

Improvement of Islanding Detector Using Interharmonics Current Injection Method and Its Applications

Sadayuki ISHIKURA*, Hideyuki NAKATANI, Junya TAKAGI, Tsutomu FUKADA, Shoji NISHIMURA and Yoshihiro HADA

When distributed power sources, such as renewable energy sources, are interconnected to electric power grids, anti-islanding protection devices are necessary. In 2001, we developed an islanding detector using the interharmonics current injection method, and since then it has been widely used. This paper introduces the principle, fault ride through (FRT) capability, and applications of the detector.

Keywords: grid interconnection, distributed power source, interharmonics, reverse power flow, islanding detection

1. Introduction

Recently, distributed power sources derived from renewable energy, such as photovoltaic, wind, hydraulic, waste-heat (that uses waste heat from garbage incineration facilities), and biomass power generation, are being increasingly used. When such distributed power sources are connected to the power grid, the islanding operation attributed to the reverse charging in the event of loss of the grid power source must be prevented. Conventionally, a transfer cutout system is used to ensure protection; however, it poses difficulties in terms of installation space, cost, maintenance, and operation. Specifically, a transfer cutout system requires both a transferring system and a receiving system at the substation and a distributed power source equipment establisher. A custom communication line must be provided between the substation and the distributed power source equipment establisher (top figure in Fig. 1).

In a joint research operation with the Kansai Electric Power Co., Inc. (KEPCO), in 2000, we developed an islanding detection system (hereafter, “this system,”) based on a new theory. Equipped with proprietary features, this system operates based on an interharmonic-injection method (see the bottom figure in Fig. 1).

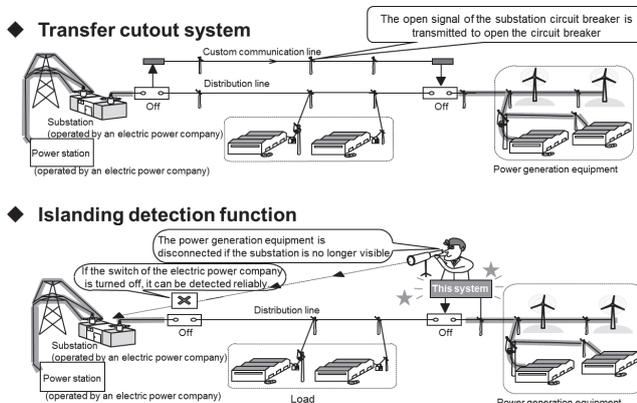


Fig. 1. Comparison between a transfer-cutout system and an islanding operation detection system

This system has been delivered to all electric power companies in Japan, and is being operated smoothly in their jurisdictions. This paper presents the mechanism, solutions, verification test results, improvements, and applications of this system.

2. Development of the Islanding Detection Method

2-1 Mechanism of the interharmonic-injection method

Interharmonics refer to the non-integer-order harmonics present between the integer-order harmonics (Fig. 2). The interharmonic components in the grid voltage and current remain very low, and those in the voltage account for approximately 0.01% of the fundamental harmonic components.

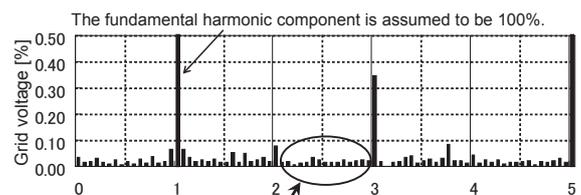


Fig. 2. Frequency characteristics of power distribution grid voltage when no interharmonics are injected

Only a small amount of interharmonic current will be injected from the connection point, and the voltage and current corresponding to the order of the interharmonics injected at the connection point can be measured. In this manner, the grid impedance can be measured easily.

The interharmonic-injection method is applied to detect the islanding operation, as described below. The grid

impedance is constantly monitored from the connection point, as shown in Fig. 3.

The grid impedance is generally small because it is mostly derived from the leakage impedance of the substation bank transformer and the distribution line impedance; however, it increases significantly when the power supply from the grid stops. The islanding condition can be determined by detecting the changes in the impedance (Fig. 4).

