

Microgrid System for Isolated Islands

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ABSTRACT

There are many inhabited isolated islands throughout the world and most of these operate with independent power systems. Because such power systems located on small isolated islands are small in size and their generators have low inertial energy, they are sensitive to fluctuations in the output of renewable energy. To solve this problem, Fuji Electric has studied the configurations of microgrid systems for isolated islands and the challenges for isolated systems when introducing a large amount of renewable energy, and also has examined ways in which to best address those challenges. This paper describes the challenges and solutions for the application of microgrid systems to small isolated islands and also presents an overview of demonstration projects being carried out on six islands in Kyushu and three islands in Okinawa.

1. Introduction

To address global environmental issues including the reduction of greenhouse gas emissions, the creation of a framework and the setting of goals on a global scale are being examined. In this context, the adoption of renewable energy is considered to be effective both for resolving environmental issues as well as fostering new industries, and future developments are expected.

Meanwhile, the mass adoption of renewable energy raises concerns about possible deleterious effects on the power system.

Since the latter half of the 1990s, countries of the European Union (EU) have advanced the adoption of large quantities of wind power in order to tackle global environmental issues, but various system problems have become evident and a solution is urgently needed.

Since 2009, Fuji Electric has studied microgrid system configurations for isolated islands, the issues involving independent systems when large amounts of renewable energy are introduced, and methods for resolving those issues.

This paper presents an overview of the control functions and the types of equipment that are installed when applying these microgrid systems to isolated islands.

2. Application of Microgrids to Island Power Systems

2.1 Microgrid system

A microgrid system uses multiple distributed power sources and operates a power supply system while maintaining a regional balance between power demand and supply. A microgrid system has the following

characteristics.

- (a) Applicable to special regions where multiple consumers exist
- (b) Configured from distributed power sources and a small-scale power supply network
- (c) Onsite power supply system capable of operating separately from a pre-existing large-scale power supply system
- (d) Configured as either a system linked-type that is linked to the power system, or an independent-type separate from the power system
- (e) Typically uses Information and Communication Technology (ICT) for integrated control of multiple distributed power sources and loads

As an interchange power supply system that uses renewable energy, this type of small-scale system is an environment friendly power system that, because it contains equipment for storing energy and heat, is able to absorb the fluctuations in demand and output arising from renewable energy within the region, and is expected to come into widespread use as a system that is compatible with existing systems and that does not negatively affect pre-existing power sources.

2.2 Goals and issues in the application of microgrids to isolated islands

An isolated island microgrid system is a specialized small to medium-sized independent power system that inherits the original microgrid characteristics and that aims to maintain the quality and to ensure the reliability of power in an independent system when large amounts of renewable energy are introduced.

Countless inhabited islands exist worldwide, the majority of which are supplied with electric power by independent systems. Japan has the largest number of isolated-island independent power systems of any country.

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In independent power systems for isolated islands, due to problems with operational constraints and the like, power is typically supplied from internal combustion power generators, which use fossil fuel and have a relatively large CO₂ emission factor. Additionally, the transportation of fuel to remote areas adds to the cost of power generation, and economic efficiency is an issue for isolated islands.

The mass adoption of renewable energy, without requiring fossil fuels, by isolated islands is thought to provide the solutions of both reduced environmental load and improved economic efficiency.

The mass adoption of renewable energy, however, leads to a decrease in power quality and supply reliability of the power system, and measures to reach a solution are needed. The challenges when renewable energy is adopted by an isolated island are listed in Table 1.

Table 1 Challenges for adopting renewable energy on isolated islands

Item	Challenge
Supply/demand operation management	Balance between supply and demand must be maintained at all times (allowable fluctuations are within range of the governor following capability for pre-existing generators)
Frequency and voltage sustainability	Renewable energy and load fluctuations cause large and instantaneous changes in frequency and voltage
Reserve power	Reserve power is extremely low (because the generator unit capacity is small)
Economic feasibility	If sufficient reserve power (increased margin) is provided to compensate for the amount of fluctuation in renewable energy, the diesel generators will operate at a point of low output and the fuel efficiency will decrease.

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The introduction of a microgrid system provides an effective resolution for the various issues of concern in the case of a mass adoption of renewable energy at an isolated islanded.

