

Interconnection Technology for Engine Generators

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ABSTRACT

The development of the 1 kW-class inverter unit with a small engine generator that conforms to “Guideline for the interconnection technology requirements” has succeeded. To connect distributed electrical sources such as wind power generation, photovoltaic generation, or cogeneration to the utility grid, it is necessary to detect demand-side problems including the distributed sources (short circuit, ground fault, troubles in generated voltage or frequency) and to detect problems in the grid (power failure and troubles of voltage or frequency). It is also necessary to protect electric power systems, distributed sources, and electrical appliances. The inverter unit uses both passive and active islanding detection methods. Total distortion factor is reduced to less than 1% by applying two kinds of input current to the power supply unit. Efficiency of the interconnection inverter unit has achieved 91% and total efficiency of power generation of the cogeneration unit has achieved 20%.

1. Introduction

The micro-cogeneration unit described in this report differs from typical portable generators in that it can be connected directly to the power utility grid. This capability is referred to as interconnection. Both grid supplied electricity and electricity from micro-cogeneration units are supplied to electrical appliances. To insure human safety as well as safety to load installations inside the home and appliances – whether inside or outside of the home – while maintaining the quality of residential distribution lines, it is imperative that a standard of rational technology requirements be adopted to govern the connected operation of various power supplies.

The “Guidelines for Interconnection Technology Requirements”⁽¹⁾ issued by the Agency of Natural Energy and Resources, describe the necessary technological requirements for interconnecting distributed power sources, methods for detecting power failures, and procedures for detecting problems with distributed power sources such as wind power generation and photovoltaic generation, as well as problems emanating from the power grid.

These requirements however do not take into account connectivity of rotary generators to low-voltage distribution feeders and do not provide testing details for evaluating whether a connection is appropriate or not. To address this shortfall, the Investigation Committee on Interconnection

Technology has issued the “Testing Methodology Guide for Protection of Interconnection with Gas Engine Cogeneration Systems”.

This report introduces the interconnection inverter technology for 1 kW-class inverter units, which conform to the “Guidelines for Interconnection Technology Requirements”.

2. Development Concept

The inverter used in the micro-cogeneration unit has numerous technology features that enable interconnection and set it apart from typical portable generator inverters. The development of the micro-cogeneration unit was first started to establish autonomous technologies when testing for determining conformity with the interconnection guidelines, which were not yet available.

In adapting the interconnection inverter for the micro-cogeneration unit for residential use, the following conditions were focused on.

- (1) Must conform to the interconnection guidelines, including the implementation of two methods of power failure detection.
- (2) Must embody a high quality power that is generated at low noise levels.
- (3) Must perform at high levels of efficiency.
- (4) Must be able to be integrated into the main cogeneration unit.

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3. Specifications and Features

3.1. Interconnection Inverter Unit Specifications

The interconnection inverter unit adopts a 32-bit CPU control circuit and is comprised of a system for monitoring power supplied by the grid and a controller to enable the inverter unit to convert power from the generator to high-grade power. Table 1 lists the specifications for the inverter unit and Fig. 1 shows a block diagram of the control system.

Table 1 Specifications

Type of inverter	Self-exciting and voltage type power current control system
Type of switch control	PWM
Type of insulation	Non-insulating non-transformer type
Rated capacity	1.0kW
Type of interconnection	Single-phase three-line
Rated voltage	AC 202V (AC101V two-phase)
Rated frequency	50/60Hz
Output power factor	Over 0.95
Total output current distortion	Under 5 %
Type of electric power controlling system	Regulating output electric power
Protective measures	Over voltage protection
	Under voltage protection
	Over frequency protection
	Under frequency protection
	DC injection protection
Type of anti-islanding protection	Passive: Detecting saltatorial drift of voltage phase
	Active: Phase shifting system
Type of Restraining power output	Effective power controlling system



Fig. 2 Inverter unit

4. Component Technology

4.1. Interconnection Inverter Controller

The following functions are requirements for the interconnection inverter.

