

Introduction of Micro-combined Heat and Power Generation Unit with Backup Function

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ABSTRACT

A micro-combined heat and power generation (micro-cogeneration) unit which can be used as a backup power generator in an emergency has been developed. A battery, DC-DC converter unit, and inverter unit were newly developed to enable autonomous operation of the generator. The DC-DC converter unit converts power from the battery when backup operation commences, and supplies power to the starter. It also applies charging control to extend battery life. In addition, the inverter unit is the same size as the model currently on the market, which does not have a backup power function, but it incorporates both grid-connected and backup generation functions. Output power as an emergency generator during backup operation has been increased 1.5 times against the previous model. The realization of hybrid power generation through the use of battery assist has reduced voltage sag when an electrical load is connected, and thus, the amount of usable electric load and types increased.

1. Introduction

The G8 Leaders Summit held in Japan in 2008 expressed their intention to reduce the amount of greenhouse gas emissions in the entire world to at least half by 2050, spurring their full-fledged efforts toward the realization of low-carbon society. However, energy consumption in the civil sector (household) is growing steadily, with a skyrocketing rate, which accounts for a key factor in the growth of energy consumption as a whole. In the future, it will be necessary to establish more stable power supply in order to meet the increasing demand for electric power due to the electrification of mobility and other factors.

Cogeneration system, which uses a generator to produce electricity, while simultaneously recovering and reusing the heat generated, has already been used in large-scale facilities, including factories, and is expected to effectively reduce CO₂ emissions⁽¹⁾. Nonetheless, we have been facing the issues for the practical use of small-scale cogeneration system, such as its cost, service life, and other issues. Using unique technologies based on small gasoline engine and inverter generator, Honda has

overcome those issues, launching the sales of the world's first small gas engine cogeneration unit for household (hereinafter called "micro-cogeneration unit")⁽²⁾ in February 2003 in Japan, and 2007 in the U.S. In the U.S., because natural disasters, such as flooding of rivers caused by heavy rains, large-scale hurricanes, and blizzards frequently lead to power interruptions⁽³⁾, market for backup generator was firmly established. Since the household cogeneration unit is a power generation system for everyday use that places a very low burden on the environment, it will benefit our customers to use the unit as an backup generation equipment in case of power outage from the perspective of home security.

In this paper, we will introduce Honda's micro-cogeneration unit, backup power generator in case of power outage, which Honda launched in January 2009 in the U.S.

2. Main Specifications of the Product

The micro-cogeneration system is a household energy supply system that consists of Honda micro-combined heat and power generation unit and cogeneration unit with

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recuperator that was jointly developed by a city gas company and water heater manufacturer. It was considered that there is demand for micro-cogeneration unit with backup power generation function in the U.S., where the electrical power condition is different from that of Japan.

Figure 1 illustrates how the system is utilized in a household. Electricity generated by the Micro Combined Heat and Power Generation unit goes through a power distribution board, and is consumed by the electric appliances in the household. In the system that is used in Japan, for example, when the engine unit generates electricity, the heat that is recuperated from the engine is temporarily kept as hot-water in a hot-water storage tank, which not only supplies hot water, but also contributes to underfloor heating, heater and dehumidifier for the bathroom, and other uses. In the U.S., on the other hand, the heat is directly exchanged with the air through a hot-air heater, and is used for hot-air heating.

Figure 2 shows the appearance of Micro Combined Heat and Power Generation unit with a gas engine generator, heat exchanger, grid-connected inverter, and other components. Table 1 shows the main specifications of the unit. The housing of previous model was equipped with new battery and DC-DC converter unit.

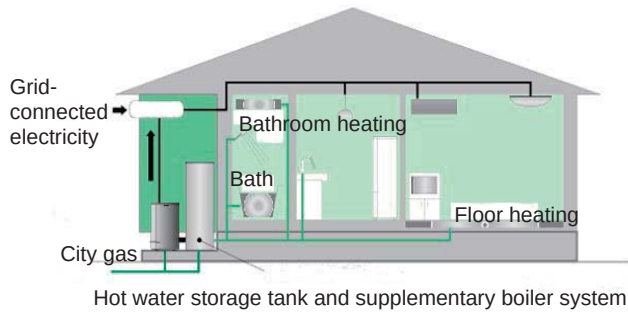


Fig. 1 Micro-cogeneration system



Fig. 2 External view of micro-cogeneration unit

Table 1 Specifications (US model)

		Normal	Boost	Backup
Output	Electricity	1 Φ 3W 240 V/120 V 60 Hz		1 Φ 2W 240 V 60 Hz
		1.2 kW	1.8 kW	1.8 kVA
	Heat	3.2 kW or more		
Power supply		Grid connection by inverter		Inverter
Heat recovery		80 °C Hot water		
Efficiency	Electricity	23.0% or more		
(LHV)	Heat	62.5% or more		
Dimensions (LxWxH)		380 × 580 × 880 mm		
Mass		82 kg		
Noise		47 dB(A)	55 dB(A)	
Engine	Type	Liquid-cooled 4-stroke OHC vertical single cylinder		
	Displacement	163 cm ³		
Starting system		Starter generator		

3. Technological Issues and System Configuration

In addition to the grid connection mode, which was the only operating mode used in the previous model, the new model features two new operating modes, grid connection boost mode and backup generation mode. The grid connection boost mode refers to the system that sells electricity in response to the request from power company, when there is a demand for power from extensive area, where power plants do not cover. In this situation where power is insufficient, higher power output is required. The backup generation mode, on the other hand, refers to the mode that the unit autonomously generates power as a backup generator during power outage as indicated in the above. In the backup mode, higher generator output is also required to allow the user to use more electrical load. According to the survey conducted by Honda in the U.S., 23% of purchasers of Honda gasoline engine generator, EU2000iA (rated output: 1.6 kVA), needed it as a backup power supply during power outage. Therefore, the output of new model in backup mode as well as grid connection boost mode was set at 1.8 kVA. Because the rated output of grid connection mode remains 1.2 kW, the same as that of the previous model, the output of the engine, which functions as the input source to increase generator output, is increased by accelerating engine speed, and thus, the output performance of inverter is also facilitated. In order to increase electrical load that can be used in backup mode, battery assists generator in producing more output.