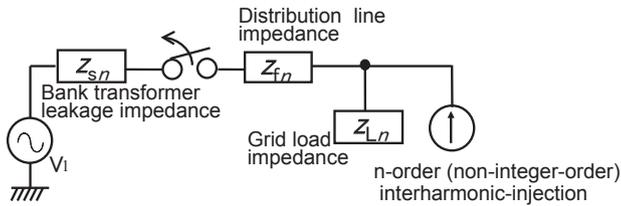


Fig. 3. Grid model in the event of islanding operation

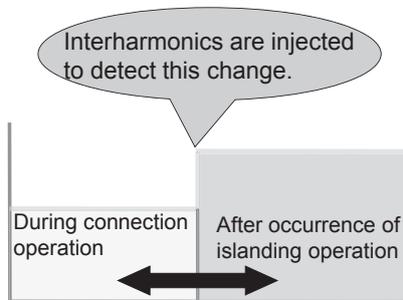


Fig. 4. Islanding detection mechanism

2-2 System configuration and solutions for commercial use

Figure 5 shows the system configuration of this method and configuration of the islanding detection system.

The system consists of an interharmonics signal generator, current-injection unit, and determination unit.

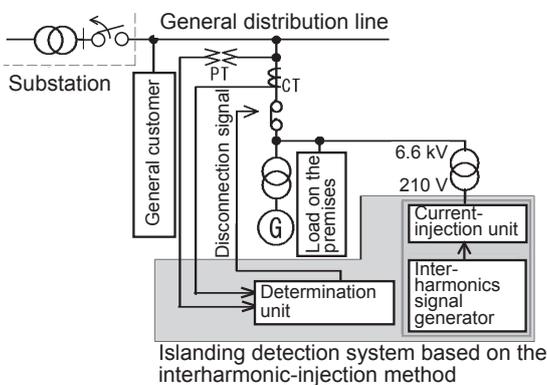


Fig. 5. System configuration of this method and configuration of the islanding detection system

The current-injection unit (which consists of small-capacity inverters) injects current to the grid based on the injection signals from the interharmonics signal generator.

The determination unit transforms the measured voltage and current waveforms, using discrete Fourier transforms (DFTs), and calculates and monitors the grid impedance for the injected frequency (order).

As one of the improvements for commercial use, an LC resonance circuit (injected interharmonics: near the resonance frequency, fundamental harmonics: far from the resonance frequency) is inserted in series in an interharmonic-injection inverter to reduce the capacity of the injection inverter (presented in Fig. 6).

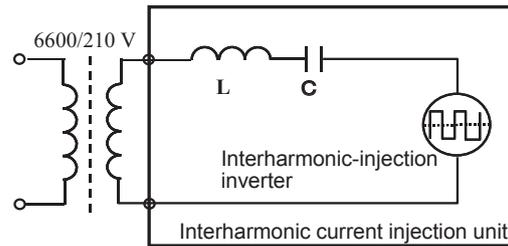


Fig. 6. Reduction in capacity of the interharmonic-injection inverter

2-3 Verification test on an actual grid

We measured the grid susceptance during grid connection at the Kurokawa wind farm in the Kurokawa power distribution grid operated by KEPCO. Specifically, we injected 2.4-order harmonic current (144 Hz) to the power distribution grid using this system.

Figure 7 shows the grid-voltage-frequency characteristics. As shown in the figure, we injected the harmonic current to cause a distortion of approximately 0.3% in the 6.6-kV grid fundamental harmonic voltage so that interharmonics injected from this system would not affect the grid.

The injected interharmonics order (2.4-order) components are sufficiently larger than other (peripheral) interharmonic components. This shows that this method can separate the injected interharmonic orders with high precision, and that mutual interference does not occur even when multiple islanding detection systems based on this method are installed, as long as the injected interharmonic orders are separate.

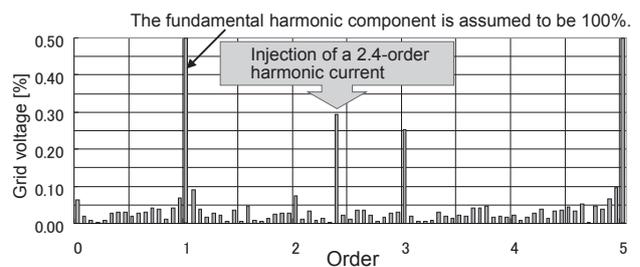


Fig. 7. Grid voltage frequency characteristics of interharmonic current injection at the Kurokawa wind farm

We conducted a test to verify the detection of islanding operation and activation in the wind farm by generating an islanding condition (Fig. 8).

