"MELPRO-i" Series Edge Device for Advanced Monitoring and Control

Authors: *Takeo Hikita** and *Ryoya Yamamoto**

1. Introduction

Against the backdrop of introduction of a licensing system established by Japanese law with the aim of increasing the use of renewable energy and distributed energy resources with a view to achieving carbon neutrality, local production and local consumption of energy, and building communities with a high resilience against disasters. There is an anticipated increase in microgrid systems capable of supplying power in a self-sustaining manner using grids independent of electric utility companies in the event of large-scale power outages due to disasters or other causes. Meanwhile, there is a growing need in the field of electrical safety for more efficient and advanced (smart) service and maintenance operations associated with the aging deterioration of electrical facilities as well as the lower birthrate and aging population of society. MELPRO-i has been developed and released to meet these needs, complies with the IEC 61850 international standard for communication protocols and provides functions like edge AI, Programmable Logic Controller (PLC) and security.

This paper outlines the purpose of development of MELPRO-i, details of the factors behind development, and various use cases.

2. Aim of Development

Today's protection relays, also called Intelligent Electronic Devices (IEDs), are feature-rich products that include communication functions, PLC functionality and record functions. In addition to use cases as protection relays, there is an increase in use cases where IEDs are being applied for measurement and control devices for system data required for the operation of distributed energy resources and microgrids.

Mitsubishi Electric has already commercialized IEDs, but has developed and released MELPRO-i with the aim of further increasing use cases and achieving more advanced monitoring and control by including and expanding the following functionalities.

- Compliance with IEC 61850 Edition 2.0
- Include Mitsubishi Electric's Maisart AI technology
- Expanded PLC function
- Cybersecurity

3. Details of Development

3.1 Compliance with IEC 61850 Edition 2.0

The IEC 61850 communications protocol is already available to provide protective control for substations, and is currently transitioning to Edition 2.0. MELPRO-i complies with Edition 2.0, and also includes the following new communication services.

- Support for Select Before Operate with enhanced security (SBOes)
- Remote setting (change setting values within Setting Groups)
- Sending/receiving Value Generic Object Oriented Substation Events (Goose)
- Software updates (using File Transfer)

There is no definition for software updates in IEC 61850, but MELPRO-i uses defined communication services and object models to update its software.

3.2 Includes Mitsubishi Electric's Maisart AI technology

(1) Dedicated AI processing CPU

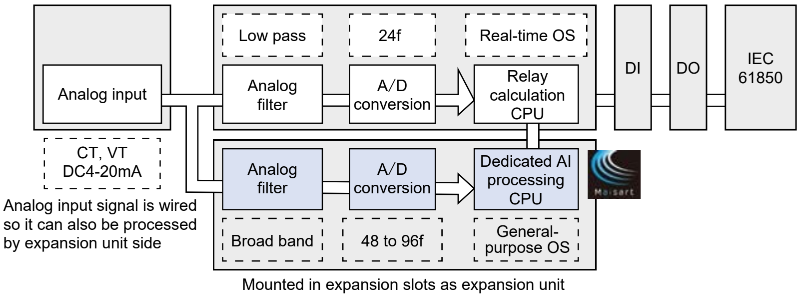
MELPRO-i features expansion slots that allow optional units to be mounted, and installing expansion units with dedicated AI processing CPUs in expansion slots allow the use of edge AI functions (Fig. 1). Analog input signals that are input for relay calculations are wired so that they can also be read by the expansion unit side—they are sampled at high speed (up to 5,760 Hz) via an analog filter with wider broadband frequency characteristics than those for relay calculations. MELPRO-i features a fanless design to take into account the installation environment, product life spans and other factors.

(2) Mitsubishi Electric's proprietary AI engine

The software configuration of edge AI is as outlined in Fig. 2. As described above, MELPRO-i features a fanless design and performs preliminary calculations to determine whether or not to launch the AI engine using the edge AI app—optimizing the execution of the AI engine helps to reduce power consumption.

Compatibility with Mitsubishi Electric's IoT platform INFOPRISM allows its proprietary AI engine to be used. AI engines that are currently available use technology for the recognition of similar waveforms(1).