Figure 3 shows the system configuration of previous model. Power output from the alternator (hereinafter called “ALT”) is converted to DC in the rectifier, and then to

constant DC voltage in the boost converter of the grid-connected inverter (hereinafter called “inverter”) installed in the micro-cogeneration unit. In the MOSFET section, the power is further converted to a form, which can be connected to the commercial power supply, to complete electric interconnection. When starting the engine, the use of rectifier as a starter driver with the system as the power source, enables the inverter to function as a starter driver as well. This configuration enables the inverter unit to use the power line in both directions⁽⁴⁾, thus eliminating dedicated starter devices, switching relays, etc. The engine control unit (hereinafter called “ECU”) is the master unit of Micro Combined Heat and Power Generation unit, issuing commands, organizing operation, and communicating with the externally connected water heating unit or heater. Although it was possible to eliminate the electronic unit for startup in the configuration of previous model, the engine could not start during power outage, since it used the system as its power

source. In order to realize autonomous startup and power generation, and to fulfill the performance requirements for backup generation, the following items were placed on our development agenda.

(1) Power source for autonomous startup

The unit should be fitted with Ni-MH battery to help ensure a power source for engine startup during power outage. Long-life battery is desirable to avoid frequent maintenance. Also, it is necessary to check the battery condition in order to help ensure engine start in case of power outage.

(2) DC-DC converter unit

DC-DC converter unit (hereinafter called “DC-DC converter”) is necessary to convert the power from low-voltage battery to the equivalent voltage to the system voltage in order to provide it to the inverter. The DC-DC converter deals with high-current, which generates heat and electromagnetic noises. This promotes us to develop highly efficient and low-noise DC-DC converter.

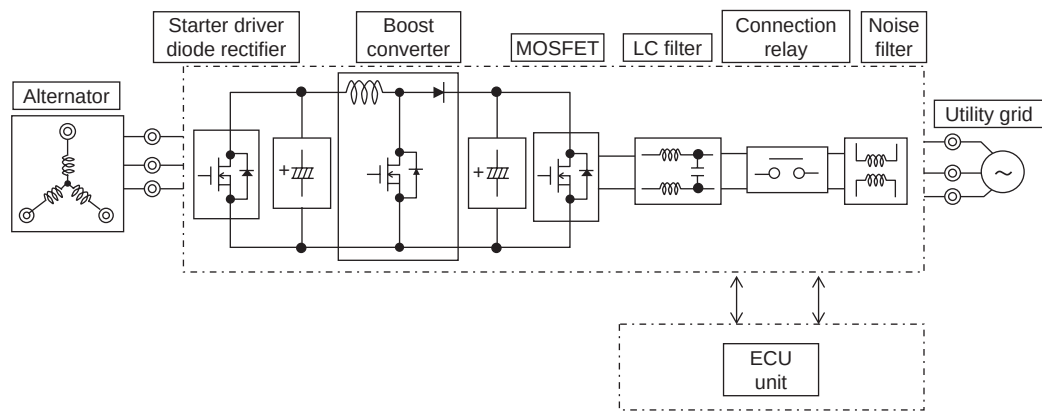


Fig. 3 Diagram of previous system

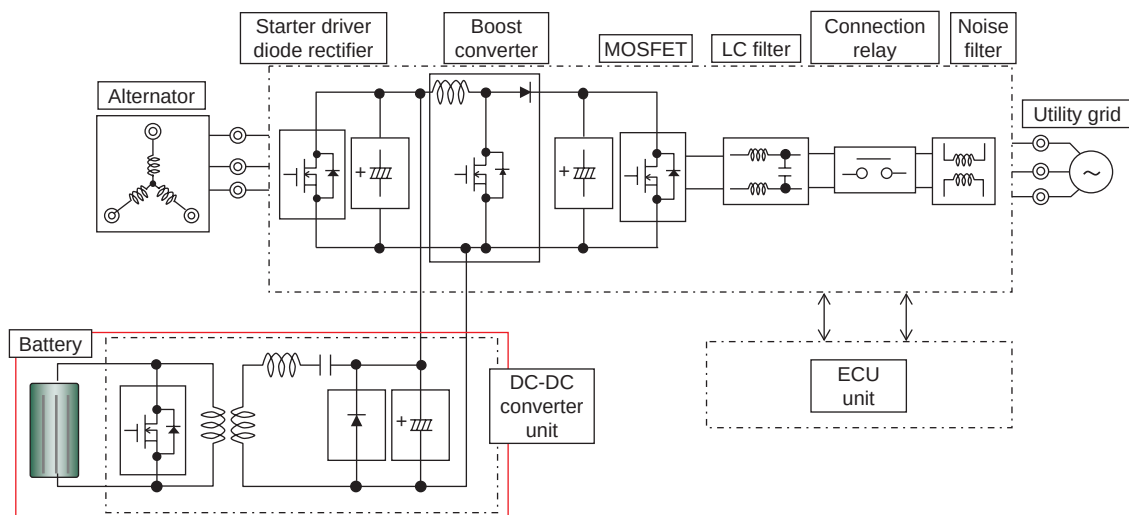


Fig. 4 Diagram of newly developed system

- (3) Inverter unit which is capable of electric interconnection and independent generation

Another issue is the fact that all electric interconnection, electric boost interconnection, and backup generation are performed in a single hardware. With regard to the performance of backup generation, the LC filter settings that enable electric interconnection need to meet the requirements for backup generation, and output should be 1.5 times higher than that of the previous model in the same size. In addition, hybrid generation should be available by means of battery assist in order to increase electrical load during backup operation.

Figure 4 shows the configuration of newly developed system. In the following chapter, we will discuss actual operation of this system in detail.