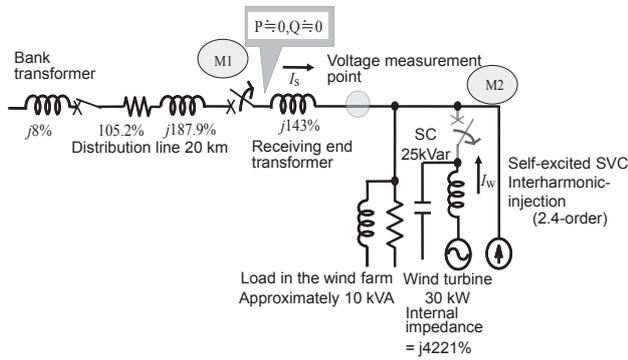


Fig. 8. Grid circuit model for an islanding verification test

The load in the wind farm and the self-excited static var compensator (SVC) were adjusted to attain equilibrium between the electricity demand and supply at the power station's receiving end. The islanding conditions at the wind farm were achieved by opening the circuit breaker at the receiving end of the wind farm.

The susceptance (i.e., the imaginary part of the reciprocal of the impedance) was monitored because it was easy to detect. Figure 9 shows the test results.

The islanding detection conditions of this system are as described in (1) and (2) below.

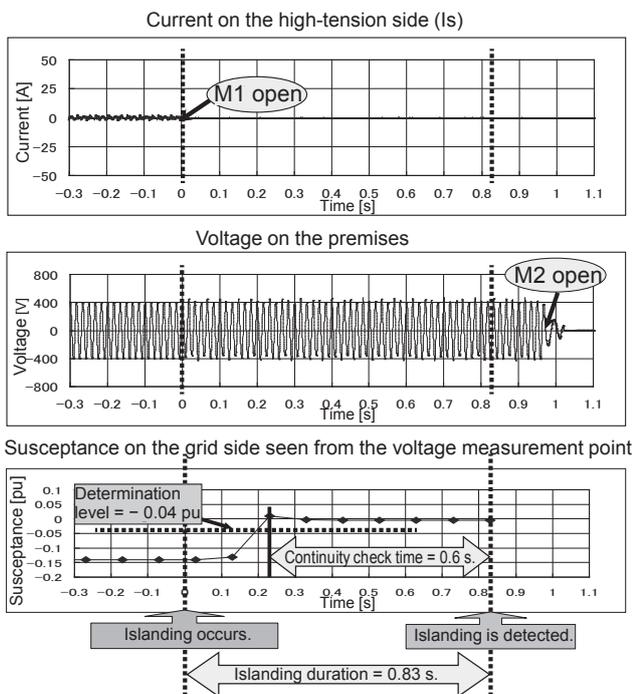


Fig. 9. Results of the islanding detection verification test

(1) Level set to determine the change in the grid susceptance

for the islanding condition = -0.04 pu

This value is about 30% of -0.14 pu (a grid susceptance measurement value obtained during connection; 10 MVA, 6.6 kV = 1 pu). This grid susceptance measurement value almost agrees with the value of the injected interharmonics order (2.4-order) susceptance ($-j0.123$ pu) based on the circuit calculation (effective value calculation) in Fig. 8.

(2) Duration of islanding = 0.6 s

The circuit breaker at the receiving end of the wind farm was opened (occurrence of islanding operation) at 0 s of the measurement time in Fig. 9.

We created a condition where equilibrium was attained between the electricity demand and supply to balance the wind turbine output with the load in the wind farm (including the self-excited SVC) during islanding operation, and thereby, maintain the islanding conditions.

Opening of the circuit breaker at the receiving end (occurrence of islanding) changed the grid susceptance value. Islanding operation was detected by this system 0.83 s after the occurrence of islanding. The islanding condition was detected quickly within 1 s. The field test results were satisfactory.

3. Features

3-1 Protection system required for connection

Connection of a distributed power source to a power grid requires protective relays to be installed to ensure protection in the event of failure of the distributed power source or a connection-grid accident and to prevent islanding. The technical requirements for grid connection are specified in the Grid-interconnection Code.

This system incorporates all the protective relays that are required to connect a distributed power source with the power grid (Table 1).