1) To enable grid connectivity and output

In connecting to the utility grid, the inverter unit must adopt specifications that conform to the “Guidelines for Interconnection Technology Requirements” issued by the Agency of Natural Resources and Energy, a division of the Ministry of International Trade and Industry in 1986.

Table 2 provides an overview of these guidelines.

2) Accommodate Regional Variations

There is some variation in utility voltage depending on regional location. Also, utility power sources may experience short interruptions, voltage dips and voltage phase variations. To enable follow-up operation for these variations in power standards, the unit must be able to accommodate a threshold of 7 different protective functions that can be set at 5 levels. A customized communication software package has been developed for PC-based application to enable multiple settings according to regional variation.

3) Allocate Priority to Environmental Issues

Cogeneration systems have been designed to provide efficient use of energy and are highly efficient. Running cogeneration systems at a constant level of power output and

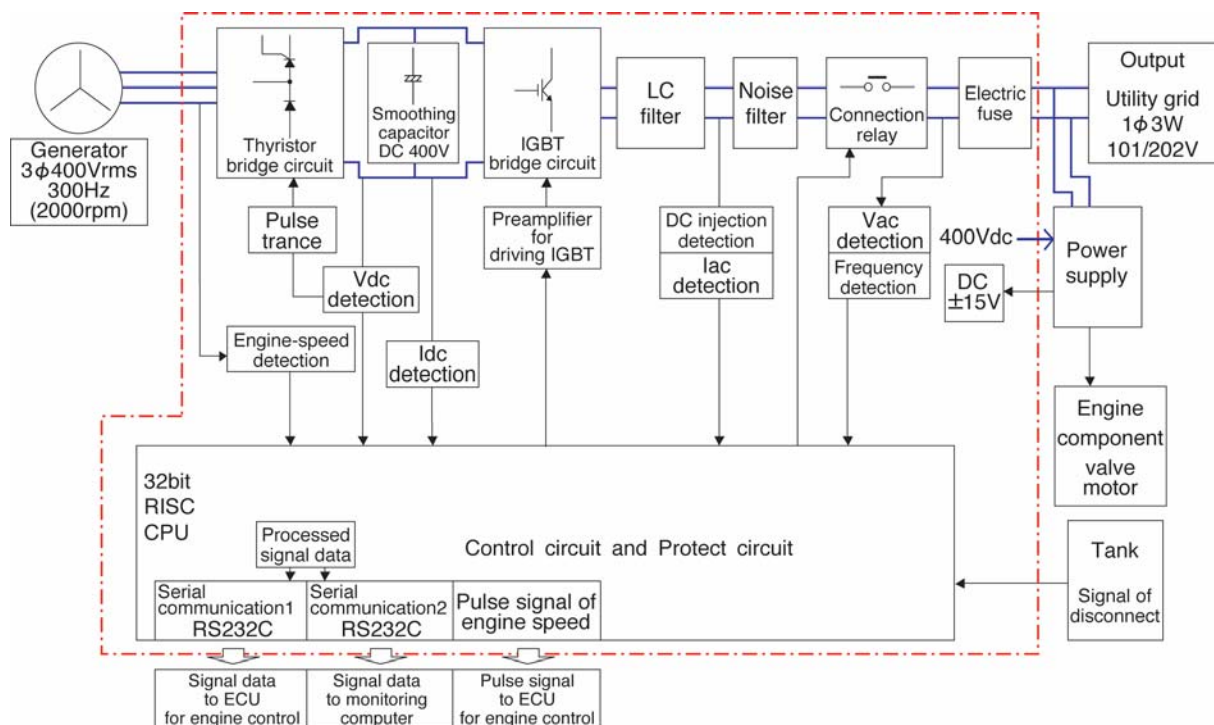


Fig. 1 Control system diagram

Table 2 Guideline for utility-interconnection

Test term	Benchmark			
	Action	Protect level	Operating time	Action after a utility disturbance
Over current protection.	Disconnect from a utility grid.	Setting level $\pm 0.2\%$ Max. Setting level is below 150% of rated current	0.5 sec Max.	–
Over/Under DC current protection.	Disconnect from a utility grid.	–5% Min. +5% Max. against working voltage.	0.5 sec Max.	–
Detecting DC injection.	Disconnect from a utility grid.	1% Max. against rated AC current.	0.5 sec Max.	–
Over/Under AC voltage protection.	Disconnect from a utility grid.	Setting level –0.2% Min. +0.2% Max.	Setting time –0.1sec Min. +0.1sec Max.	Do not reconnect after a period.
Over/Under frequency protection.	Disconnect from a utility grid.	Setting level –0.1Hz Min. +0.1Hz Max.	Setting time –0.1sec Min. +0.1sec Max.	Do not reconnect after a period.
Active detecting islanding.	Disconnect from a utility grid.	–	0.5sec Min. 1sec Max.	Do not reconnect after a period.
Passive detecting islanding.	Disconnect from a utility grid.	–	0.5 sec Max.	Do not reconnect after a period.
Blocking after a utility disturbance in a period.	–	–	–	Do not reconnect after a period.
Detecting instantaneous over voltage.	Disconnect from a utility grid.	Setting level –5% Min. +5% Max. Only 135V Max.	1 sec Max.	–
Restraining rising output voltage	Restraining power output under 107V when working voltage is 100V.	–	–	–