4. Function of Each Component

4.1. Ni-MH Battery

4.1.1. Battery specifications

A small Ni-MH battery, which is capable of high-output, is employed in the system to maintain sufficient power to start engine during power outage. Figure 5 shows the appearance of the battery with 12 V of rated voltage and 6.4 Ah of rated capacity, equipped with built-in current and temperature fuses and a temperature sensor. Figure 6 indicates required battery output to start the engine along with the temperature characteristic of the battery output. It suggests that high output is necessary for engine start, because engine friction increases at low



Fig. 5 Ni-MH battery

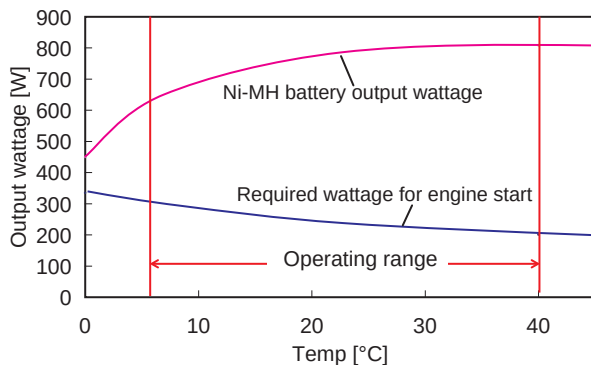


Fig. 6 Ni-MH battery output wattage

temperatures on the one hand, the battery output declines at low temperatures on the other. Therefore, we decided the battery specifications on the basis of the temperature characteristics of the battery to fulfill the output requirements in the most severe conditions for the battery.

4.1.2. Technologies to increase battery life

We employed Ni-MH battery, which has a twice longer lifespan than that of lead battery. Since the lifespan of Ni-MH battery declined with a rise in temperature, the battery was positioned by the vent that admits cooling air, as shown in Fig. 7, to control the rise of temperature below 10°C. In order to minimize battery degradation due to charging, intermittent charging method was also adopted, as shown in Fig. 8. The DC-DC converter constantly monitored battery voltage, and applied charge control to help ensure sufficient state of charge (SOC) to start the engine. When the battery was used to start the engine, the DC-DC converter calculated the amount of power taken out of the battery to start the engine, and conducted a fundamental charge to cover the loss. Following this, trickle charge was conducted to help ensure uniform charge throughout the cells, and to maintain a hundred percent charge. Compared to the previous model in which the battery was constantly

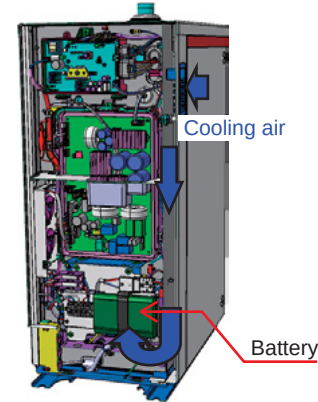


Fig. 7 Ni-MH battery layout

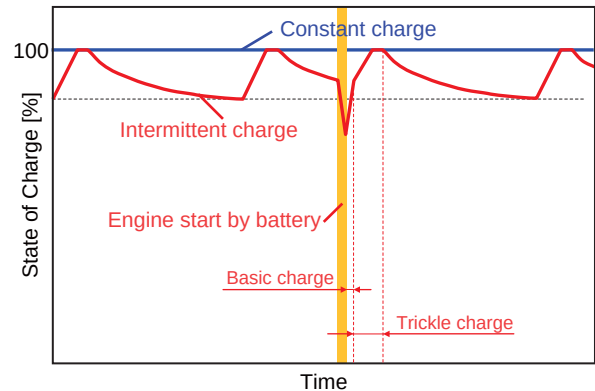


Fig. 8 Ni-MH battery intermittent charge

charged, this system maintains sufficient SOC to start the engine even in the worst-case scenario, while reducing battery degradation due to overcharging.

4.1.3. Checking battery degradation resulting from internal resistance

For the new model, the state of battery should be checked periodically, and monitored on a routine basis, by starting the engine with battery power, in order to help ensure that the engine can start during power outage without fail⁽⁵⁾. The status of battery degradation is checked based on Eq. (1). Using previous voltage and current before discharge, voltage and current at discharge, and current correction factor and temperature correction factor, the internal resistance of battery, R , is calculated based on the above equation. Note that the internal resistance is calculated, when the discharge current reaches or exceeds a predetermined figure.

$$R = k_i k_t (V_0 - V_1) / (I_1 - I_0) \Omega \quad (1)$$

V_1, I_1 : Voltage and current at discharge

V_0, I_0 : Voltage and current before discharge

k_i, k_t : Current correction factor, temperature correction factor

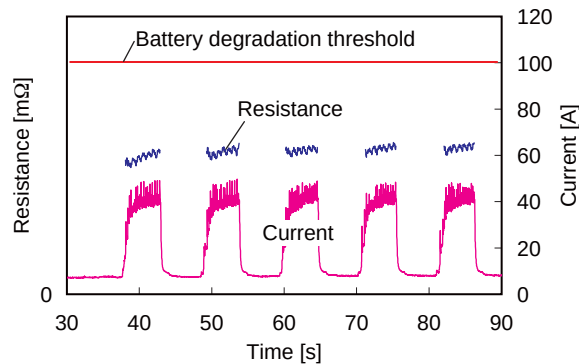


Fig. 9 Battery degradation threshold and resistance

The internal resistance of battery at the limit for engine start in the engine startup tests was deemed to be the threshold value of battery degradation. In cases of exceptional degradation of battery, this periodic calculation of internal resistance also enables us to detect it in advance.

Figure 9 shows the results of calculations of internal resistance, using a battery that exceeded the assumed battery lifespan of new model. Based on the considerable gap between the threshold and the battery's internal resistance, we confirmed that the battery had a sufficient length of battery life.