To connect a distributed power source with a reverse power flow, either a transfer cutout system or an islanding

Table 1. Protection system required for grid connection (in the case of high-tension connection)

Type of power generation equipment	Synchronized power generator		Induction generator		Inverter	
	Yes	No	Yes	No	Yes	No
Type of reverse power flow						
Protection target, etc						
Protect the grid in the event of a failure of power generation equipment	OVR, UVR					
Ensure protection in the event of a grid short-circuit accident	DSR		UVR			
Ensure protection in the event of a grid ground-fault accident	OVGR					
Prevent islanding	OFR	-	○	-	○	-
	UFR	○	○	○	○	○
	RPR	-	○	-	○	○
	Transfer cutout system or islanding detection function	○	-	○	-	○
Prevent an accident when a circuit is reclosed again	System to check on-voltage on the line					

○: Installation required - : No installation required

detection system must be implemented. Recently, the islanding operation detection function has been increasingly employed, compared to the transfer cutout system, from the viewpoint of installation space, cost, maintenance, operation, and construction period, among other factors.

The islanding detection function also causes different circuit breakers based on active and passive methods to achieve disconnections, making it possible to eliminate a system to check the no-voltage condition on the line (whose installation is required to prevent accidents when the circuit is reclosed).

3-2 Features of the interharmonic-injection method

This system has the following features, compared to the islanding detection systems based on other methods.

(1) The impact on the grid is negligible.

This method uses interharmonics as the injection current. The grid impedance can be measured (monitored) by distorting the grid voltage of the frequency component by only about 0.1% vis-à-vis the fundamental harmonic voltage with a small capacity. Unlike the conventional method, this method does not cause voltage variations (flicker) due to the cyclic variation of fundamental harmonics.

(2) Installation of multiple systems does not cause mutual interference.

Even if multiple systems are installed in the same bank, mutual interference can be avoided by monitoring the grid impedance at the respective injected interharmonic orders (frequencies).

(3) Islanding operation can be detected quickly (in approximately 1 s).

This method is designed to constantly extract injection harmonics based on the voltage and current measurement data, and calculate the impedance of the harmonics, achieving detection of islanding operation in approximately 1 s. Conventional methods take several seconds to achieve this.

(4) This system can be used for any distributed power source.

This system can be installed externally in a distributed power source. It is applicable to any distributed power source and is highly versatile.

(5) Multiple distributed power sources can be protected collectively.

This system can protect multiple distributed power sources if there is only one connection point. This helps reduce cost.

(6) This system can cope with the switching of multiple grids.

The settings can be changed to enable detection on multiple grids even in the case of grid switching (distribution line route change). A single system can cope with the switching of multiple grids.

(7) This system is also applicable to extra-high voltage grids.

This method is designed to enable detection based on the impedance change. Thus, it is applicable to extra-high voltage grids (35 kV or less) for which the conventional transfer cutout system used to be the only option available, and therefore, it helps reduce the cost.

4. Compliance with the FRT Requirements

4-1 What are FRT requirements?

Recently, the amount of grid connections of distributed power sources (photovoltaic power generation, wind power generation, etc.) have been increasing. Simultaneous disconnections (e.g., instantaneous voltage drop due to an accident in the transmission lines) and continued output drops of these distributed power sources are likely to have a significant impact on maintaining the voltage and frequency of the entire grid.

Against this backdrop, the Grid-interconnection Code was revised in 2012. The fault ride through (FRT) requirements were added for the respective distributed power sources to minimize the impacts from spreading in the event of a grid accident. Specifically, the FRT requirements specify the requirements to continue operation and restore the outputs of distributed power sources in response to an instantaneous drop in the grid voltage (primarily due to a grid accident) or transient variations in the grid frequency.

4-2 Islanding operation detection method and FRT requirements

This system employs an interharmonic-injection method (an active method) and a voltage phase jump detection method (a passive method) for an islanding detection function specified in the grid-interconnection code.

The FRT requirements provide the conditions for the power generation equipment to continue operation and restore output in the event of a voltage drop or frequency variation due to an accident in the grid transmission line. It should be noted that the detailed conditions are different depending on the connection distribution line voltage (low-voltage, high-voltage extra-high-voltage) and the type of power generation equipment.

Designed to ensure protection, this system must not cause unnecessary disconnections in the events of voltage drop or frequency variation prescribed in the FRT requirements. Meanwhile, this system must meet the islanding prevention requirements.

