of equipment design of the Instrumentation and Control (I&C) system that handles reactor control and automation of operation(1). In the small modular reactor market, it is important to create economic advantages during construction as a factor differentiating from conventional large reactors. Therefore, we are promoting the development of I&C systems that actively incorporate digital technology with the aim of reducing initial costs and maintenance costs.

Among I&C systems, EIS and IIS, which have core monitoring functions, are two of the main instrumentation equipment (Fig. 1). The EIS contributes to reactor protection, monitoring, and control by measuring neutrons that leak from the reactor using neutron detectors installed around the reactor pressure vessel. The IIS enables monitoring the core in detail by measuring neutrons inside the reactor using neutron detectors installed inside the reactor core.

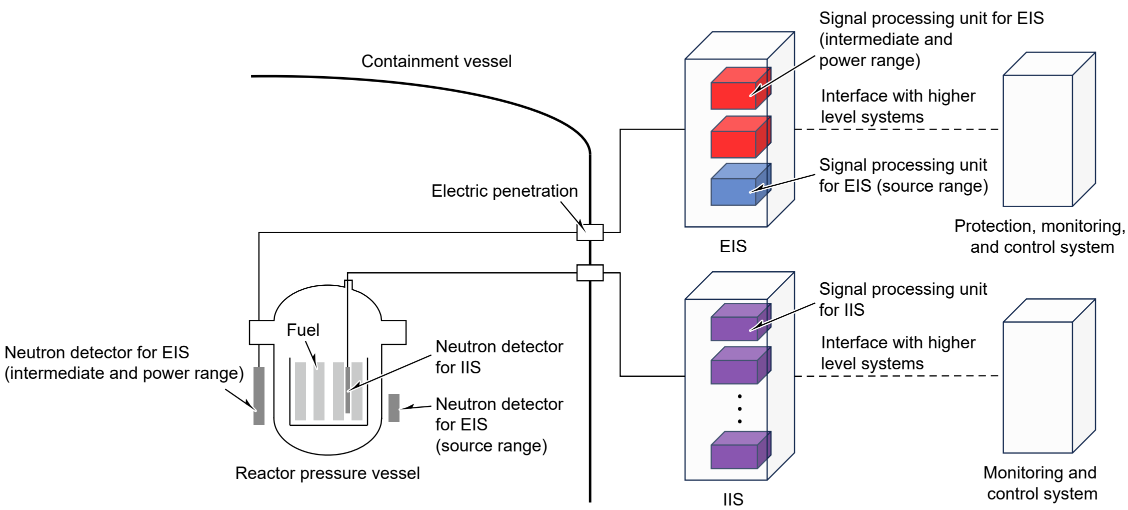


Fig. 1 System configuration of EIS and IIS

In small modular reactors overseas, there is a possibility of using neutron detectors and detection methods that differ from those in existing domestic PWRs for which Mitsubishi Electric has supplied equipment. In addition, there is a need to reduce construction and maintenance costs, including both existing domestic PWRs and advanced nuclear reactors, and to address these needs, we are developing new models of EIS/IIS that utilize digital technology[(2)].

2. Signal Processing and Digitalization in Nuclear Instrumentation System

In nuclear instrumentation system that monitors reactor power and status, signal processing of detector output signals is essential for measuring the neutron flux incident on neutron detectors installed inside or external to the reactor core.

2.1 Digitalization of signal processing methods and related issues

Conceptual diagrams of signal processing methods developed for nuclear instrumentation system and related issues are shown in Fig. 2 and Fig. 3.

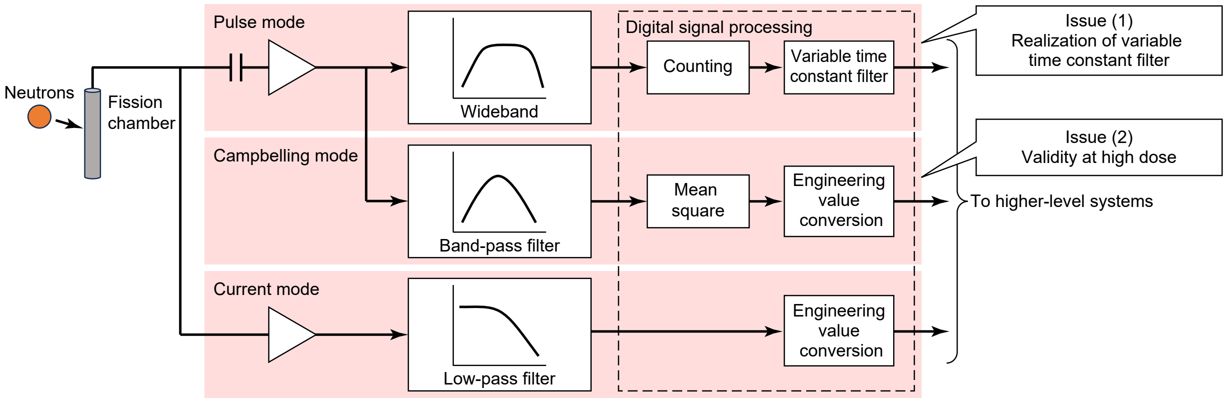


Fig. 2 Conceptual diagram of signal processing methods and issues for EIS

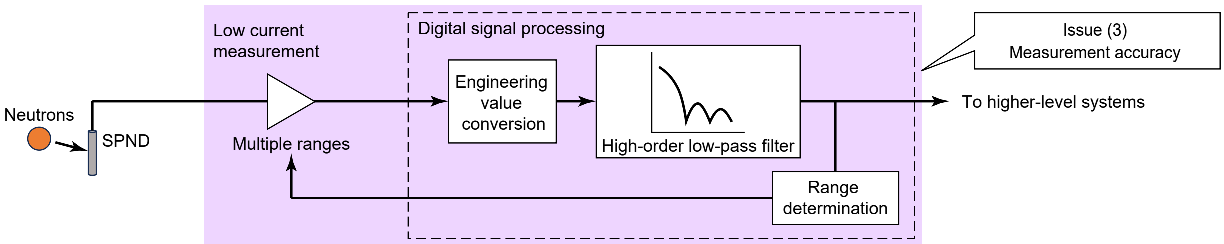


Fig. 3 Conceptual diagram of signal processing methods and issues for IIS

Neutron detectors for EIS include BF3 proportional counters, fission chambers, and uncompensated ionization chambers. Three different measurement methods are used according to neutron flux and detector characteristics: pulse mode, Campbelling mode, and current mode. Among these, digital signal processing technologies for pulse mode and Campbelling mode suitable for fission chambers were newly developed for EIS successor models. In realizing digital signal processing technologies suitable for both measurement methods, there are the following respective issues:

Issue (1) (pulse mode): Realization of digital filters (variable time constant filters) that meet required accuracy regardless of count rate

Issue (2) (Campbelling mode): Validation of signal processing methods for output signals from neutron detectors in high-dose-rate conditions

For IIS neutron detectors, top-mounted fixed in-core instrumentation that inserts SPNDs from the upper part of the reactor for improved safety has recently become mainstream in newly constructed PWRs. The detector signal range of SPNDs is typically small at approximately 1nA to 1μA and requires ensuring accuracy over a wide dynamic range. Therefore, IIS compatible with SPNDs has the following issue:

Issue (3) (low current measurement): Ensuring measurement accuracy suitable for low current applications and achieving the required dynamic range.

These issues and their corresponding solutions are described in detail in sections 2.2, 2.3, and 2.4.