4.2. DC-DC Converter

In order to allow the micro-cogeneration unit to autonomously operate during power outage, the following functions are necessary for DC-DC converter:

- (1) Detection of power source outage in the power grid
- (2) Charging control of battery
- (3) Power source to start engine during the engine's autonomous operation

Figure 10 shows the detailed system configuration of the DC-DC converter outlined in Fig. 4. The unit consists of grid voltage detect circuit, which monitors the status of the normal grid power supply and power outage, battery charge control circuit, which controls charge, and DC-DC converter section, which boosts battery voltage, and supplies power to the inverter.

4.2.1. Grid voltage detect circuit

The grid voltage detect circuit reduces the grid-supplied voltage to low voltage with insulated transformer, and then, the CPU monitors the grid voltage to constantly make a judgment whether the status of the normal grid power supply should be recovered or not. When an outage in the grid power supply is detected, the ECU unit sends a command to boost the battery voltage in order to supply the inverter unit with power to start engine. If

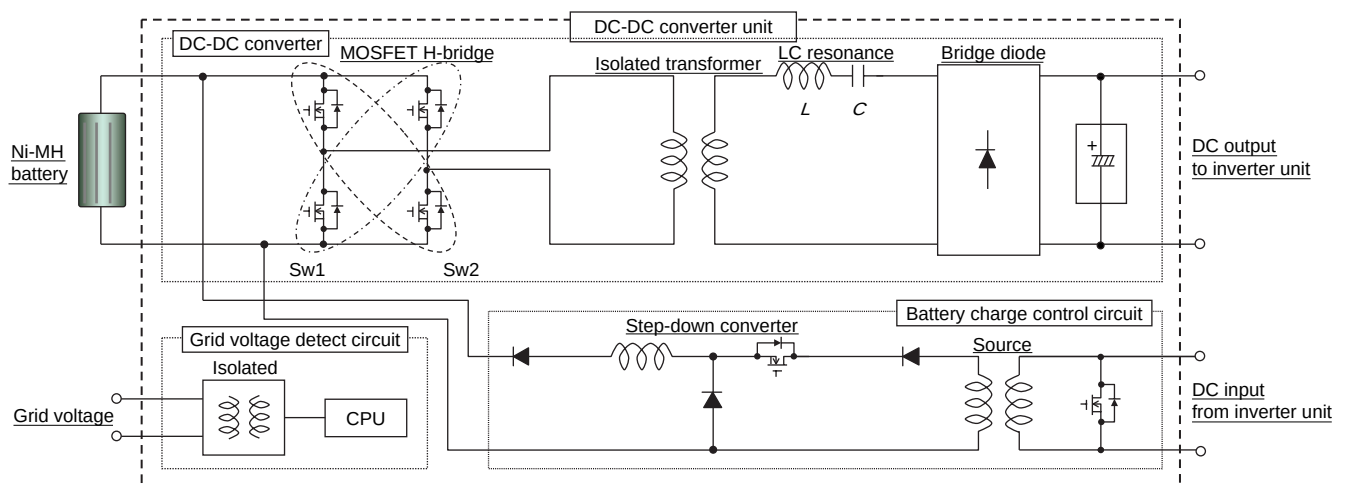


Fig. 10 DC-DC converter unit

disconnection or short-circuit occurs in the grid voltage detection lines, the self-diagnostic function of DC-DC converter allows the user to aware of anomaly.

4.2.2. Battery charge control circuit

The battery charge control circuit applies charge current control by means of a step-down converter, with DC voltage rectified from the grid power input by the inverter, or DC voltage rectified from the ALT output during engine operation, as the power source.

4.2.3. DC-DC converter

In a state of normal grid connection, the inverter starts the engine, using the grid voltage as a power source. During power outage, however, the battery is used as the power source to start engine. In order to share the inverter hardware, it was necessary for the DC-DC converter to boost the voltage input from the battery to close to the grid voltage. Considering the DC voltage of 340 V rectified from the grid voltage ($340 \text{ V} = 240 \text{ V} \times 1.414$), the battery voltage in the newly developed model was set to be 270 V, approximately a 20-fold increase, to share the parts. In addition, it was necessary to use an insulated DC-DC converter in order to provide inverter unit, which is isolated from the casing, with power from the battery, which is connected to the engine earth and the casing earth. By switching between MOSFET (metal oxide semiconductor field effect transistor) H-bridges Sw1 and Sw2, as shown in Fig. 10, the voltage supplied from the battery impresses a rectangular AC voltage in the transformer.

As a result, a voltage representing the voltage ratio between the primary and secondary coils is output from the secondary coils of the transformer as a rectangular AC voltage. Conversion of this rectangular AC voltage waveform into an isolated DC voltage is achieved by its full-wave rectification and transformation into a DC voltage by the bridge diodes. Elements with a low level of ON resistance were selected for the MOSFET section to cope with low voltage and high current. However, when switching is conducted in the high DC current range, increased switching loss leads to generate heat and noise. For this issue, in order to realize high efficiency and low noise in the newly developed model, a resonance converter and resonance coils were employed, as shown in Fig. 10, to enable current resonance type of zero current switching (ZCS). The resonance frequency, f , can be expressed by Eq. (2), using the capacity of the resonance condenser, C , and the inductance of resonance coils, L as shown below.

$$f = 1/2\pi\sqrt{L \cdot C} \quad (2)$$

Switching at 0 A by means of current resonance is enabled by synchronizing the carrier frequencies of the H-bridges, Sw1 and Sw2, with the resonance frequency, f . As a result, switching loss was reduced, and high

Table 2 Specifications (DC-DC converter unit)

Boost type	Current resonance type isolated converter
Switching type	Zero current switching
Rated input voltage	14 V
Rated output voltage	270 V
Rated output power	440 W
Switching frequency	40 kHz
Dimensions (LxWxH)	277 × 187 × 32 mm
Mass	1510 g

efficiency and low noise were achieved⁽⁶⁾.

In addition, each of the input circuits was designed for high-impedance input, in order to reduce standby energy in the state of normal household, where the unit stood by for long time. As a result, the standby energy of DC-DC converter was reduced to a negligible level of 1/100 less than the battery's self-discharging level of 0.3 mW.