In the process of making improvements, we conducted verifications of all patterns based on the detailed conditions of voltage drop and frequency variations prescribed in the grid-interconnection code. We verified that the FRT requirements could be applied to any power generation equipment.

4-3 Improvements in the islanding detection method

(1) Active method

The interharmonic-injection method is designed to inject a small amount of interharmonic current from the connection point, measure the grid impedance based on the voltage and current value for an injected interharmonic order, and detect an islanding condition based on the changes in these values.

Since this mechanism is not affected by variations in grid voltage or frequency, it does not cause unnecessary disconnections due to voltage drops or frequency variations prescribed in the FRT requirements.

(2) Passive method

We made the following improvements to prevent unnecessary activation caused by the voltage drops and frequency variations prescribed in the FRT requirements.

① Voltage drop requirements

In the conventional method, only the Vab phase was

monitored to measure the voltage and phase jump. The system was likely to be activated by a two-phase short-circuit accident in other phases, as prescribed in the FRT requirements.

We made improvements to monitor the voltage conditions in three phases (only V_{ab} is monitored for phase jump).

② Frequency variation requirements

Ramp variations and step variations prescribed in the FRT requirements may be misidentified as phase jumps.

We reviewed the frequency variation compensation processing and frequency leveling processing, and made changes to combine phase jump determination with frequency variation determination.

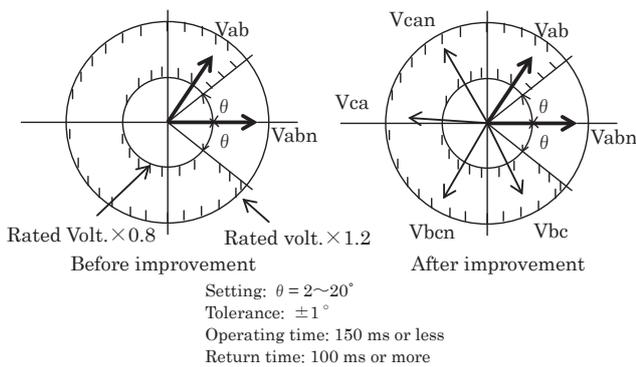


Fig. 10. Passive method operation characteristic

Due to these improvements, this system meets the respective FRT requirements for all power generation equipment as prescribed in the revised 2016 version of the Grid-interconnection Code.

5. Application Status

5-1 Application to large-scale (mega-solar) photovoltaic power stations

Recently, large-scale (mega-solar) photovoltaic power stations have attracted public attention as sources of renewable power generation.

At a mega-solar power plant, multiple power conditioners (hereafter, “PCSs”) (output: approximately 100 kW–500 kW each) are connected in parallel to attain MW-class power generation, in general.

Many PCSs are equipped with an islanding detection function based on the reactive power variation method, which poses the following issues.

- (1) In general, multiple PCSs are synchronized to control the reactive power and detect the islanding conditions. Synchronized control may not be attained for PCSs manufactured by different manufacturers.
- (2) Large-capacity PCSs may affect the power distribution grid due to reactive power variations.

- (3) An SVC function is provided in some cases as an accessory function for a PCS. Due to interference with the reactive power variation method, the islanding conditions may not be detected normally.
- (4) When multiple PCSs are used in the master–slave configuration (in which all slave PCSs are synchronized based on the signals from the master PCS), the islanding detection function may be lost in the event of a failure in the master PCS.

The interharmonic-injection method of this system can solve the above issues. At a mega-solar power station, only a single system is required at one connection point at the primary side of all PCSs (see Fig. 11).

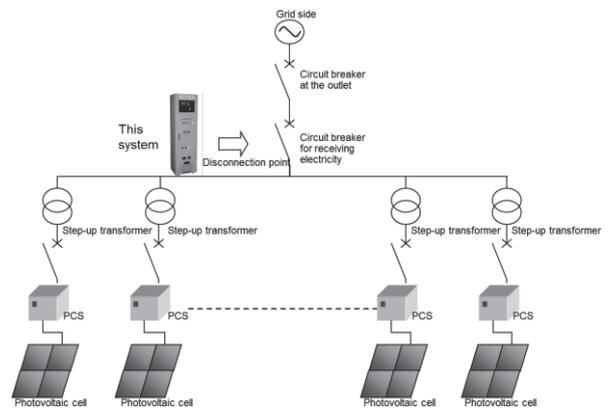


Fig. 11. Conceptual image of application to a mega-solar photovoltaic power station

5-2 Application to multiple distributed power sources in the same distribution line

Conventional islanding detection functions (active methods) include the reactive power variation method, reactive power compensation method, QC mode frequency shift method, and load variation method.