implementing optimal design settings for inverter efficiency along with the incorporation of an efficient engine design have enabled a high level of unit efficiency.

4.2. Islanding Detection

A key feature of interconnection technology is that when a malfunction in a cogeneration unit or a defect in the source side power is detected, the generator is halted and the connection is immediately interrupted. It is essential that the system embody detection functions to monitor malfunctions caused by leakage currents or over current occurrences, as well as the ability to detect abnormalities in distribution line voltage or frequency problems.

When a problem occurs in the source side power, the generating appliance is autonomously halted and the connection is immediately interrupted. The unit will not establish connectivity until the source side power has recovered.

When the power distribution line is disconnected from the main source due to power failures, malfunction, or for some other reason, the power from the cogeneration unit and power being consumed from the distribution line tend to create a static state of equilibrium. If this occurs, the cogeneration unit will only carry the loading from the distribution line and resume operation with the distribution feeder as it is being charged. This phenomenon is called islanding. Since there is no change in the distribution line voltage or frequency when islanding occurs, the normal protection relay is not able to detect the islanding occurrence.

Islanding conditions are potentially dangerous to

distribution line technicians and may also cause large over currents caused by the difference in voltage phase between the line experiencing islanding and the main source when the connection with the main source is closed again. Islanding ultimately causes undesirable damage to distribution line equipment and appliances. For this reason, the system must be able to autonomously halt the generator when the distribution power line is disconnected.

4.2.1. Passive islanding detection

Passive islanding detection picks up small fluctuations in line voltage frequency, voltage phase, or harmonic voltage that are brought on by vacillating current and loading levels, which occur during islanding. Although this detection mode is noted particularly for its rapid detection capability, it has a low level of detection capability when the generated power and loading levels are at perfect equilibrium. The principles adopted in the passive islanding detection mode used by the interconnection inverter unit are described below. This detection mode uses what is referred to as voltage phase-skip detection, which detects the amount of change in frequency.