3. Isolated Island Microgrid Systems

3.1 Basic configuration

Figure 1 shows the basic configuration of an isolated island microgrid system.

The system, which consists of an existing internal-combustion power generation system and renewable energy and electric power storage systems, measures with a sensor the generated power and power quality assessment items (frequency, reactive power, etc.) and sends the measured values via a high-speed transmission path to a microgrid control system.

A small-scale system operates mainly with small capacity internal combustion generators having low inertial energy and is susceptible to decreases in power quality due to instantaneous fluctuations in frequency or the like caused by outages or abrupt changes in the output of renewable energy. The control device (governor control) of an existing system is unable to follow such abrupt changes, and unless countermeasures are implemented, the frequency may deviate from the pre-

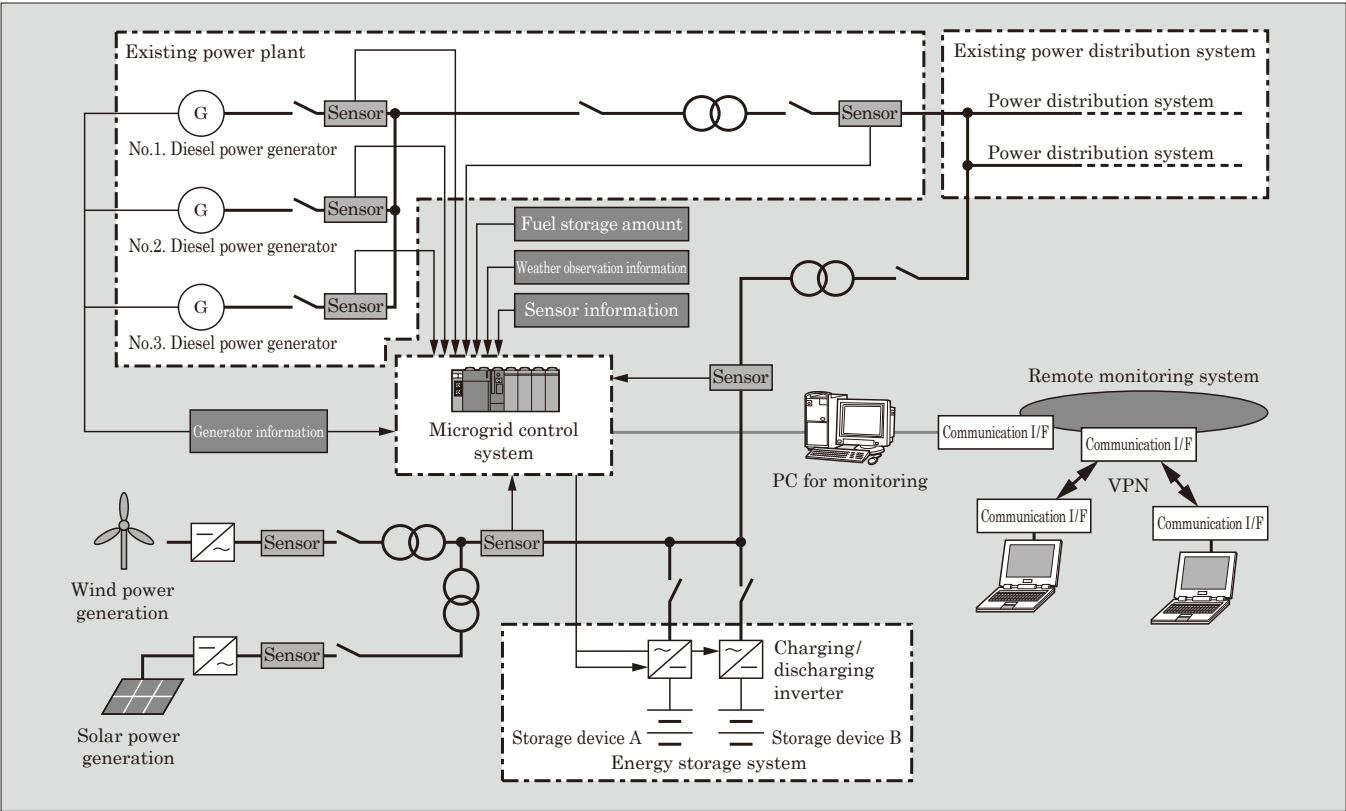


Fig.1 Basic configuration of isolated island microgrid system

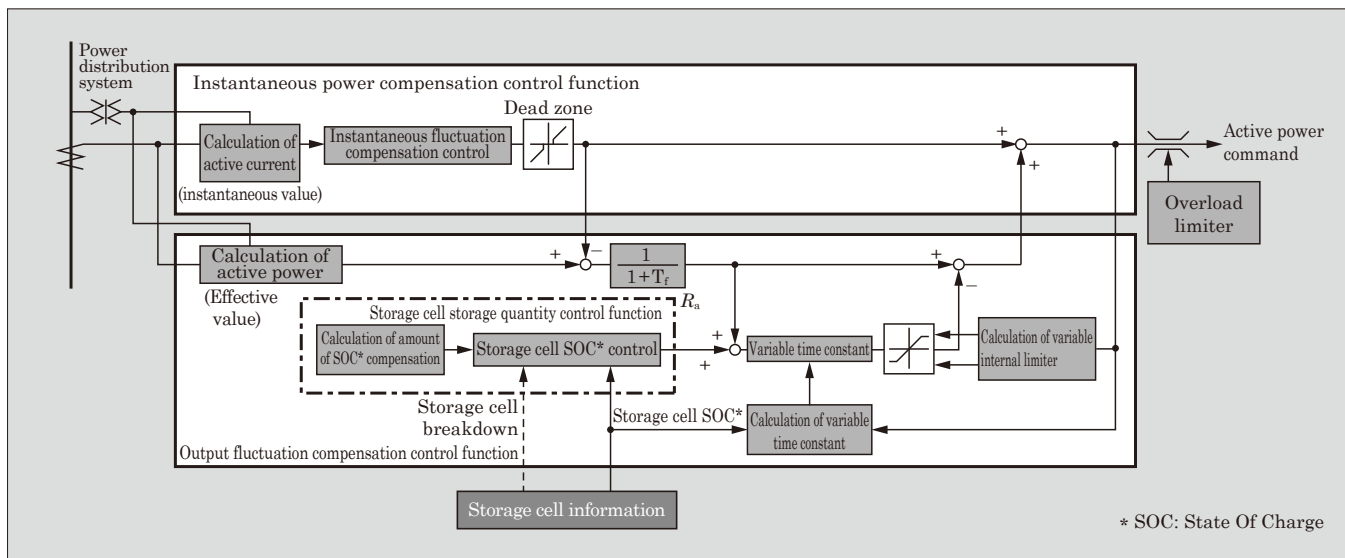


Fig.2 Configuration of control function for a small-scale isolated island system

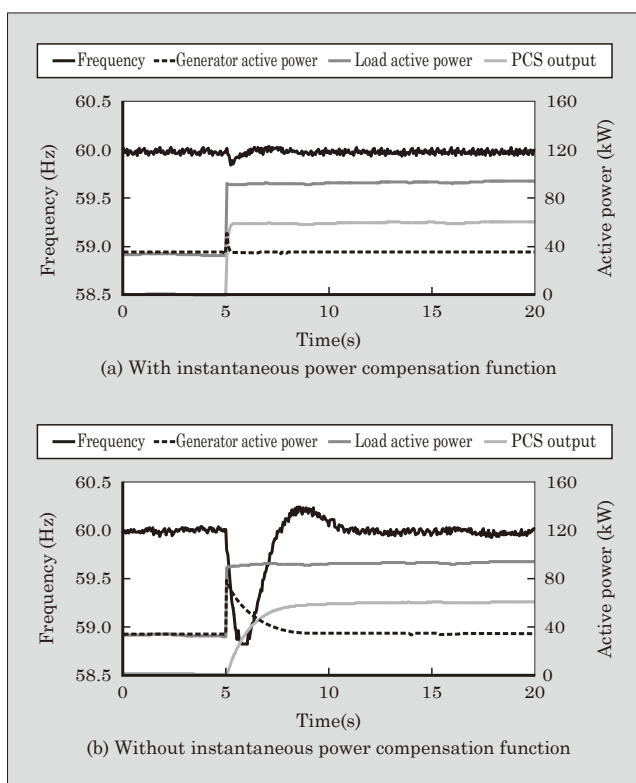


Fig.3 Suppressive effect of frequency fluctuation by instantaneous power compensation

scribed value and the power quality of the system will deteriorate.