The following issues may occur when these methods are employed for multiple distributed power sources in the same distribution line.

- (1) Installation of multiple systems may cause mutual interference, resulting in a failure to detect the islanding conditions properly.
- (2) Installation of multiple systems may cause flicker.
- (3) It may take longer than usual to detect the islanding condition.

This system enables the user to select one of the 12 interharmonic frequencies to be injected (from CH 1 [2.26-order] to CH 12 [2.73-order]) by using a simple setting. Each system monitors the grid impedance of the injected interharmonic order assigned to the system. Thus, this system can be applied to multiple distributed power sources on the same distribution line by avoiding the same injected interharmonic order in the same bank at a power distribution substation, when this system is introduced (Fig. 12).

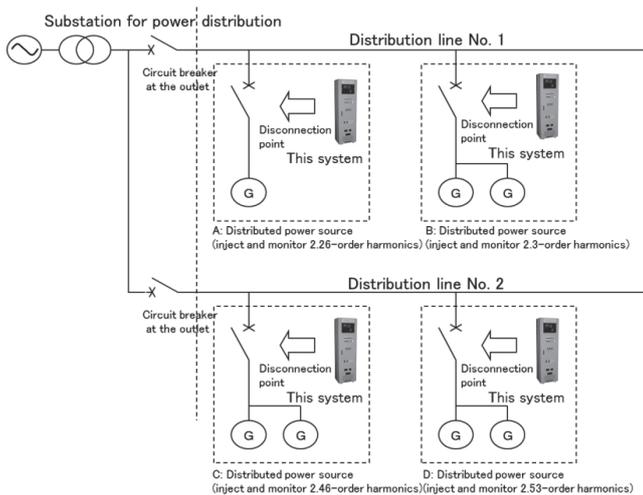


Fig. 12. Conceptual image of installing multiple systems on the same distribution line

6. Conclusion

This system can detect the islanding conditions quickly and reliably, and achieve highly versatile islanding detection regardless of the type, capacity, and number of distributed power sources. Thus, the distributed power sources can be configured more efficiently and reliably than before.

In the process of developing this system, we conducted a performance verification test on an actual grid, as part of a joint research with KEPCO Technical Research Center (currently R&D Center) to verify the performance. After commercialization in 2001, more than 350 sets have been introduced (as of 2016). We believe that this system will continue to help increase the use of distributed power sources.

References

- (1) Grid-interconnection Code JEAC 9701-2016, Special Committee on Grid Interconnection, Japan Electric Association (2016)
- (2) Yamamoto, Nishimura, Minowa, Natsuda, "An Advanced Islanding Detection for Dispersed Power Sources using Interharmonic Current," J. IEIE Japan, Vol.24 (2004.12)
- (3) Tamura, Nishimura, Uemura, Ishikura, Yamamoto, "Islanding Protection Device of a Distributed Generators by Interharmonics Injection Method," 2006 National Convention Record IEEJ Japan, G2, 2006-8
- (4) Nishimura, Minowa, Shikata, Emura, Takeuchi, Okuda, Kitano, Hada, "Advanced Islanding Phenomenon Detection Method for Dispersed Power Sources and a New Product," Nissin Electric Technical Review, Vol.46, No.2 (2001.5)
- (5) Ishikura, Takagi, Fukada, Tamura, "Improvement of Islanding protection Device for FRT Function," 2014 National Convention Record IEEJ Japan, G2 (2014.3)

Contributors

The lead author is indicated by an asterisk (*).

S. ISHIKURA*

- Senior Staff, System Equipment Division, Nissin Electric Co., Ltd.



H. NAKATANI

- General Manager, System Equipment Division, Nissin Electric Co., Ltd.



J. TAKAGI

- Group Manager, System Equipment Division, Nissin Electric Co., Ltd.



T. FUKADA

- Chief, System Equipment Division, Nissin Electric Co., Ltd.



S. NISHIMURA

- Dr.Eng.
Chief Engineer, Power Technology Laboratories, R&D Division, Nissin Electric Co., Ltd.



Y. HADA

- Senior Staff, Power Technology Laboratories, R&D Division, Nissin Electric Co., Ltd.