4.2.4. Test results

Table 2 shows the specifications of DC-DC converter, and Fig. 11 shows its appearance. Figure 12 shows the measured waveforms of the switching voltage and the transformer input current in the DC-DC converter. The measured current waveform on the primary side of the



Fig. 11 DC-DC converter unit

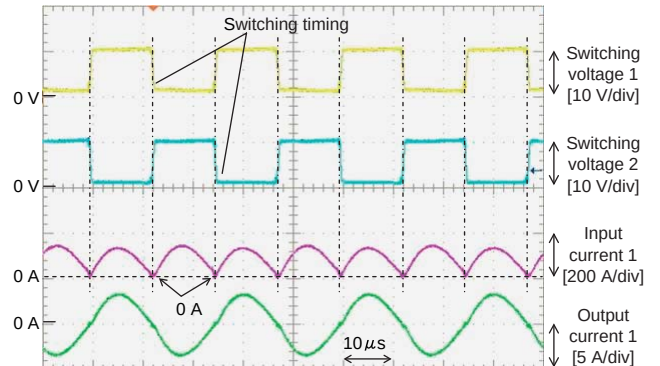


Fig. 12 Zero current switching

Table 3 Test results of DC-DC converter unit

Input voltage	14 V
Output voltage	273 V
Efficiency (rated output power)	91.6 %
Maximum output power	1168 W
Output voltage (no load)	297 V

isolated transformer (Input current 1) suggests that the ZCS operation was conducted with switching at 0 A. Because manufacturing variations in the resonance condensers and the resonance coils resulted in variations in resonance frequency, a correction term for the switching frequency was set with software. The correction term was set in the inspection prior to shipping the DC-DC converter to enable the ZCS operation. Figure 13 shows the load efficiency of DC-DC converter for 12 V and 14 V of input voltage. Table 3 shows test results for the unit. The ZCS operation achieved 91.6% of efficiency at the rated output of 440 W. In addition, even the input voltage achieved an efficiency of 89.5% at the engine start-up, when the maximum power was used. The realization of high efficiency in the isolated DC-DC converter continuously enabled rated power output, using only natural heat dissipation, without necessitating external cooling.

4.3. Inverter

Figure 14 shows the system configuration of the inverter outlined in Fig. 4. The system is composed of starter driver / diode rectifier, which enables the engine to start, and converts the power from the ALT to AC or DC during power generation; boost converter that raises DC voltage; a MOSFET section that converts DC voltage rectangular voltage based on pulse width modulation (PWM); LC filter that converts rectangular voltage to sine voltage; relay that connects to or disconnects from the grid; a noise filter that removes noise; a current sensor that detects output current; current limiters for autonomous operation and grid-connected operation, which limit the currents used in these operating modes; voltage sensor that

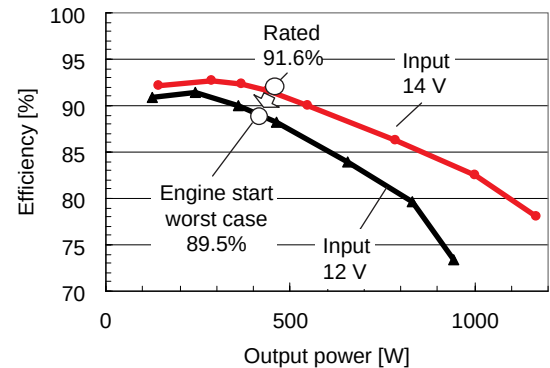


Fig. 13 Load efficiency characteristics of DC-DC converter

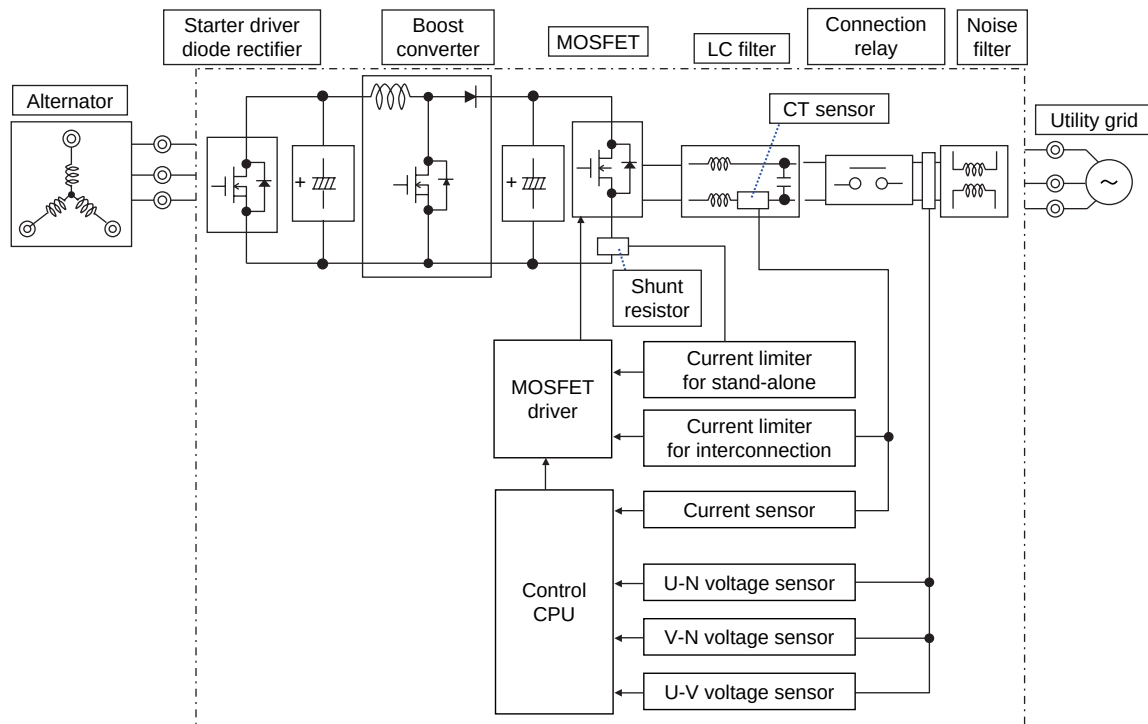


Fig. 14 Block diagram of interconnection inverter with backup function

detects U-N, V-N, and U-V voltages; control CPU that controls generation; and drive circuit that controls drive of the MOSFET section.