In the case of an isolated island system of about several hundred kW, these instantaneous frequency fluctuations tend to become noticeable, and a high-speed function for compensating for these fluctuations is needed. Furthermore, on a small-scale isolated island, the number of generators in operation is few, and the operation can only be adjusted over a small range. Thus, if the percentage of power generated by renew-

able energy increases, stable operation within the operating range of the existing generators will be difficult to maintain, and measures such as peak shifting by controlling the output of the renewable energy, adding redundant electric power storage systems and increasing capacity are needed.

Additionally, in the case of an isolated island system of about 1,000 kW (a medium-scale isolated island system), the system operates mainly by controlling multiple internal generators, and a wide operating range can be set if there is a sufficient margin of reserve power. Thus, a microgrid system is able to realize the most economical system configuration within the control range of pre-existing generation equipment.

3.2 Control functions in a small-scale isolated island system

Fuji Electric has commercialized its "UPS 8000 G" series of uninterruptible power supplies that are equipped with an absorber function for assisting the load-following performance when a load is applied to a high-efficiency gas engine generator. These uninterruptible power supplies sense instantaneous fluctuations in the load and are able to provide instantaneous fluctuation compensation of approximately several milliseconds to 10 ms. In addition, a demonstration tests for stabilization equipment that aims to suppress output fluctuations of wind farm has been underway since 2008 at the Nishime Wind Farm operated by Win-power Co., Ltd. (a wholly owned subsidiary of Fuji Electric).

As a result of the demonstration tests, stabilization technology and technology for the operation and management of storage devices has been established. Based on these technologies, a microgrid control function for small-scale isolated island systems was developed.

Figure 2 shows the configuration of a control func-

tion for a developed small-scale isolated island system. This control function enables control to be implemented in response to instantaneous fluctuations due to wind turbine cut-out, outages of photovoltaic power conditioner and the like, without deviating from the system frequency. Fig. 3 shows the results of simulations comparing the cases with and without the instantaneous power compensation function.

3.3 Control functions in a medium-scale isolated island system

In a medium-scale isolated island system where multiple rotating-type electric power generators are operating at all times, a certain amount of transient fluctuation is absorbed by the inertial energy of the generators. In such a system, the generators are able to operate over a relatively wide range, and the selection of suitable storage devices and reduction of generator capacities are important factors to consider so that the installation of equipment will be economical.

Furthermore, as the scale of the system increases, there will be a greater number of installed sites of renewable energy, and fluctuations in the output of the renewable energy will become more difficult to detect. In such cases, fast frequency compensation for the system, including demand fluctuation, is effective.

3.4 Selection of storage devices

When configuring a microgrid, the selection of storage devices is important in terms of both operation and economic efficiency. Fuji Electric, with the help of storage device manufacturers, has conducted validation testing of nickel metal hydride batteries, high-cycle lead-acid storage batteries and electric double-layer capacitors at the Nishime Wind Farm.

As a result of this validation testing, Fuji Electric has developed a storage device management function that considers the allowable depth of discharge and cycle life characteristics for each device.

The different types of storage devices have different characteristics as shown in Fig. 4. The selection of storage devices must consider, in addition to these

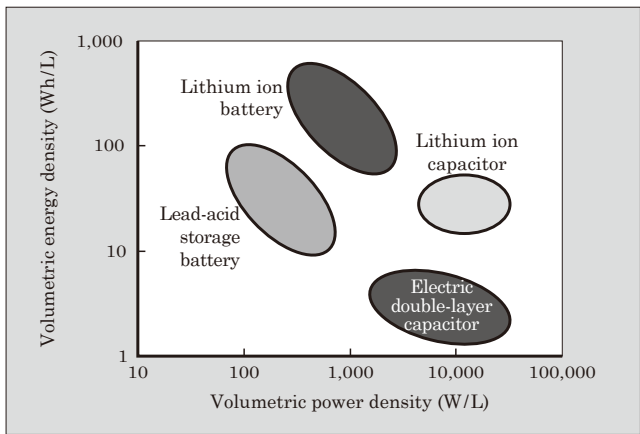


Fig.4 Storage device type and performance

characteristics, the cycle life, required space for installation, and the economic efficiency.