Although electric loading conditions in residences change for a variety of conditions, when loading requiring reactive power is connected where the power factor $\neq 1$, the voltage frequency is normally stabilized at 50/60 Hz. When a power failure occurs, the interconnection inverter generates a constant rate of AC power. When a power load is connected where the power factor $\neq 1$, the voltage phases are advanced or delayed according to the loading reactive power value. The voltage frequency before or after a failure occurrence varies greatly at points where the failure occurs. Looking closer at

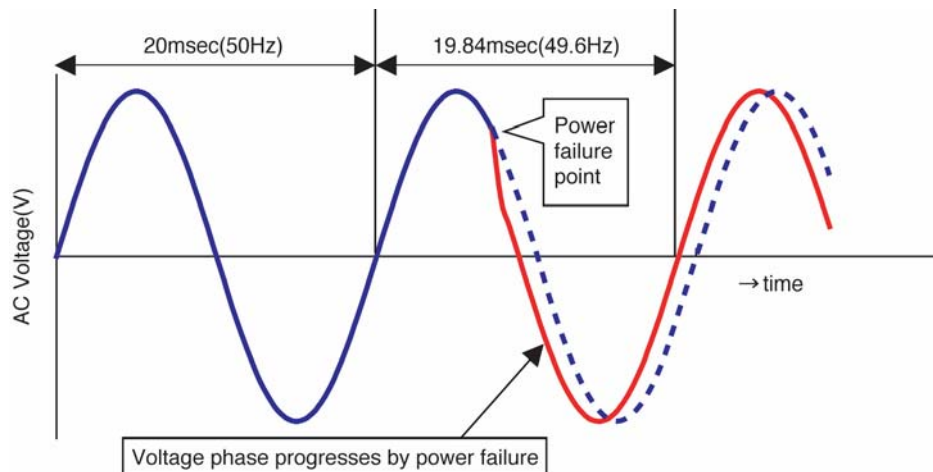


Fig. 3 Voltage wave pattern in power failure with connected inductance load

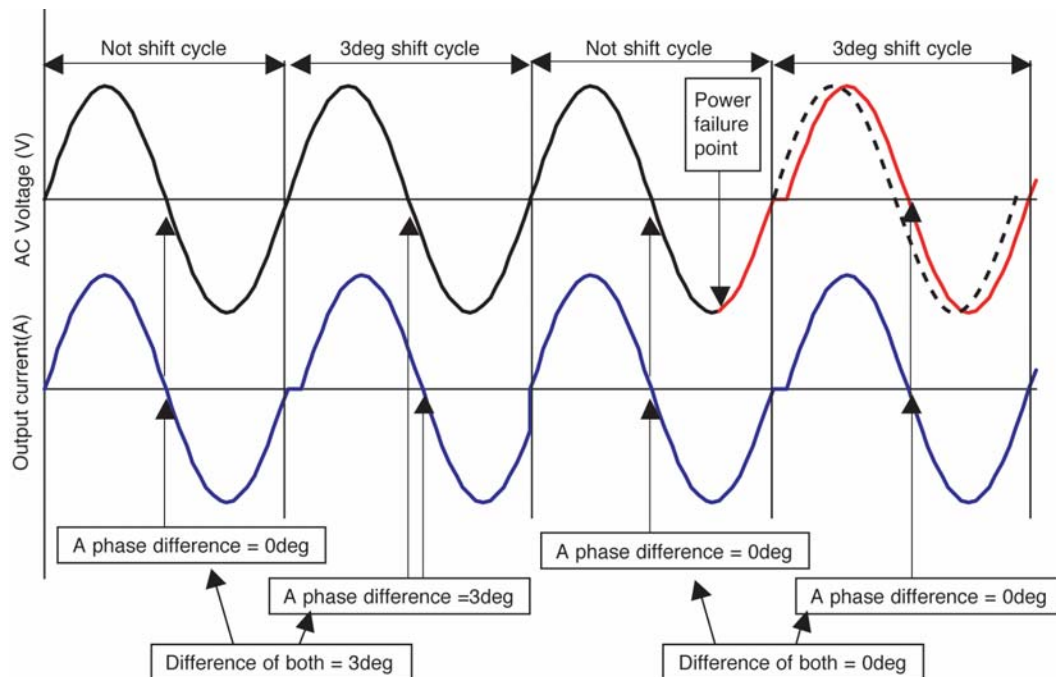


Fig. 4 Control method of active islanding

this phenomenon, when the change in voltage frequency is greater than 0.8%, a power failure is presumed to have occurred and power output is halted. The threshold can be adjusted in 5 different levels ranging in 0.2% ~ 1.0%.