By contrast with the grid-connected inverter installed in the previous model, the newly developed model includes a backup generation function for power outage. Also, while using a base plate in the same size as the previous model, the new model generates more power in the backup mode and grid connection boost mode. The hardware and software used to achieve this will be discussed in the following sub-sections.

4.3.1. Increasing power output

When backing up, the power output of newly developed model is 1.8 kVA, 1.5 times higher than the output, when connected to the grid. In order to increase output as high as 1.5 times, the size of the LC filter coil (L) was increased to make maximum flux density higher, and the diameter of coil wire was also increased. The more the output increases, the more the ripple voltage of the DC voltage input to and output from the boost converter become higher. Because of this, the ripple current to the electrolytic condenser also increases, and heat generation shortens the lifespan of condenser. In order to help prevent this, the inductance of the boost converter coils and the capacity of the electrolytic condenser were increased to reduce ripple current, and to control temperature increases in the condenser. As a result, the lifespan of electrolytic condenser was doubled from that of the assembled micro-cogeneration unit. Because the heat generated by the boost converter and MOSFETs also increases in proportion to power, a dedicated inverter cooling fan, which operated in high temperature, was also added to the unit to facilitate its cooling performance. Despite the same size as the previous one, in this way, the new model successfully generates 1.5 times more output.

4.3.2. Addition of backup functions

(1) Addition of U-V voltage detect circuit

As shown in Fig. 15, when the system was connected to the grid, U-N voltages and V-N voltages were separately detected to find irregular grid voltages and to increase the resolution of voltage detection. By adding these voltages, we found the voltage between the U and V phases, which could be used for the proportional, integral, and differential control (PID control) of voltage feedback. However, as shown in Fig. 16, the N phase became disconnected due to the output from two-wire single-phase operation during the backup operation as a standalone generator. This is because the MOSFET section that converts output from DC to AC was a single-phase full bridge. For this reason, the addition of U-N to V-N voltages did not simply give the U-V voltage. Detection of U-V voltage is therefore conducted to enable voltage feedback during backup generation.

(2) Addition of current limiter circuits

Current limiter circuit was installed for high current load during backup generation in addition to the current limiter for grid connection in the newly developed system. The threshold value of current limiter circuit for grid connection was set at 150% of the rated current, during the grid connection boost operation. The threshold value of the current limiter circuit for backup operation was set at 250% or more than the value of the limiter circuit for grid connection to sustain the load of mercury lamp or compressor, which required high-current. The threshold values were determined based on the results of tests and simulations, in order to help prevent the FETs used as the inverter switching elements from suffering heat damage, when high current of electrical load was required, or short circuit occurred. During backup generation, the grid connection current limiter circuit was set not to operate following the setting of the software.

(3) Modification of current detection circuits

A single current sensor was used to detect both the currents in the grid connection operation and backup operation. In the previous inverter generator, the current of FET bridge arm was detected. However, the shared use of current detection circuit for detection of current downstream from the LC filter during grid-connected operation in the new model enabled the

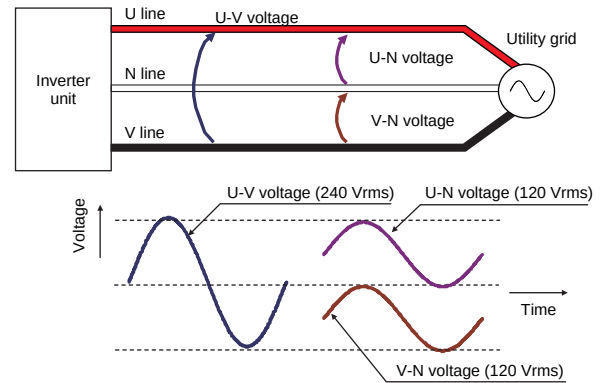


Fig. 15 Three-wire single-phase (grid connection)

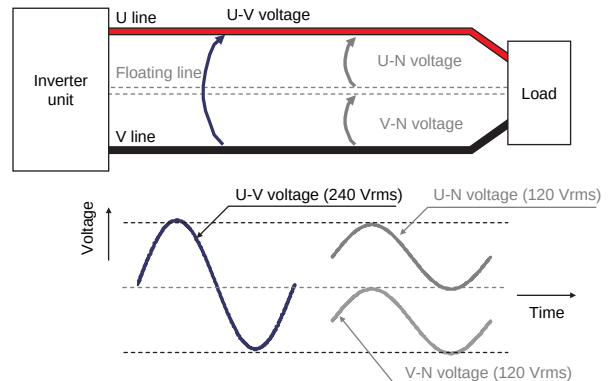


Fig. 16 Two-wire single-phase (backup)

number of circuits to be reduced. Because the system handles high currents during its backup operation, the size of conducting wire in the current sensor was enlarged to increase the rated current from 10 A of the previous model to 30 A. This rated current was set to include a sufficient margin in relation to the excess current limiters discussed in the above.

4.3.3. Grid connection control and backup generation control

Three control modes, grid connection control, grid connection boost control, and backup generation control, are employed in the new model, with the same CPU as the previous model. As Fig. 17 shows, sharing of software for the input and output levels of each mode allowed to share hardware for each operating mode. Because backup operation is carried out during power outage, the grid voltage is not input, which is supposed to provide a benchmark for this control. Because of this, a benchmark that modeled the grid voltage (an internal standard sinusoidal wave) is formulated in the computation section of the control system, to output sine wave.

The actual program implemented two unique types of control: 1) fixed current control in the grid connection that controlled output current by superimposing the output waveform on the grid voltage, 2) fixed voltage control in the backup generation that outputs rated sinusoidal voltage, no matter what loads are connected. Judgment to which mode should be applied is based on the data of power interruptions provided by the externally connected devices and DC-DC converter.