2.2 Approach to Issue (1) (pulse mode): Modeling of analog circuits and recurrence formula expression

With pulse mode, a count rate proportional to reactor power is obtained by determining the number of pulse signals generated when neutrons react in the detector. However, signals occur randomly, so when signal occurrence frequency is low, variations in count rate become large during short-term measurements, and that is unsuitable for reactor protection and monitoring. Therefore, with the typical pulse mode in EIS, processing is performed while varying the time constant so that the standard deviation meets the required accuracy regardless of the magnitude of the count rate. Mitsubishi Electric has previously realized this processing using a dedicated analog circuit (logarithmic amplifier) that utilizes the exponential characteristics of transistors. This also has the characteristic of fast response when changing from low count rates to high count rates.

When digitalizing the pulse mode, the issue was to reproduce characteristics similar to the aforementioned logarithmic amplifier through digital signal processing. Therefore, digitalization was achieved by modeling the analog circuit of a logarithmic amplifier using ideal transistors and expressing the relationship between input and output as a recurrence formula for minute steps (Fig. 4)[(3)].

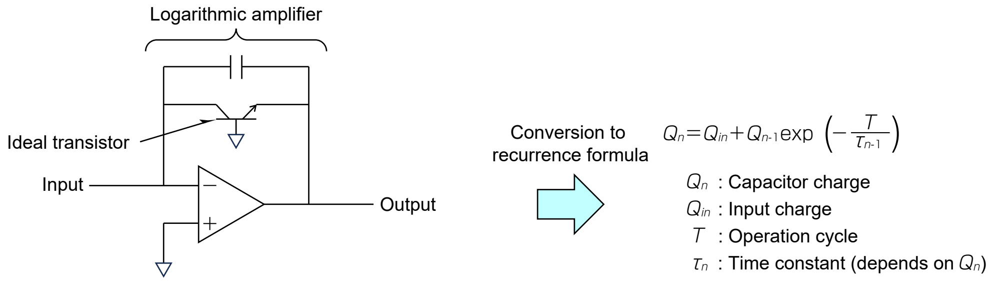


Fig. 4 Modeling of logarithmic amplifier analog circuit

2.3 Approach to Issue (2) (Campbelling mode): Model-based design enabling system verification

In developing EIS and IIS, evaluation using actual signals is difficult because measurements in high neutron irradiation fields cannot be easily performed. Since the detector signals are also complex, conventional methods for EIS digitalization design validity in particular could only perform static confirmation using normal test environments or simulated signals, and that was a hurdle for the development and verification of signal processing methods.

Therefore, model-based design was applied to reproduce neutron detectors, analog circuits, digital signal processing, and even higher-level control and monitoring systems in digital space (MATLAB/Simulink)*1 (Fig. 5). This enabled not only efficiency improvements in implementation design and the development process for digital signal processing methods, but also system-level validation. Dynamic and high-dose simulated signal confirmation, which could not be performed until the actual equipment test stage, was implemented at the design stage, confirming the validity of signal processing logic including the Campbelling mode for EIS, which had previously been an issue.

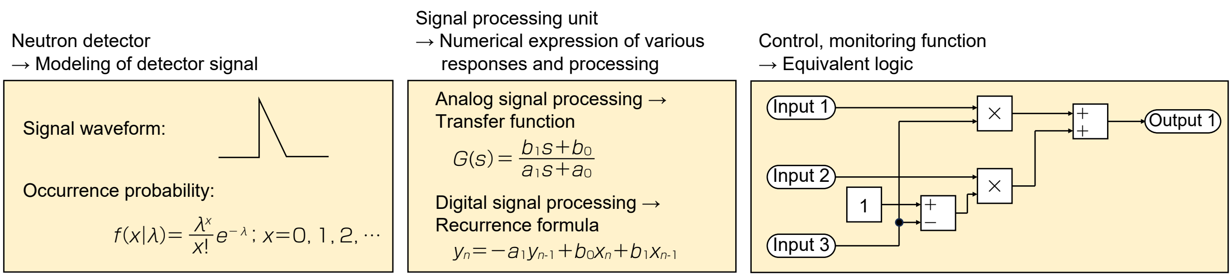


Fig. 5 Application of model-based design

*1 MATLAB and Simulink are registered trademarks of The MathWorks, Inc.

2.4 Approach to Issue (3) (low current measurement): Application of automatic range switching method

To ensure measurement accuracy corresponding to the required dynamic range while targeting low currents for measurement, an automatic range switching method was developed that continuously measures while appropriately switching the amplification factor of the first-stage amplification circuit.

Generally, in low current measurement circuits that ensure high accuracy, a long time that cannot be ignored in measurement is required until the output voltage settles, when the amplification factor of the first-stage amplification circuit is switched. With the developed method, this settling time was significantly shortened through analog circuit innovation, and continuous measurement was achieved by digital-signal filtering of short-term data immediately after switching[4].

3. Miniaturization of Nuclear Instrumentation Equipment through Digitalization

Signal processing units for EIS and IIS were each prototyped. These units employed the digital signal processing logic described in section 2.3 (Fig. 6 and Fig. 7). The board area required for signal processing circuits was significantly reduced by implementing the signal processing logic in one computing element (Field Programmable Gate Array (FPGA)). This enabled the signal processing circuits, the main elements of nuclear instrumentation equipment, to be consolidated into a single unit, realizing miniaturization of nuclear instrumentation equipment.

Fig. 6 Prototype of signal processing unit for EIS

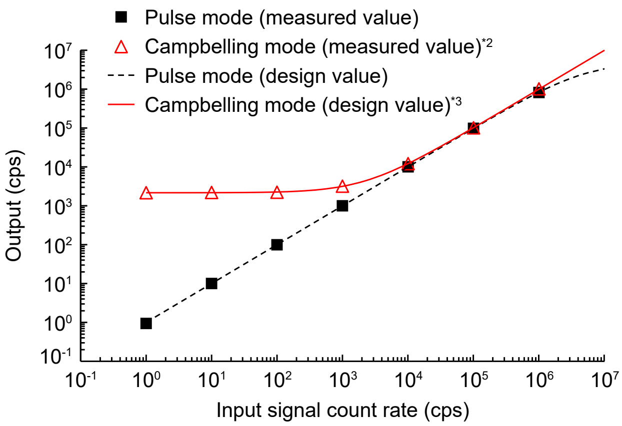
Fig. 7 Prototype of signal processing unit for IIS

4. Performance Evaluation and Validity Confirmation

Performance of the signal processing units was evaluated by inputting simulated signals to the prototypes. Results were obtained where measured values matched well with design values, as described in section 4.2. This confirmed validity of the digital signal processing logic and feasibility as a product.

4.1 Evaluation results for EIS signal processing unit

The input/output characteristics of pulse mode and Campbelling mode are shown in Fig. 8, and the evaluation results of the time constant in the pulse mode are shown in Fig. 9. The generation probability of input signals was set to a Poisson distribution with count rates of 1cps (count per second), 10cps, ..., or 10^6cps. As a result, linearity was obtained in the expected range for input/output characteristics, and for response time, response was confirmed to be proportional to the reciprocal of the count rate as designed.