In general, for load balancing purposes, such as peak shifting, larger capacity storage devices are required, and storage cells having a relatively high volumetric energy density are advantageous.

On the other hand, for fluctuation compensation purposes, various storage devices are considered for application. As a stabilization measure for relatively short-period fluctuations lasting several minutes or less, a capacitor is advantageous in terms of cycle life and volumetric power density. Moreover, for the compensation of long-period fluctuations lasting several tens of minutes or more, various types of storage cells, including new batteries such as lithium ion batteries and the like, are applied.

Fuji Electric has verified the application of these various types of storage devices and has also promoted the joint development of storage devices. Lithium ion capacitor modules for power converters are products that were jointly developed by Fuji Electric and FDK Corporation. These lithium ion capacitor modules can be used for nearly the same purposes as electric double-layer capacitors and are smaller and lighter weight than electric double-layer capacitors of the same capacitance.

The external appearance of a lithium ion capacitor

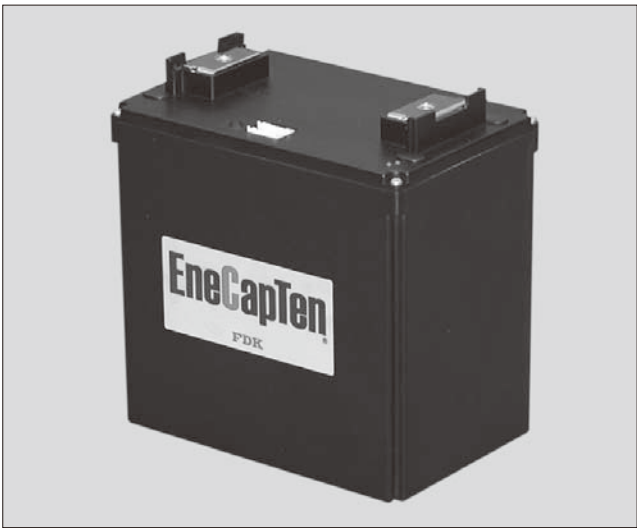


Fig.5 Appearance of lithium ion capacitor module

Table 2 Specifications of lithium ion capacitor module

Item	Specifications
Rated power	DC45 V (27 to 45 V)
Initial static capacitance	200 F or higher (for 1 A discharge)
Initial internal DC resistance	19 mΩ or less (for 100 A discharge)
Charge and discharge current (rated)	20 A
External dimensions	W203×D134×H193 (mm)
Mass	6 kg

is shown in Fig. 5, and its specifications are listed in Table 2.

3.5 Fast frequency detector

Frequency detection in the microgrid provides not only an indicator of the power quality, but is also an important indicator for assessing the balance between the supply and demand of power within a microgrid that includes internal combustion generators.

In order to achieve coordinated control over the entirety of an independent power system on an isolated island, the microgrid control must function effectively in response to instantaneous frequency fluctuations that pre-existing control devices are unable to follow.

The principle of system frequency detection is based on, for example, the number of times that the system AC voltage transitions from a negative voltage to a positive voltage within a certain period of time, and a method⁽¹⁾ for computing the time of an AC cycle from the time required for N transitions, or the like is used. In this case, the frequency detection requires a detection time ranging from several hundred milliseconds to ten seconds.

Using the system AC voltage as a signal source, and a proprietary error compression algorithm and an optimized characteristics filter, Fuji Electric has developed a fast-frequency detector that achieves a

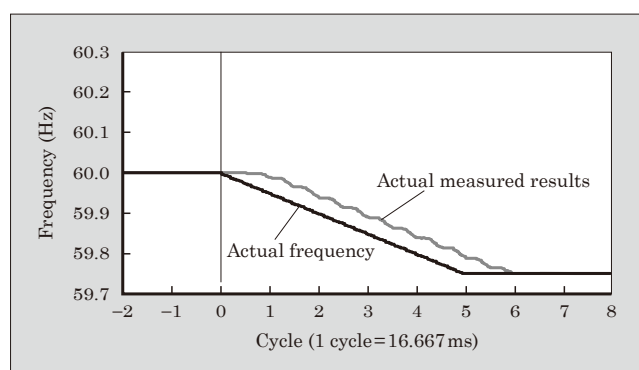


Fig.6 Example measurement results of fast frequency detector

Table 3 Overview of equipment to be installed (small-scale isolated island system)