4.3.4. Generation performance during grid-connected operation and backup operation

Table 4 shows generation performances when the unit

Table 4 Power generation performance of interconnection

Output power		1.2 kW / 1.8 kW	
Engine speed		1950 rpm / 2800 rpm	
Rated voltage		AC 120 V / 240 V (1 Φ 3 W)	
Rated frequency		60 Hz	
Efficiency		92% or more	
Power factor		97% or more	
Output current distortion		5.0% max	
Total			
Individual harmonic of odd order	3-9 order		4.0% max
	11-15 order		2.0% max
	17-21 order		1.5% max
	23-33 order		0.6% max
	35-39 order		0.3% max
Individual harmonic of even order	2-10 order		1.0% max
	12-16 order		0.5% max
	18-22 order		0.375% max
	24-34 order		0.15% max
	36-40 order		0.075% max

is connected to the grid. The system operates in two modes, when connected to the grid: normal grid connection operation (1.2 kW) and grid connection boost operation (1.8 kW). In both modes, the unit generates a high-quality power output that meets the UL 1741 safety standard for grid-connected inverters⁽⁷⁾ established by Underwriters Laboratories Inc. in the U.S..

In addition to the grid connected operation, because the system also operated, using the settings for the LC filter constant in the backup mode, the output voltage waveform for the load that rapidly varied currents, such as diode rectifier load, was distorted with approximately 14% of distortion rate. The system therefore identifies the diode

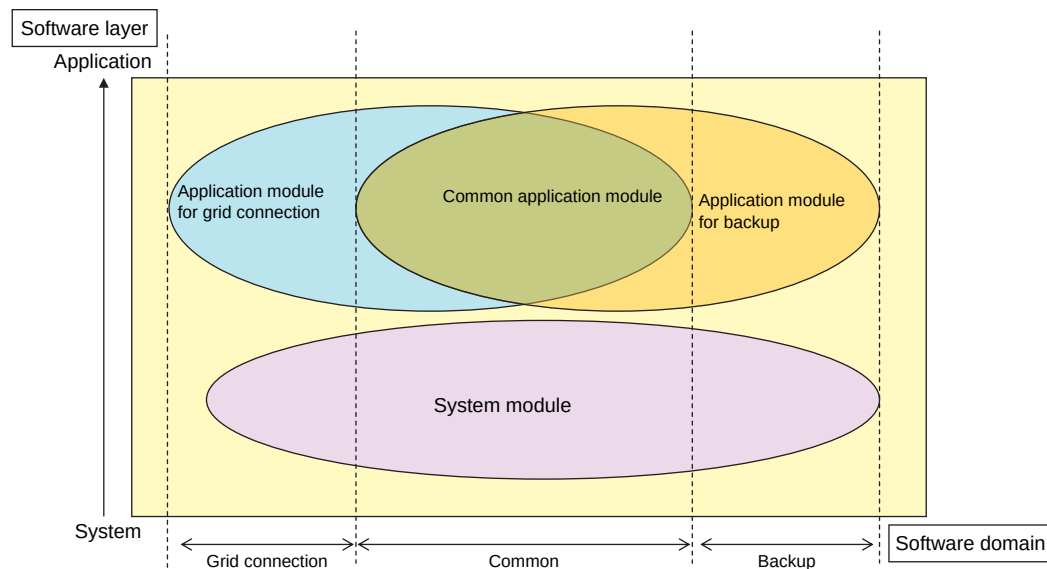


Fig. 17 Software architecture

rectifier load based on the magnitude of the crest factor (maximum current / effective current), and applies feedback control to minimize distortion rate. As shown in Fig. 18, we reduced the distortion rate by 4.7 points to 9.2%, achieving equivalent performances to those of Honda inverter generator⁽⁸⁾. Table 5 shows its generation performances during backup operation. During backup operation, the system supplies power at its rated power of 1.8 kVA, which meets the UL2200⁽⁹⁾ standard for stationary generators.

4.3.5. Battery assist performance

Engine generator converts engine output to electricity, and supplies this power to load.

For this reason, we can make the unit more commercially appealing by increasing the usable amount and type of electric load based on enhanced instantaneous responsiveness to rated output, or to the inrush current at

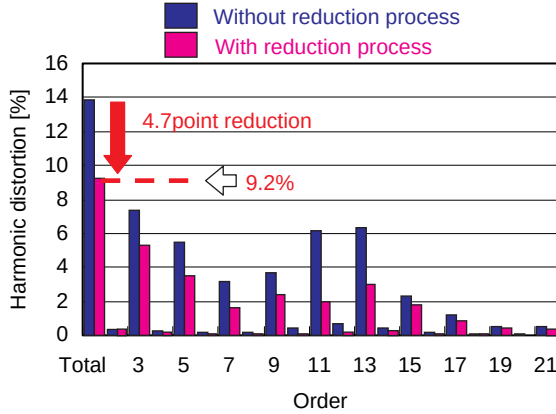


Fig. 18 Output voltage harmonic distortion With and without reduction process

Table 5 Power generation performance of backup

Output power		1.8 kVA
Rated voltage		AC 240 V (1 Φ 2 W)
Rated current		7.5 A
Rated frequency		60 Hz
Efficiency		92% or more
Output voltage distortion	Resistance load	3.0% max
	Rectifier load	10.0% max

startup of an inductance load, such as a motor. The newly developed model is fitted with a battery and a DC-DC converter, which enables hybrid generation with engine power and battery power. As shown in Fig. 19, when instantaneous excessive power is demanded on the engine during backup operation, a command from the inverter increases the battery voltage through the DC-DC converter, and the battery supplies power to the inverter⁽¹⁰⁾. When receiving more than the rated load, or inrush current of high-load, in this way, the battery assists the engine output by engaging in hybrid generation. This facilitates the transient response of the engine, and makes the unit more commercially available as an engine generator. Figure 20 shows the change in the voltage waveform, when a load is input. Voltage sag was evaluated based on the index expressed by Eq. (3) below.

$$\text{Voltage sag} = (V1 - V2)/V1 \times 100\% \quad (3)$$

Figure 21 shows the differences in the same load, which resulted from the presence of battery assist. As Table 6 shows, voltage sag reduced by approximately 40 points, and stabilization time reduced by 0.8 sec, when 120% of the rated load was input.