*2 Corrected based on input signal of 1×10^6cps
*3 Measured value (at input of 1cps) is added as offset

Fig. 8 Evaluation results for input/output characteristics

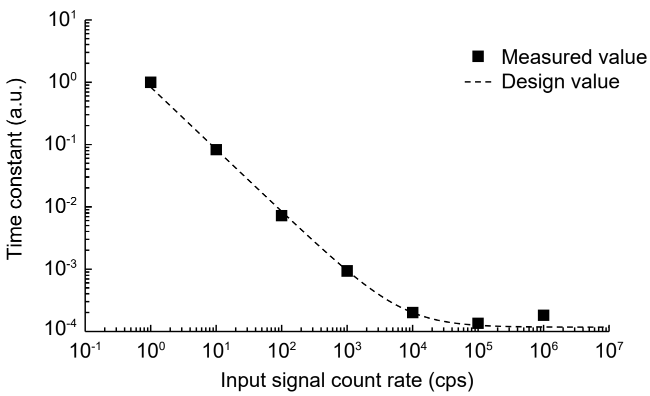


Fig. 9 Evaluation results for response time of pulse mode

4.2 Evaluation results for IIS signal processing unit

To evaluate the automatic range switching function implemented with digital signal processing, current source input was used, and the calculation results inside the unit were recorded when the amplification factor of the analog circuit switched from high range to low range due to range switching (Fig. 10). The output before and after range switching was seamless, which confirmed the effectiveness of the automatic range switching function.

Also, the attenuation amount representing the filter effect for AC signals at 5 to 25Hz was evaluated as an evaluation of the noise removal performance of the high-order low-pass filter (Fig. 11). The attenuation amounts at the measured frequencies matched well with the design values that considered the characteristics of both the analog and digital filters, confirming that the filter with high noise removal performance functioned as designed.

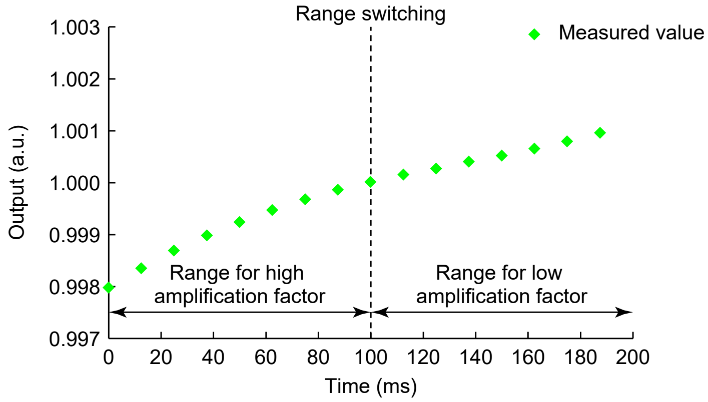


Fig. 10 Evaluation results for automatic range switching function

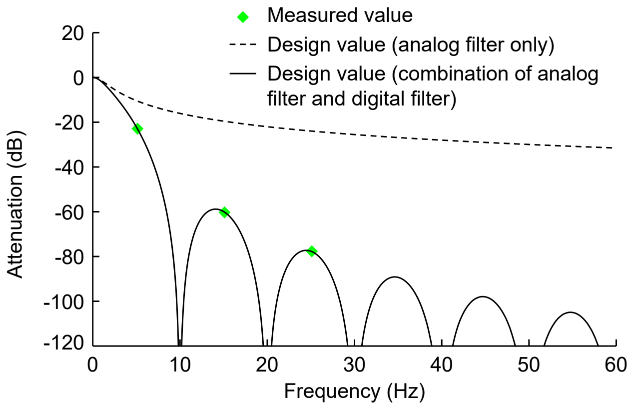


Fig. 11 Evaluation results for high-order low-pass filter

5. Conclusion

This paper has described the developed signal processing technology and its evaluation results, as performance evaluation for the new model of nuclear instrumentation system equipment. By applying this newly developed digital signal processing technology, it will be possible to realize equipment suitable for advanced nuclear reactors. Since validity of basic performance has been confirmed, we will proceed with environmental testing and acquisition of US certification in the future, and advance development toward commercialization.

Also, for the purpose of evaluating characteristics of neutron detectors used in IIS, neutron irradiation tests(5) using the Kyoto University Research Reactor are being conducted through joint research with Kyoto University, and evaluation is being performed using the signal processing units described in this paper. Similarly, experiments using the same research reactor are planned for evaluating measurement methods for EIS. We plan to describe these results in another paper.

Some of the results related to IIS described in this paper were obtained as a result of the Ministry of Economy, Trade and Industry's "Nuclear Industry Infrastructure Strengthening Project."

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GIS Initiatives to Address the Diversification and Advancement of Digital Data

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Abstract

To address issues relating to social infrastructure such as deteriorating equipment, intensification of natural disasters, and increasing grid complexity, there is a need to comprehensively analyze and visualize location information and spatial information (information related to temporal changes in location information) on digital maps, and to efficiently raise the level of equipment maintenance, resilience response, power system design, and so forth. In addition to the above items, Mitsubishi Electric provides a Geographic Information System (GIS) that supports new data types such as 3D and point cloud data.

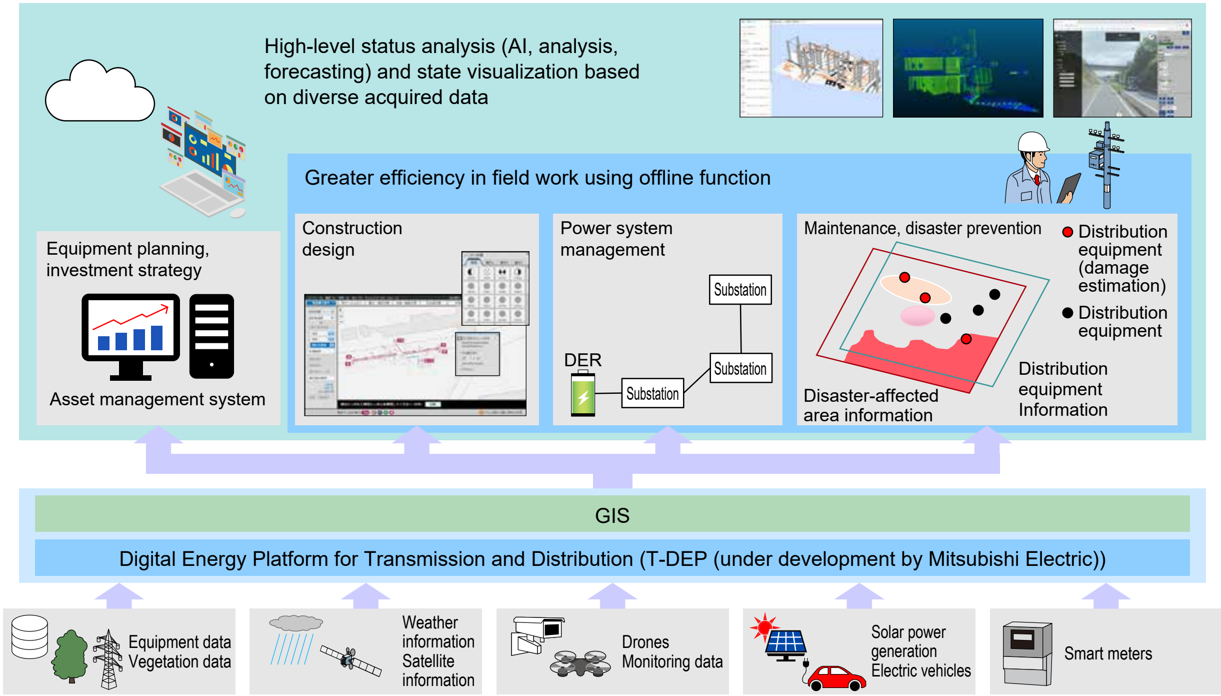
1. Introduction

Transmission and distribution operations of power companies are facing a changing environment in light of carbon neutrality, and there is a need to deploy services to diverse players through dissemination of renewable energy and utilization of power data. The issues faced include proliferation and increasing sophistication of contracts and resource management accompanying the spread of renewable energy, rapid response during disasters, and decreasing numbers of field technicians.