Noise generated from large power loading associated with appliances, whether ON/OFF, tends to cause changes in voltage frequency. The passive detection mode is able to detect this variation. When the variation is detected, the inverter CPU is turned OFF for 5 seconds (gate blocking) without causing the interconnection relay to turn OFF. If an actual power failure were to occur, the AC under voltage protection (UVR) function is initiated and the interconnection relay is turned OFF. If there is no power failure, the relay is automatically re-established in 5 seconds.

Although the principles governing the passive islanding method of detection have been discussed, there are, logically speaking, conditions in which passive islanding detection is not able to detect a power failure.

When a connection is established at a residence with power loading $\cong 1$ kW and a loading power factor = 1, there is no change in voltage and also no change in frequency because of phase skipping. Therefore power failure cannot be

detected. The active islanding detection method has been implemented to compensate for such conditions.

4.2.2. Active islanding detection

Active islanding detection creates small fluctuations in generated power voltage, frequency or voltage phase and works to break the static equilibrium between the generated power and loading levels that occur with islanding. This ultimately leads to some voltage and frequency malfunctions but stops the occurrence of islanding. The active islanding detection mode is effective in instances where a static state of equilibrium has occurred between the generated power and loading levels.

The principle adopted in the active islanding detection mode used by the interconnection inverter unit is described below. This detection mode uses what is referred to as phase shift mode of detection.

Figure 4 shows the deliberate changes to current and voltage phase that alternate at fixed cycles from 0° to 3° (where a delay has occurred). Normally, the difference between a 0° phase and a 3° phase is 3° . When a power failure occurs, a loading with a power factor of 1 is

connected, and the current from the cogeneration unit is equal to the voltage waveform. So even if the displacement is 3° , the voltage phase remains 0° as no phase change occurs.

The active islanding detection mode recognizes a power failure when the phase differential is less than 3° .

When the active islanding detection function is active, the gate blocking setting and interconnection relay are turned OFF. After verifying that the voltage and frequency during a fixed interval are within a range of operational normalcy following power recovery, the connection is re-established. The fixed interval can be set at 5 different stages within a period of 120 ~ 300 seconds in accordance with guideline specifications.

4.3. Power Quality

The system has been designed to filter out reactive power transmission from the engine generator and to avoid exerting any changes in voltage on the distribution line. Additionally, the system harnesses the highest quality power by suppressing harmonic currents and preventing interference to other electrical components or appliances, and prevents any occurrence of electromagnetic interference.

4.3.1. Harmonic currents

The interconnection inverter adapted to the cogeneration unit, adopts the following technological principles. The cogeneration unit's main power supply and auxiliary units and controller exert the same degree of electrical load on the interconnection inverter as on domestic appliances. When the power from the interconnection inverter has passed through the cogeneration unit's main power supply and auxiliary unit load, the power factor from the cogeneration unit is reduced thereby creating distortion in the current. To avoid this malfunction, the power supply unit has been designed to accommodate 2 types of power input, the grid supply and converted DC current, which takes place within the inverter unit. Figure 5 shows how the grid supply is consumed when the engine is started. The figure also shows how the power and auxiliary units operate with only DC current from the generator when the cogeneration unit is generating power. After the AC/DC conversion takes place, quality power sent from the inverter output channel is transmitted to the

distribution line without passing through the main power supply or auxiliary unit.

By implementing this method of power generation, the control power supply is preserved when the engine is started even if a short interruption were to occur on the grid power side.