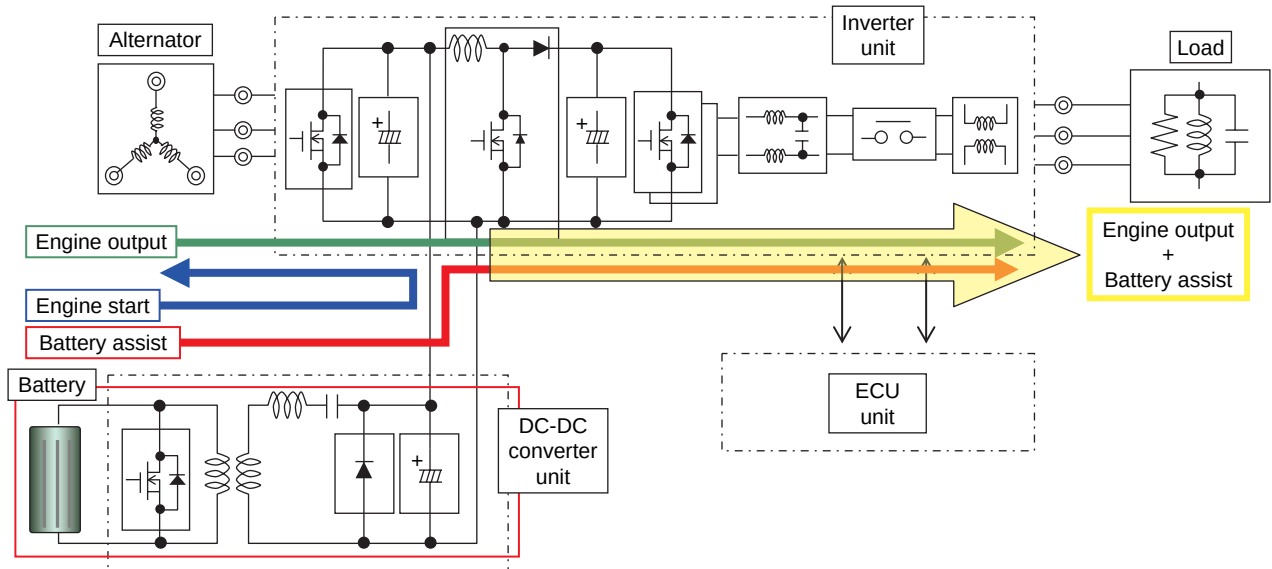


Fig. 19 Hybrid power generation

Table 6 Comparison of battery assist on-off

	Assist off	Assist on
Voltage sag	59.3%	16.6%
Stabilization time	2.54 s	1.71 s

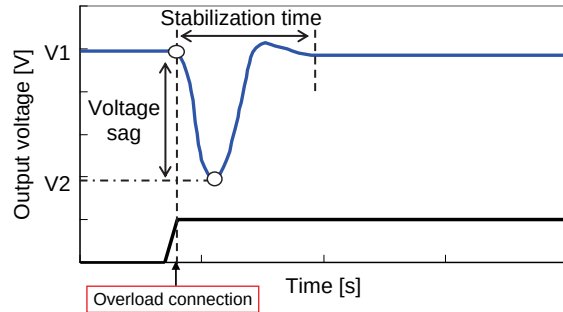


Fig. 20 Voltage sag and stabilization time

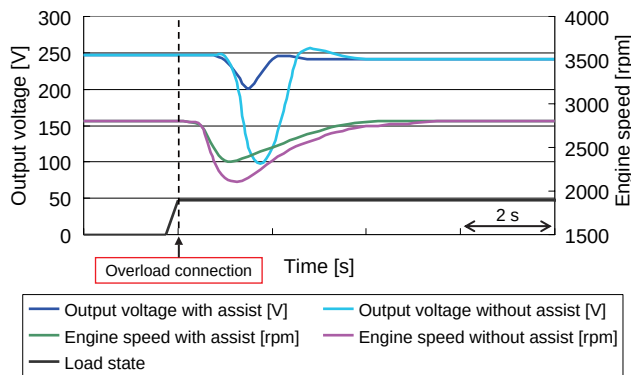


Fig. 21 Comparison of battery assist on-off

5. Conclusion

A micro-cogeneration unit for domestic use with the capacity for autonomous power generation was developed to function as a backup generator during power outages. Increasing the speed of the engine for standalone power generation in power outages increased output 1.5-fold in comparison with the previous model, which only operated based on the grid connection. Because the unit is also able to recover heat as a micro-cogeneration unit, when used as a backup generator, achieving total efficiency of 85.5% or more of primary energy. The features of the newly developed unit are further outlined below:

- (1) The realization of automatic switching between grid connection and autonomous operation as an inverter, in addition to the development of highly efficient isolated DC-DC converter, enabled both autonomous generation and hybrid generation in the same size of housing as that of the previous model.
- (2) By increasing engine speed, we increased output 1.5 times more than that of the previous model, while keeping the same size of circuit board.

- (3) The realization of current resonance ZCS operation enabled the development of highly efficient isolated DC-DC converter that achieved 91.6% efficiency at 14 V of input voltage and 440 W of output.
- (4) In addition, the use of long-life Ni-MH battery, optimization of component layout, and intermittent charging allowed us to actualize a maintenance-free battery.

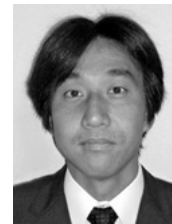
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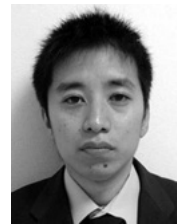
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