Equipment to be installed Name of isolated island	Solar power (kW)	Wind power (kW)	Lead-acid batteries (kWh)	Lithium ion batteries (kWh)
Kuroshima	6.0	10	256	66
Takeshima	7.5	—	—	33
Nakanoshima	15.0	—	80	—
Suwanosejima	10.0	—	80	—
Kodakarajima	7.5	—	80	—
Takarajima	10.0	—	80	—

frequency-following performance of approximately 30 ms for frequency fluctuations in an actual power system, and has applied this fast-frequency detector to fast-frequency fluctuation compensation as part of the microgrid control function. Fig. 6 shows an example of actual measurement results obtained with the newly developed fast-frequency detector.

4. Demonstration tests of Isolated Island Microgrid System

4.1 Demonstration tests in small-scale isolated island system

Fuji Electric has delivered isolated island microgrid-related equipment to the Kyushu Electric Power Co., which has received an “Island Independent-type New Energy Demonstration Project Grant” from the Japanese Ministry of Economy, Trade and Industry. A summary of the equipment installed is listed in Table 3.

The amount of new energy adopted in relation to the scale of the system varies by approximately 10 to 30% depending on the island, but exceeds 50% of the minimum demand occurring during an intermediate



Fig.7 Appearance of storage containers



Fig.8 Overall view of system (Kuroshima)

Table 4 Overview of equipment to be installed (medium-scale isolated island system)

Equipment to be installed Name of isolated island	Solar power (kW)	Electrical power storage system	
		Converter capacity (kW)	Capacitor capacity (kWh)
Taramajima	250 (25)	300	7.2
Yonagunijima	150 (15)	200	4.7
Kitadaitoujima	100 (10)	100	2.9

Note: Values enclosed in parentheses show the capacity of Fuji Electric's film-type amorphous solar cell "FWAVE"



Fig.9 Overall view of system (Taramajima)

period such as the Spring or Autumn. Storage cells, consisting of high-cycle life lead-acid storage batteries and lithium ion batters, are used for fluctuation compensation, peak shifting and other smoothing purposes. Because these islands are far from the mainland and the transport constraints are severe, electrical products such as interconnecting equipment and inverters are all installed and wired in small storage containers on the mainland, and are then shipped in order to streamline the onsite construction work.

Figure 7 shows the external appearance of storage containers and Fig. 8 shows the overall view of the system.

4.2 Demonstration tests in medium-scale isolated island system
Fuji Electric has also delivered isolated island

microgrid-related equipment to the Okinawa Electric Power Co., which has received an "Island Independent-type New Energy Demonstration Project Grant" from the Japanese Ministry of Economy, Trade and Industry. A summary of the equipment installed is listed in Table 4.

In this system, the abovementioned lithium ion capacitor module was applied to system stabilization for the first time in the world. Capacitors for each type of equipment were designed so as to be able to smooth the steep output fluctuations occurring in the system within the response range of pre-existing control equipment. Additionally, the control apparatus employs fast-frequency control that utilizes a fast-frequency detector, and for fluctuations in the system frequency, is provided with a function that aims to stabilize the frequency prior to the response of the governor-free function of a pre-existing power generating system. Fig. 9 shows an overall view of the installed system.

5. Postscript

This paper has introduced Fuji Electric's characteristic products and application technology for isolated island microgrids. In the future, with system standardization and the completion of packaging, Fuji Electric plans to pursue economic efficiency, and streamlined transportation and execution with an eye on overseas markets.

Finally, the authors wish to thank all the relevant individuals from the Kyushu Electric Power Co., Okinawa Power Co., and Okinawa Enetech Co. for their tremendous cooperation and guidance regarding the adoption of equipment for the demonstration projects and their cooperation in providing materials for this manuscript.

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