To address these issues, Mitsubishi Electric is developing solutions for solving social issues, such as the utilization of Internet of Things (IoT) technology and smart devices, adoption of initial response support systems employing satellite images and drones to support rapid response during disasters, and the development of systems to visualize and manage such information.

The role of GIS is becoming increasingly important for effectively supporting these solutions. GIS enables various types of data processing and management, map creation, and analysis, and by overlaying and visualizing these data, it realizes efficiency improvement in field operations and acceleration of disaster response (Fig. 1). Moreover, linkage with IoT technology and smart devices will enable real-time data sharing and visualization, and this is expected to greatly contribute to higher work efficiency.

In promoting these initiatives, there will be an even greater need going forward for diverse digital data and ease of linkage with other systems. This paper describes the technical issues and solution methods, as well as future prospects, for the GIS that needs to be expanded toward next-generation systems.



DER: Distributed Energy Resources, T-DEP: Transmission and Distribution-Digital Energy Platform

Fig. 1 Sectors using GIS

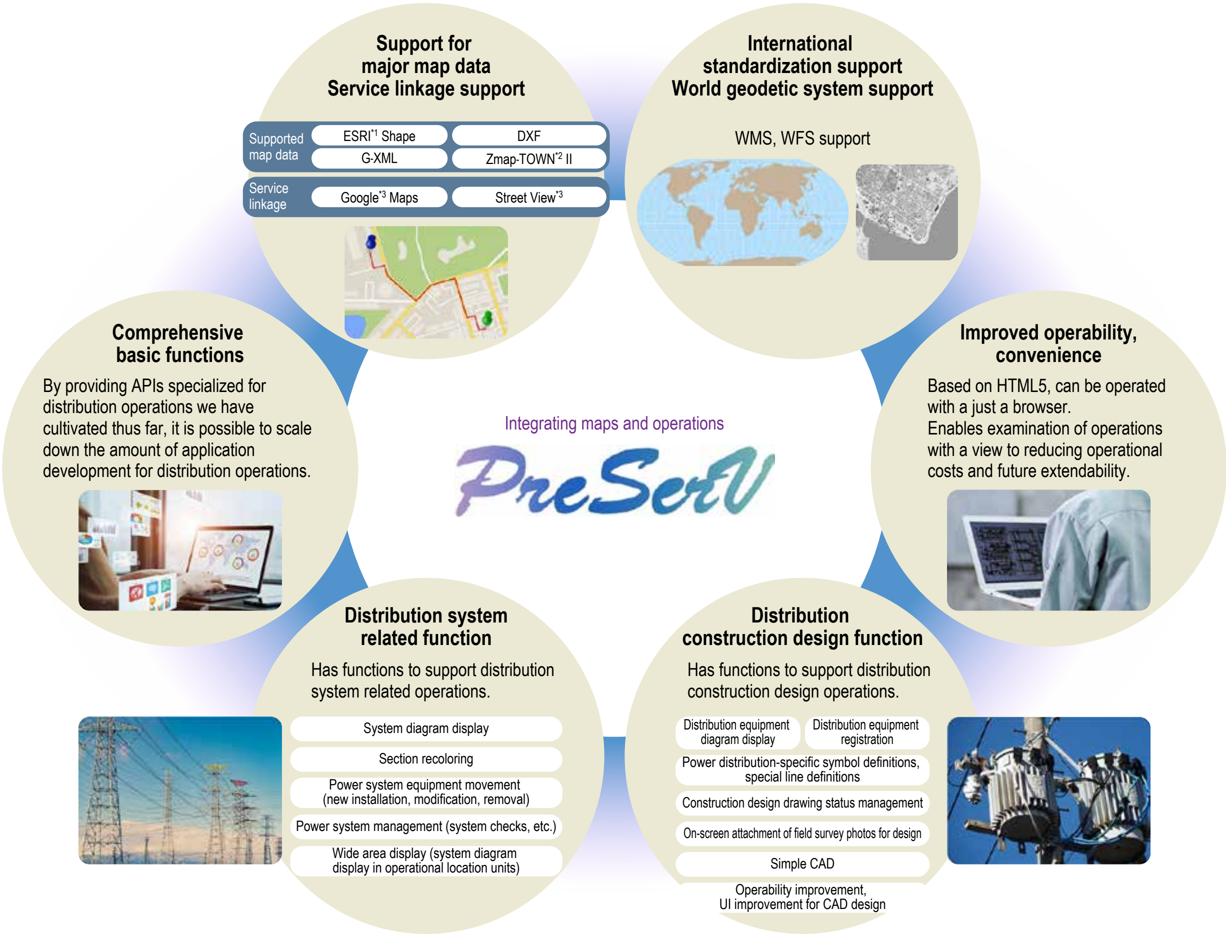
2. GIS

GIS is an information system technology that handles data with various types of information on locations, on electronic maps. In this field in recent years, there has been a need to respond to diversification and increasing sophistication of data types. Within that trend, utilization of 3D data and point cloud data is attracting particular attention, and they are expected to contribute to efficiency improvements in equipment maintenance, disaster response, and power system management.

This chapter describes the development situation to date and future initiatives for PreSerV-X, a GIS that we are developing for the purpose of improving the efficiency of operations utilizing maps at power companies.

2.1 Overview of PreSerV-X

PreSerV(1) is a GIS product developed by Mitsubishi Electric. It has been adopted at social infrastructure-related companies—mainly power companies and government agencies—and local governments. This product has a 30-year history since its initial release and has evolved while responding to various technologies and standardization. In the current latest model PreSerV-X, functions specialized for the distribution field are provided, by leveraging past development achievements, to improve productivity in field operations and efficiency of system development (Fig. 2).



WMS: Web Map Service, WFS: Web Feature Service, API: Application Programming Interface, UI: User Interface
*1 ESRI is a registered trademark of Environmental Systems Research Institute, Inc.
*2 Zmap-TOWN is a registered trademark of ZENRIN CO., LTD.
*3 Google and Street View are registered trademarks of Google LLC.

Fig. 2 Product concept of PreSerV-X

We have been working on adding new functions of PreSerV-X as a state-of-the-art GIS, to differentiate it from other companies' products. One function developed in recent years is the offline function. "Offline function" refers to achieving functionality equivalent to that in an online environment without using communications.

In power transmission and distribution operations, work is often performed in mountainous areas where communication is difficult, so a function that does not require communication is vital. The offline functionality developed by Mitsubishi Electric utilizes technology compliant with HyperText Markup Language (HTML) Living Standard, an HTML specification established by an organization called Web Hypertext Application Technology Working Group (WHATWG). This enables realization of functions and performance assurance on a par with online operation using only a web browser. This function is expected to further improve the efficiency of field operations. The system configuration is shown in Fig. 3.