A comparison was conducted on the single circuit system in which the power passes through the main power supply and auxiliary unit and the two-circuit system. Figure 6 shows the results of this comparison. As shown in the figure, the distortion factor reaches a level high of 3.86% in the single circuit system while the two-circuit system registers a low distortion factor of 0.89%.

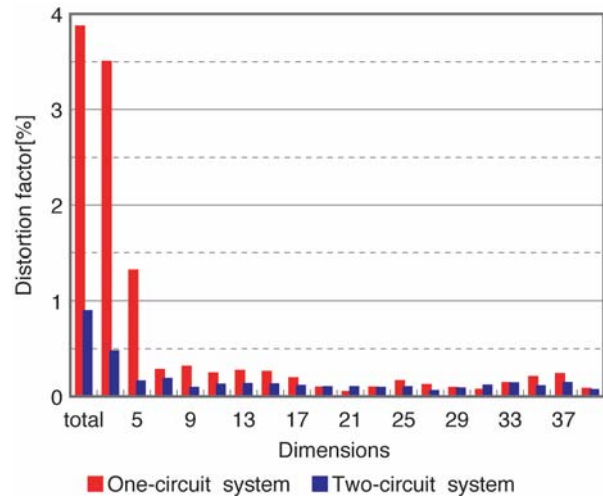


Fig. 6 Test results of distortions factor

5. Applications to the Cogeneration Unit

For details regarding the cogeneration unit with inbuilt interconnection inverters, refer to the technical report published by Takaishi et al⁽²⁾.

Based around a 1 kW power output unit, which is suitable for the typical residence, Fig. 7 shows the interconnection inverter efficiency level at a peak of 91%, which provides a power efficiency level of 20%. Figure 8 provides a general view of the installed micro-cogeneration system. Power produced from this unit is sent to electrical appliances throughout the house by the interconnection supply. The overall level of efficiency, including the heat output, reaches a maximum peak of 85% and suppresses consumption of the

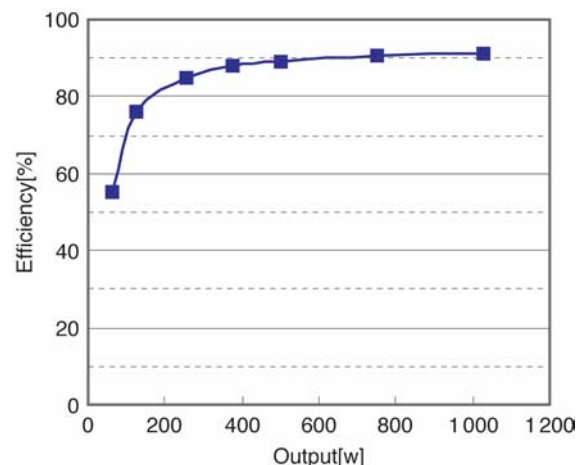


Fig. 7 Test results of inverter efficiency

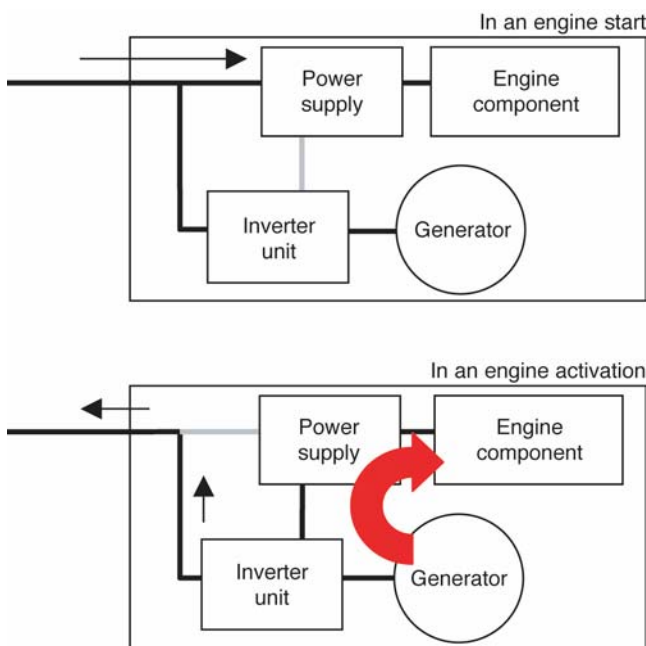


Fig. 5 Explanation of this technique

primary energy within the house.