*Transmission & Distribution Systems Center



CT: Current Transformer, VT: Voltage Transformer, DI: Digital Input, DO: Digital Output

Fig. 1 Edge AI hardware configuration

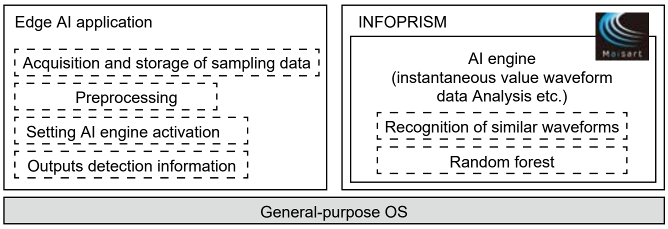


Fig. 2 Edge AI software configuration

Recognition of similar waveforms is a method used to determine the presence of faults (conditions that are different from normal). In the learning phase, score values (index that determines how similar the selected waveform is with other sections over the entire waveform) are calculated based on a learning waveform to determine the threshold for the score value. In the detection phase, score values (index that determines how similar the waveform is with the learning waveform) for the detection waveform are calculated, and if a value exceeds the threshold calculated in the learning phase, it is detected as a fault.

In the future, AI engines operating with random forest—a machine learning method used for applications like data classification (determination) and regression (estimation)—are anticipated to be used. Random forest is an algorithm that determines the feature amount (such as changes in frequency components or effective values) used for each data set, constructs a decision tree, and combines multiple decision trees—the classification output is determined by the results with the most trees. This application is anticipated to be used for cause estimation of accidents and faults.

3.3 Expanded PLC function

(1) PLC function

One feature of IEDs is the PLC function[2]. Users can program sequence logic using programming language that complies with the PLC international standard IEC 61131-3. Programming sequence logic using PLC that had previously been achieved with the software or switchboard wiring incorporated within IEDs helps to reduce costs significantly.

(2) Extended PLC functions with Mitsubishi Electric's engineering tool MELGEAR

"MELPRO-D"[3], the base model used for development, enabled the use of the simplified PLC function using maintenance tool PC-HMI (Fig. 3). This meant programming is possible by selecting AND-OR logic for blocks available on the PC-HMI screen, making operation simple even for novice users. Yet this approach suffered from restrictions in the available logic functions and low programming capacity.

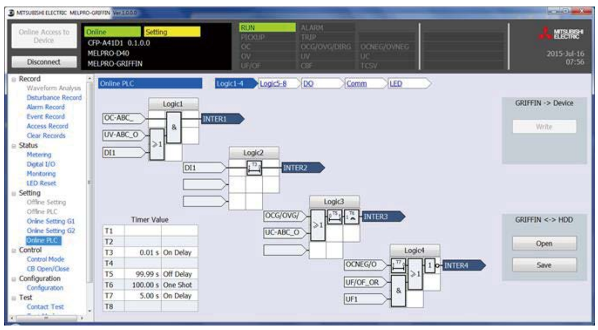


Fig. 3 PLC functions of PC-HMI

MELPRO-i resolves the PLC function issues of MELPRO-D, and the use of Mitsubishi Electric's engineering tool MELGEAR significantly expands the available PLC functions. MELGEAR allows the use of languages that comply with IEC 61131-3 like Function Block Diagram (FBD) and Structured Text (ST), and logic will be programmed by selecting the logic symbols and signals for required functions on the tool screen, as shown in Fig. 4.

Programmed logic can be converted to C and output, and after compiling is complete, a dedicated MELPRO-i software loader is used to load and run it in MELPRO-i (Fig. 5).