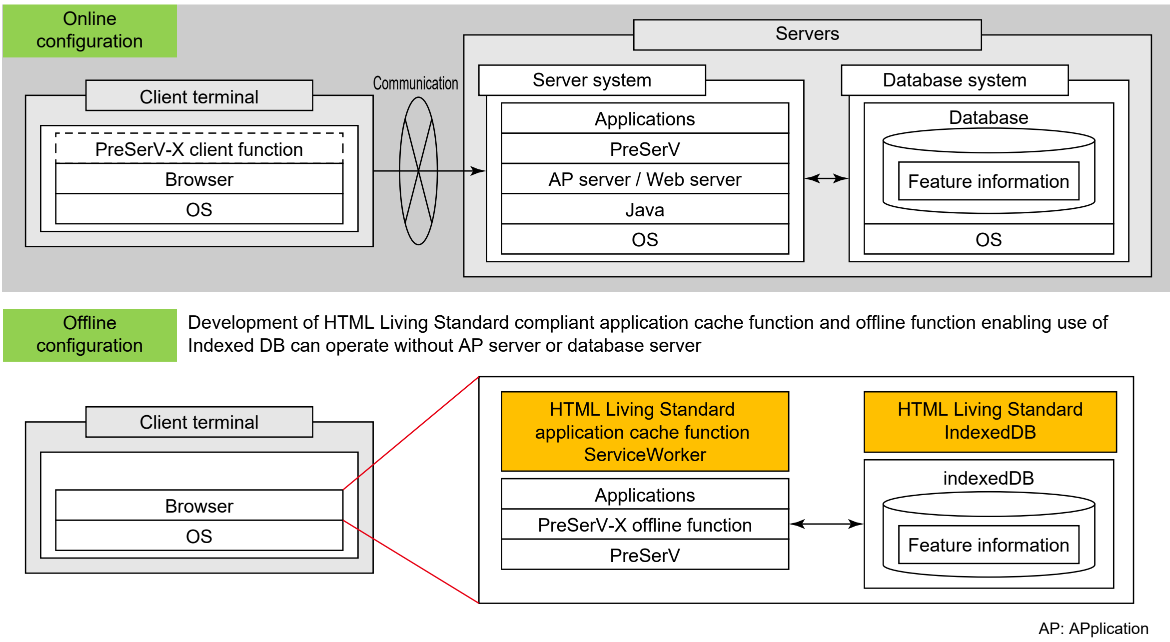


Fig. 3 System configuration of offline function

2.2 PreServ-X expansion areas

The current PreSerV-X supports 2D equipment data, vector data (a data format that represents map information through combination of points, lines, and surfaces), and raster data (a map data format with information in pixel units). There is a need for expansion of compatible data types, and in PreSerV-X development, we are developing international standard interface support and linkage with GIS made by other companies. Developing these functions will enable API enhancement for open data and real-time data acquisition, 3D and point cloud display, and more. We also achieve greater development efficiency by maintaining the APIs specialized for power distribution operations while supplementing deficient areas through linkage with GIS made by other companies. Furthermore, we are also looking to link with other packages made by our company such as BLEnDer and INFOPRISM by supporting data diversification and API enhancement. BLEnDer refers to Mitsubishi Electric's power Information and Communication Technology (ICT) solution package, the BLEnDer series, and INFOPRISM refers to our IoT platform for power and social infrastructure, which consists of hardware for easily and quickly constructing solutions utilizing IoT, and a software suite including analysis functions.

2.2.1 International standard interface support

In this development, we have implemented WFS/WMS support for international standard interface compatibility. WFS is an international standard defined by the Open Geospatial Consortium (OGC) for providing geographic feature data (physical objects, such as railways, roads, and street trees, as well as non-physical objects like boundary lines, place names, and bus routes, that appear on maps) via the web. We developed functionality to receive feature data from sources such as GIS made by other companies and manage it together with PreSerV-X managed feature data, and this made it possible to overlay feature data managed by GIS made by other companies, and display it on maps.

WMS is an international standard defined by OGC for providing map images via the web. Through linkage with Google Maps, we are developing a function that accesses Google servers via WMS and displays maps composed of acquired raster data, providing support for road maps and satellite imagery. Google Maps API enables the acquisition of map data in various formats. We examined a Google Maps API and ensured integration feasibility by leveraging our development track record from the previous years to support maps of the Geospatial Information Authority of Japan.

By supporting these international standards, we expanded the methods for acquiring map data and feature data of diverse data types.

2.2.2 Examination of linkage with GIS made by other companies

To respond to the recent growing need for sophisticated displays such as 3D and point clouds, as well as for analysis utilizing such data, we must compensate in deficient areas with GIS made by other companies that have advanced display and data analysis functions. Therefore, PreServ-X aims to provide new value through a combination of existing functions with functions from products of other companies. This will be done by managing diverse data and strengthening linkage with GIS made by other companies.

Data integration becomes a crucial point when considering linkage with GIS made by other companies. Realization of data linkage enables data sharing, integration, and utilization, and promises enhancement of data information content, improved ease of data management, and API linkage.

However, data linkage involves technical challenges. Since database management configurations and security measures differ between systems, it is necessary to study data management key linkage methods and data exchange methods. Non-functional issues also become apparent when handling large volumes of data. Furthermore, increased security risks are also a concern.

To address these issues, PreSerV-X is working on ensuring feasibility through support for major middleware and utilization of web services. Going forward, we will realize linkage by deepening our examination of countermeasures not only for functional issues but also for non-functional issues related to quality and performance.

3. Future Prospects

As transmission and distribution operations become more sophisticated, demand for GIS utilization is expected to increase for analysis functions used in equipment planning and for disaster response. Therefore, for PreSerV-X we are examining the coexistence of distribution operation-specific APIs and efficient data management mechanisms to serve as differentiators from other companies—approaches developed in our past development—with the sophisticated display and analysis APIs of GIS made by other companies. To realize these goals, it is necessary to consider database linkage, development of interfaces enabling direct data reference, and API linkage methods.

We are also continuing development of interfaces that can support international standards and major services in order to provide compatibility with diverse data types. In recent years, public institutions, research institutions such as universities, private companies, and others have started actively utilizing and providing open data. We will strive for the enhancement of PreSerV-X as a highly versatile GIS platform that can seamlessly incorporate these resources (Fig. 4).