The interconnection inverter has been incorporated and adapted to the cogeneration unit. The high voltage distribution line running from the generator is connected to the interconnection converter within the shortest possible distance. This contributes to the reduction of the number of parts required for the configuration. See Fig. 9 for an overview of the inverter unit for interconnection.

Figure 10 provides an overview of the newly developed micro-cogeneration unit.

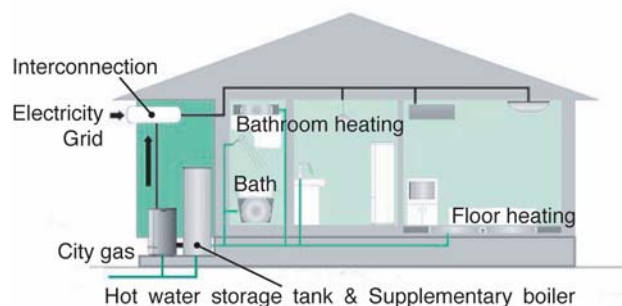


Fig. 8 General view of micro cogeneration system

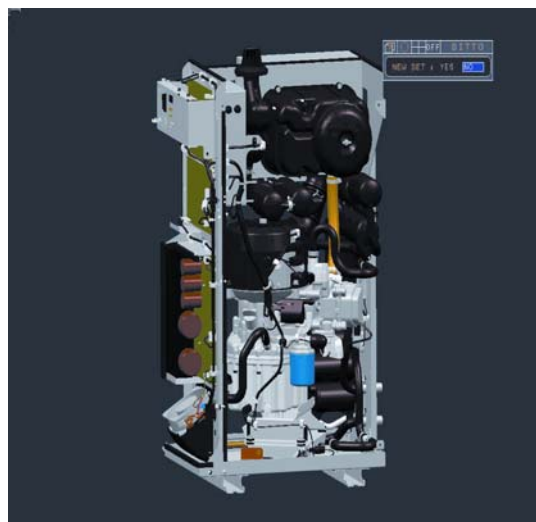


Fig. 9 Inverter unit for interconnection



Fig. 10 Overview of micro cogeneration unit

6. Summary

The interconnection sine wave inverter has been successfully adapted to the product profile and conforms to the "Guidelines for Interconnection Technology Requirements".

- (1) The system satisfies all technological principles described in the "Testing Methodology Guide for Interconnection Maintenance Appliances for Gas Engine Cogeneration Systems".
- (2) Applying 2 types of input power supply in accordance with technology measures for suppressing harmonic currents has produced a low 0.89% distortion factor and enabled the supply of high quality power for domestic applications.
- (3) Optimal settings have been adapted to the inverter unit to achieve a 91% level of efficiency for the interconnection unit.

The interconnection inverter, which is based on the configuration principles described herein, has been installed in a typical residential environment for purposes of field testing and monitor testing to provide a working example of interconnection.

The authors would like to take this opportunity to express their gratitude to the many people who have cooperated in the development of this unit.

Reference

- (1) Electricity Technology Standard Investigation Committee: Guidelines for the Distributed Power Source Technology Requirements, JEAG 9701 (1993)
- (2) Takaishi, T., Ara, M., Togawa, K.: Introduction of Micro Combined Heat and Power Generation Unit for Residential Use, Honda R&D Technical Review, Vol. 15, No. 1, p. 53-58 (2003)

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