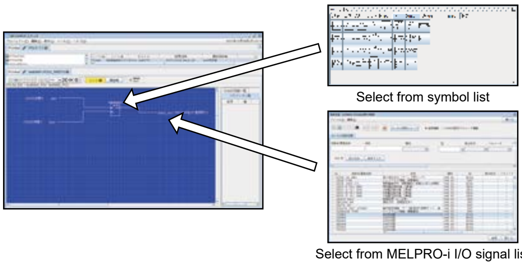


Fig. 4 Programming by MELGEAR

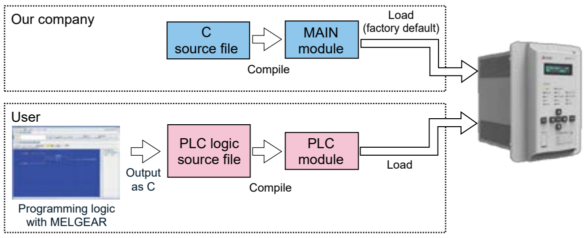


Fig. 5 Extended PLC functions of MELGEAR

Table 1 TOC of MELPRO-i

No.	Clause	Status
5.1.1	Electronic access control	Complies
5.1.2	Password defeat mechanisms	Complies
5.1.3	Number of individual users	Complies
5.1.4	Password construction	Complies
5.1.5.1	Authorization levels by password	Complies
5.1.5.2	Authorization using role-based access control (RBAC)	Complies
5.1.6	IED main security functions	Complies
5.1.7	Password display	Complies
5.1.8	Access timeout	Complies
5.2.1	Audit trail	Complies
5.2.2	Storage capability	Excluded
5.2.3	Storage record	Complies
5.2.4	Audit trail event types	Complies
5.3.1 to 5.3.6	Supervisory monitoring and control	Excluded
5.4.1	IED functionality compromise	Complies
5.4.2	Specific cryptographic features	Complies
5.4.3	Cryptographic techniques	Complies
5.4.4	Encrypting serial communications	Complies
5.4.5	Protocol-specific security features	Complies
5.5.1	Authentication	Complies
5.5.2	Digital signature	Complies
5.5.3	ID/password control	Complies
5.5.4.1	View configuration data	Complies
5.5.4.2	Change configuration data	Complies
5.6	Communications port access	Complies
5.7	Firmware quality control	Excluded

IEEE Std 1686TM-2013 (Revision of IEEE Std 1686-2007)

3.4 Cybersecurity

(1) IEEE 1686 compatibility

IEEE 1686 is defined as the security standard for IEDs, and IEDs available from international vendors are marketed with IEEE 1686 compatibility. While IEEE 1686 does not require all items of the standard to be met, it does require a Table of compliance (TOC) to be created to outline to users the compliance level of each item. The TOC being considered for MELPRO-i is shown in Table 1. Items not included in Table 1 do not meet one or more requirements defined in the standard.

(2) Role Based Access Control (RBAC) function

MELPRO-i provides protection for the front panel and locally connected PC-HMI with user IDs and passwords. Rights are also granted for each user ID, which applies limits access to each function depending on the level of rights. Four levels of rights are available, with fixed functions assigned to each level. Users will be able to configure the level of rights assigned to each user ID, and the same rights can be assigned to different user IDs.

(3) Communication encryption and communications port access

IEEE 1686 specifies that using remote access to transfer data, change settings or update software requires IEEE 1711-compliant data encryption for all ports used for remote access. MELPRO-i features an Ethernet(*1) port for IEC 61850 communications as the communications port, with encryption is planned to be available.

IEEE 1686 also specifies the use of a function in configuration settings for enabling/disabling all communication ports, whether physical or logical, and this setting is also planned to be available with MELPRO-i.

(*1) Ethernet is a registered trademark of the Fuji Film Business Innovation Corporation.

4. Use Cases

Use cases utilizing the IEC 61850 communication, edge AI, and other functions provided in MELPRO-i are introduced (Fig. 6).

4.1 Use cases utilizing IEC 61850 communications

(1) Distribution control[4]

In the event that an accident occurs along a distribution line, the current method of operation used for distribution lines temporarily interrupts power across the entire line after protection relays at the distribution substation are activated, in what is referred to as a sequential fault detection system. Switchgears starting from the closest to the distribution substation are then switched back on to restore power transmission—the segment with the accident can be identified when an accident occurs again. Power is then restored to other