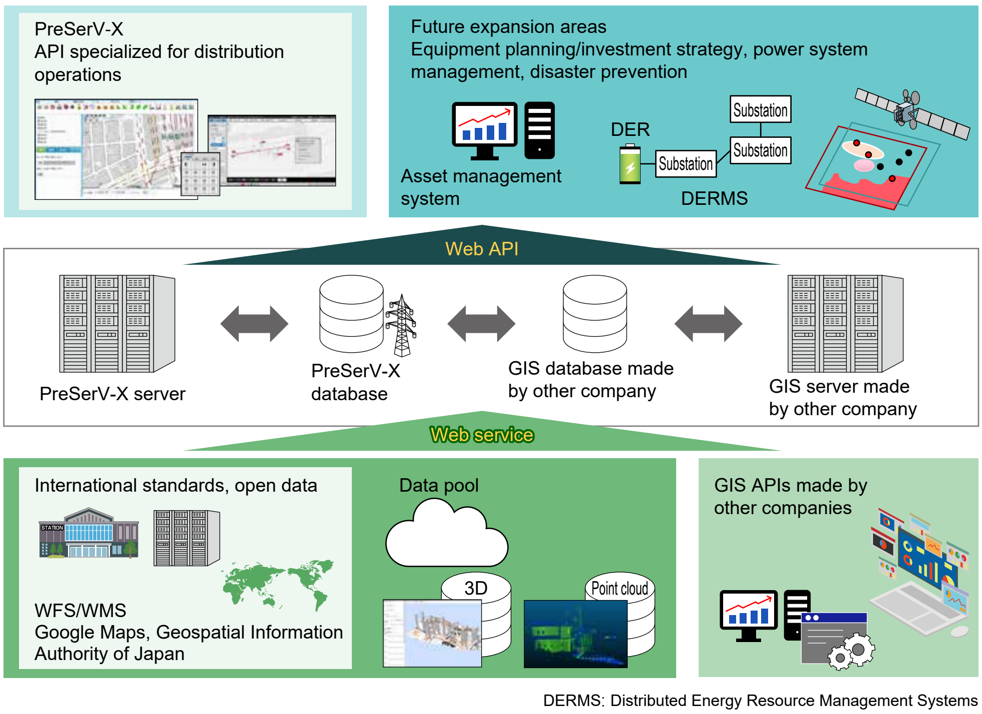


Fig. 4 Future prospects

4. Conclusion

This paper has described the overall picture and future prospects of PreSerV-X, the GIS offered by Mitsubishi Electric. By developing interfaces that support international standards and are linked with GIS made by other companies, we will enhance the ease of linkage with other systems, expand functionality to enable handling of diverse digital data, and look toward global expansion and development into solution businesses.

Also, this initiative aligns with the transformation toward circular digital engineering that our corporate group is promoting. With a view to linkage with “Serendie,” our company’s digital platform, we will enhance the versatility of PreSerV-X as a component of circular digital engineering so it can be adapted to data aggregation and utilization.

Reference

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DC High-Speed Circuit Breaker for Rolling Stock

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Abstract

Rolling stock powered by direct current are equipped with DC high-speed circuit breakers to protect electrical equipment from short-circuit faults and overcurrent. Based on the DC high-speed circuit breaking technology using air circuit breakers cultivated for DC high-speed circuit breakers(1)(2) for railway substations developed in fiscal 2016, Mitsubishi Electric has developed and commercialized on-board DC high-speed circuit breakers for rolling stock that achieve excellent high-speed breaking performance and maintenance performance, as well as weight reduction.

1. Introduction

Either AC or DC is used for the current that serves as the power source for rolling stock, depending on the power supply system. Compared to AC, DC requires higher construction costs due to installation of more substations, but it can reduce rolling stock costs thanks to simplified on-board power equipment. Therefore, DC power supply systems have been widely adopted in urban areas where there are many railcars per area. On the other hand, most of the power grid outside of railways consists of AC, and one reason for this is that DC current breaking is difficult. When faults such as short circuits occur in DC circuits, the current increases over time and the current zero point necessary for breaking does not naturally occur, making current breaking increasingly difficult as time passes. Therefore, it is important to break DC at high speed, and DC high-speed circuit breakers (hereinafter referred to as "HB") that forcibly create a current zero point through current-limiting effects play this role. Mitsubishi Electric developed DC high-speed circuit breakers for railway substations (maximum breaking capacity 100kA) in fiscal 2016(1)(2), and recently has developed on-board DC high-speed circuit breakers for rolling stock (hereinafter referred to as "TC-type HB", maximum breaking capacity 30kA) that operate in the same power system. Due to the release of these two circuit breakers as products, it is now possible to provide fault current protection for the entire railway DC circuit. The TC-type HB product concept is shown in Fig. 1.

Reliability	Improved current breaking performance · Short-circuit current cut-off current reduced through high-speed current-limiting technology · Critical current arc time reduced through arc drive technology
Maintainability	Reduced maintenance time · Minimization of lubrication points. Disassembly is unnecessary for lubrication work · No use of parts requiring periodic replacement such as dampers
Light weight	Breaker weight reduction · Product volume and weight reduced through structure optimization of arc chute

Fig. 1 TC-type HB product concept

The TC-type HB product was developed based on the concept of improving reliability and maintainability, and lightening weight. Since short-circuit current in DC circuits increases over time, it is crucial to quickly break the current before it increases in order to reduce the burden on electrically connected equipment. With high-speed breaking performance achieved, the TC-type HB keeps the cutoff current (current peak value) of short-circuit current low, making it a highly reliable circuit breaker. Also, the number of lubrication points during maintenance has been reduced through structural optimization and adoption of oilless bearings, and the structural design enables lubrication without requiring disassembly, thereby improving maintainability. Furthermore, product volume and weight have been reduced by optimizing the structure of the arc chute that extinguishes arcs in air during current breaking.

This paper describes the features and applied technologies of the TC-type HB, focusing primarily on high-speed breaking technology.

2. Ratings and Structure

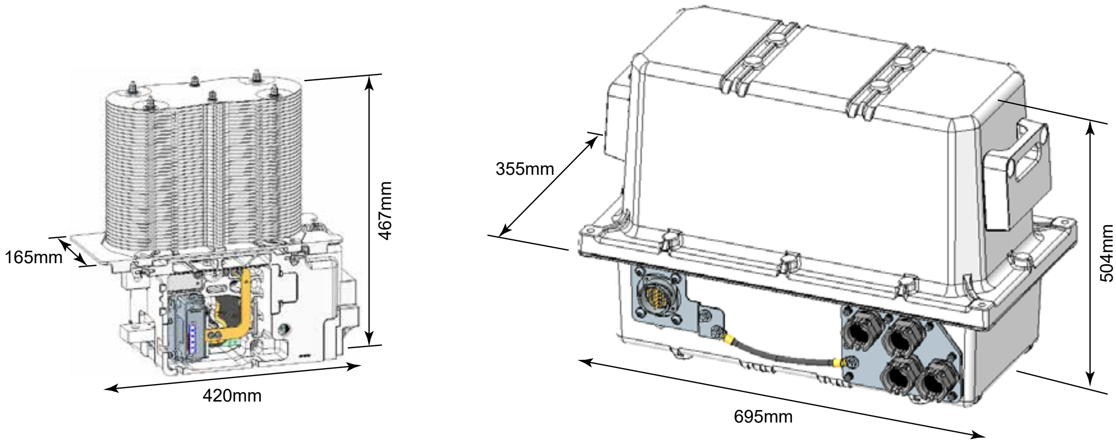
Ratings of the TC-type HB are shown in Table 1. The rated operational voltage is DC 1,800V. The rated operational current is 1,000A. The rated short-circuit making and breaking capacity can handle up to a maximum of 30kA. The over-current release mechanism, which opens the main contacts to initiate current breaking when overcurrent flows in the main circuit, enables free setting of overcurrent setting values in the range of 600 to 3,200A, even after product shipment, by making the return load variable.

Table 1 Ratings of the TC-type HB

Item	Specification
Model	18-TC-10
Rated operational voltage (V_{DC})	1,800
Rated operational current (A)	1,000
Mechanical switching service life (times)	200,000
Load switching service life (times)	800
Rated short-circuit making and breaking capacity / time constant (kA/ms)	18/0*1
	30/15
	30/40
	30/100
Current setting value of over-current release mechanism (min. to max.) (A)	600-3,200
Rated impulse withstand voltage (kV)	18

*1 Time constant 0 is the condition where no reactor is connected to the circuit

The TC-type HB has an optional lineup of enclosures that house the circuit breaker. Figure 2(a) shows the structural diagram of specifications without enclosure, and Fig. 2(b) shows specifications with enclosure. The material of the enclosure and main body molded frame is unsaturated polyester. This meets the incombustibility requirements of the rolling stock material combustion test as a flame retardancy as well as European railway standard EN45545-2:2013 R23/HL3. The TC-type HB with enclosure specifications is intended to be mounted under the floor or above the ceiling in rolling stock and connected to electrical circuits, thereby preventing collision and intrusion of foreign objects into the TC-type HB from the outside, and protecting surrounding equipment from arc gas generated during current breaking.



(a) Specifications without enclosure (b) Specifications with enclosure

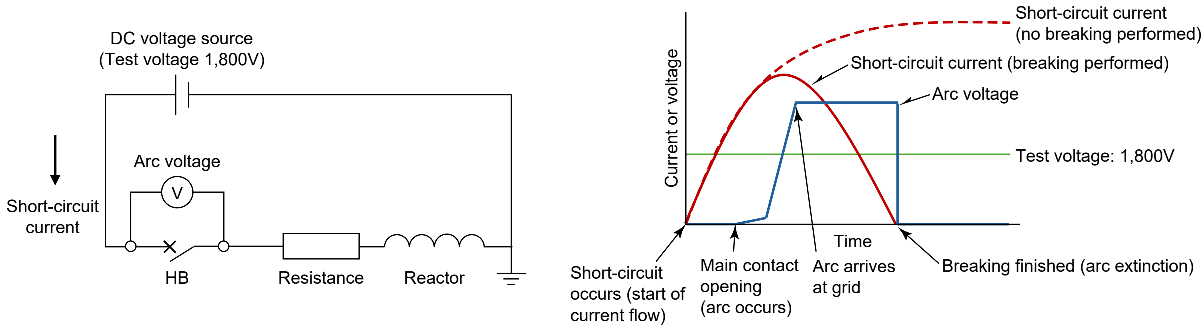
Fig. 2 Structure diagram of TC-type HB

3. TC-type HB Circuit Breaking Technology

This section describes the principles and applied technology for the TC-type HB to break DC, and the breaking performance for short-circuit current and critical current.

3.1 DC breaking principle and applied technology

TC-type HB is an air circuit breaker that breaks DC by current-limiting action. To explain the breaking principle, Fig. 3(a) shows a short-circuit test circuit diagram, and Fig. 3(b) shows a current breaking characteristic diagram. A DC 1,800V test voltage is applied to the short-circuit test circuit, and short-circuit current flows when the main contact of the HB closes. When the main contacts of the HB are opened while current is flowing, an arc occurs between the main contacts. The arc generates arc voltage in the opposite direction to the voltage source (direction that attenuates the short-circuit current) between the main contacts of the HB according to the length of the discharge path and the number and physical properties of the discharge electrodes. By maintaining arc voltage higher than the test voltage, DC current can be current-limited and broken. The TC-type HB performs the process from short-circuit occurrence to completion of breaking at high speed, suppressing the maximum value and time span of short-circuit current.



(a) Short-circuit test circuit diagram (b) Current breaking characteristic diagram

Fig. 3 Diagram of breaking principle of DC breaker

Figure 4(a) is a detailed diagram of the entire TC-type HB. The TC-type HB breaks short-circuit current through four processes: (1) fault detection, (2) main contact opening, (3) arc travel, and (4) arc extinction. This section describes the short-circuit current breaking process and breaking technology.

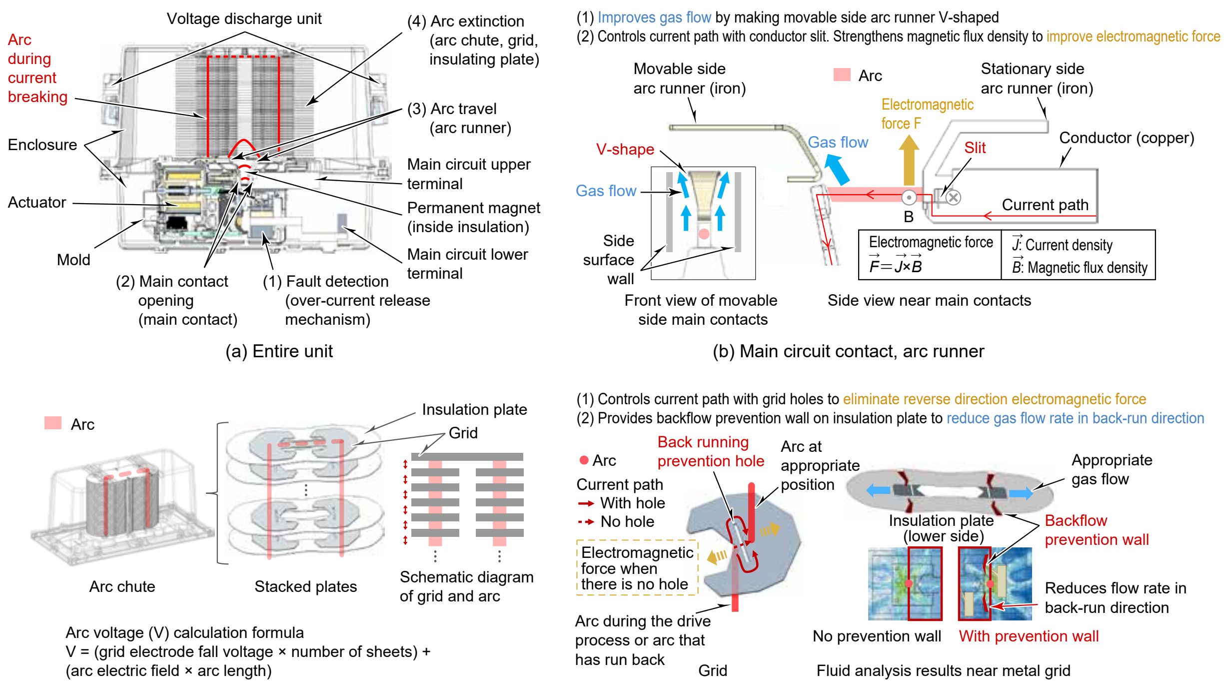


Fig. 4 Detailed diagram of TC-type HB

(1) Fault detection

The HB has a built-in over-current release mechanism, and when the main circuit current exceeds a preset current value, a release device configured as an electromagnet operates to transition the circuit breaker to the open state. In the TC-type HB, high-speed opening operation was achieved by optimizing the magnetic driving force of the electromagnet and reducing the weight of moving parts.

(2) Main contact opening

When opening and closing in the state where main circuit voltage is applied, there is a risk that main contacts fuse due to arcing between them. For the TC-type HB, we have demonstrated that fusing can be prevented by using different contact materials for the movable and stationary sides of the main contacts, and we have thereby achieved a shorter opening time by preventing fusing.

(3) Arc travel

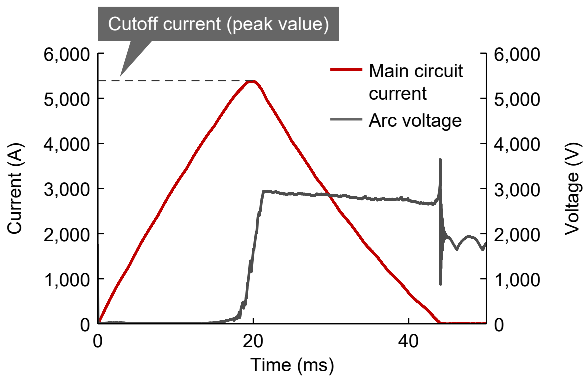
The arc generated between contacts is transferred from the arc initiation point to the arc runner and extends into the arc chute while moving along the arc runner to the tip. For high-speed breaking, it is necessary to quickly guide the arc into the arc chute. The TC-type HB has achieved faster arc drive by increasing electromagnetic force through slitting the main circuit conductor and increasing gas flow with the V-shaped arc runner (Fig. 4(b)).