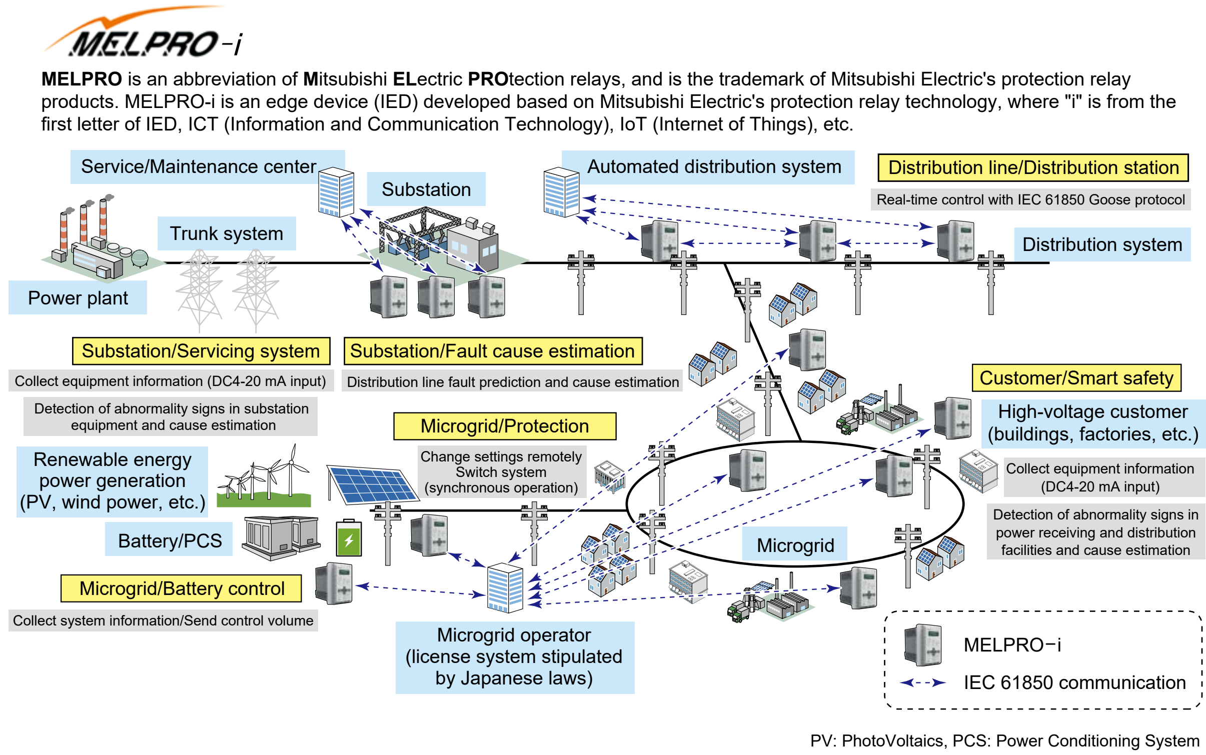


Fig. 6 Edge device "MELPRO-i" use cases

segments, but it takes several minutes to recover from the power outage.

Using MELPRO-i for distribution lines not only helps to detect accidents, but also exchanges information on detected accidents between adjacent MELPRO-i units using the IEC 61850 Goose protocol. This means affected segments can be identified and separated without interrupting the entire distribution line, as long as the fault is within the interruption capacity of switchgear.

(2) Microgrids

Efforts are being made in various areas to explore community microgrids utilizing renewable energy and distributed energy resources. Yet the configuration and scale of power systems when such communities are connected to electricity utility grids or operating their microgrids can vary significantly, which changes the scope of potential accidents. Addressing this may require changes to the setting values of protection relays installed at power plants and each customer before operating microgrids. To minimize power interruptions when switching from grid connections to microgrid operation, the setting value of each protection relay needs to be changed from remote sites via communications. MELPRO-i supports the IEC 61850 remote setting function, and caters to the requirements outlined above.

4.2 Edge AI use cases

The two following use cases are being considered as edge AI use cases.

(1) Distribution line fault prediction and cause estimation[4]

There are tens of thousands of kilometers of distribution lines installed around Japan. If power outages occur due to accidents or other causes, electricity utilities need to spend considerable effort identifying affected segments, determining the cause and restoring power transmission, and as such, there is strong demand for streamlining these operations.

MELPRO-i's edge AI records and analyzes distribution line signal waveforms like zero sequence current and zero sequence voltage, which allows predictive detection and fault cause estimation of accidents in distribution lines.

(2) Detection of abnormality signs in substation equipment and power receiving and distribution facilities

There is a growing need for more efficient and advanced (smart) service and maintenance operations associated with the gradual deterioration of electrical facilities and the lower birthrate and aging population. Equipment servicing and maintenance is becoming more sophisticated by installing various types of sensors on key equipment like circuit breakers and transformers, and utilizing the data acquired from those sensors.

In addition to zero sequence current and zero sequence voltage, MELPRO-i's edge AI reads DC4-20 mA input signals of sensor general-purpose interfaces, and records and analyzes signal waveforms for predictive detection and cause estimation of faults in various types of electrical facilities.

5. Conclusion

This paper outlined the purpose of development of MELPRO-i, details of the factors behind development, and various use cases. As communication infrastructure is put in place in the future and IEC 61850 communication is more widely adopted, use cases are expected to expand further. While edge AI currently has a shortage of available learning data (data on accidents and faults, data immediately before an accident or fault occurs), data will continue being acquired through demonstrations and other tests in each use case, to further advance prediction and cause estimation operations.

References

(1) Hirai. N., et al.: Data Analysis Technology for Equipment Maintenance Management, Mitsubishi Denki Giho, 90, No. 7, 416-420 (2016)
(2) Saka. Y., et al.: An Implementation Method for the Protection and Control Functions Defined in IEC 61850 with PLC based on IEC 61131-3, IEEJ Transactions on Power and Energy B, 140, No. 5, 395-401 (2020)
(3) Takemura. S., et al.: Development of Multifunction Relays for Customers, The Institute of Electrical Engineers of Japan Protection Relay System Research Group, PPR-17-014 (2017)
(4) Ishimoto. T., et al.: Advanced Power Distribution Technologies for Next-generation Power Distribution Grid Networks, Mitsubishi Denki Giho, 95, No.11, 682-685 (2021)