(4) Arc extinction

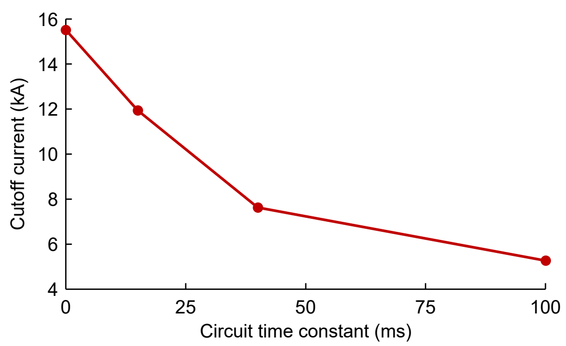
The arc that reaches the arc chute is confined to the grid, maximizing the arc voltage and breaking the current through current-limiting action (Fig. 4(c)). In the TC-type HB, backflow prevention holes are provided in the grid to control the current path within the grid, preventing generation of electromagnetic forces that hinder arc extension (Fig. 4(d)). Also, prevention walls are provided on the insulation plates to control gas flow paths, reducing gas flow in directions that hinder arc extension and achieving faster current breaking through arc voltage stabilization.

3.2 Short-circuit current breaking performance

Figure 5(a) shows the breaking current waveform from short-circuit test results of the TC-type HB, and Fig. 5(b) shows cutoff currents extracted from breaking test results under various test conditions. The breaking current waveform demonstrates that the HB's arc voltage rises steeply when the main circuit current increases and the arc voltage is maintained at a level higher than the power source voltage of 1,800V, thus completing the breaking process before the main circuit current reaches the breaking capacity of 30kA. The arc voltage waveform is smooth without sudden voltage drops, and thus the arc is controlled to a state suitable for current breaking, ensuring a stable breaking performance. Furthermore, the cutoff current characteristics show that currents with circuit time constants from 0 to 100ms can be interrupted.



(a) Breaking current waveform
(test voltage 1,800V, breaking capacity 30kA,
time constant 100ms)



(b) Cutoff current characteristic

Fig. 5 Short-circuit test results for TC-type HB

3.3 Critical current breaking performance

The HB breaks current by extending the arc to raise the arc voltage higher than the power source voltage. The main driving force for arc extension is electromagnetic force, but at critical currents (100 to 1,000A) are weak, so the generated electromagnetic force is also weak, therefore the arc does not extend sufficiently, resulting in breaking difficulties. In the TC-type HB, permanent magnets are installed inside the mold on the contact side surface to secure the electromagnetic force necessary for critical current breaking in the forward direction (current direction from the upper terminal to the lower terminal), thus achieving high-speed breaking for critical current breaking. Figure 6 shows the forward direction critical current breaking test results. Although the permanent magnets act disadvantageously for critical current breaking in the reverse direction (current direction from the lower terminal to the upper terminal), sufficient breaking performance was secured for the reverse direction critical current (600 to 1,000A) of the product specification.

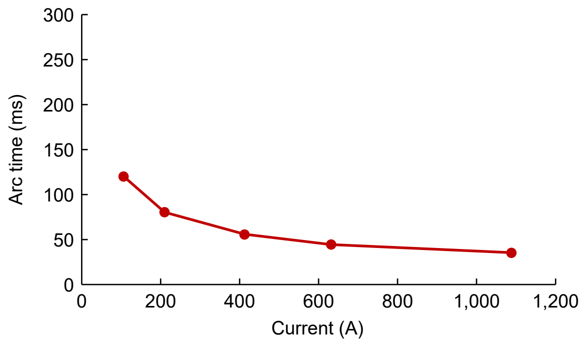


Fig. 6 Critical current breaking test results for TC-type HB (forward direction)

4. Conformity with Market Requirements

This section describes the features of the TC-type HB meeting market requirements.

4.1 Improved maintenance performance

General HBs require lubrication at multiple points during periodic inspections and this involves disassembly work, so a lot of time is required for maintenance. The TC-type HB employs oilless bearings for the mechanism's sliding parts, reducing lubrication points and enabling lubrication without disassembly. Maintenance performance is also improved by not using components that require periodic replacement such as dampers, eliminating replacement work.

4.2 Weight reduction

For the TC-type HB, we succeeded in reducing the weight of the grids and insulation plates that constitute the arc chute by optimizing the structure necessary for current breaking. Figure 7(a) shows the structure diagram of the arc chute stacked plates and arc chute of the TC-type HB, and Fig. 7(b) shows the structure diagram of the arc chute stacked plates and arc chute of a general HB. The TC-type HB reduces the volume of grids and insulation plates compared to general HBs (part indicated in red in the figure). As a result, the TC-type HB weighs 32kg, a 20% weight reduction compared to the development target of 40kg for HB weight (referring to products distributed in the market). Weight reduction of HBs contributes to improved workability and energy saving in rolling stock operation.

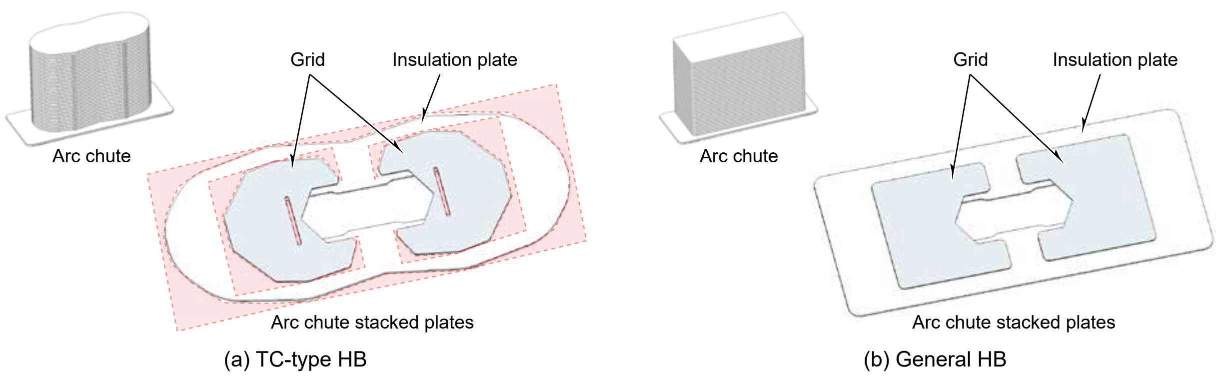


Fig. 7 Structure diagrams of arc chute stacked plates and arc chute

5. Conclusion

We have developed and commercialized on-board DC high-speed circuit breakers for rolling stock that excel in high-speed breaking performance and maintenance performance, and achieve weight reduction. In recent years, high-voltage DC transmission (HVDC), DC microgrids, and similar technologies, which leverage the superior transmission efficiency of DC, have been realized, and the use of DC in power transmission and distribution is expanding. Based on DC breaking technology established in the development of the TC-type HB, we will continue to contribute broadly to society by supplying products suited to the growing need for DC power transmission and distribution.

References

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(2) Sasaki, H., et al.: Development of a High-Speed Circuit Breaker for DC Railway Substations, 2019 IEEE Third International Conference on DC Microgrids, 4-A-4 (2019)

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