

Development of EM7000is Dual-voltage Inverter Generator

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ABSTRACT

Honda's current inverter generators have a maximum power output of 3kVA and are limited to single-voltage output. Dual-voltage output is essential when producing higher-power inverter generators, as the larger equipment connected to them requires either high current or high voltage. A new dual-voltage inverter has therefore been developed to meet these needs.

The dual-voltage inverter produces two voltages by connecting two inverters either in parallel or in series.

Sub-winding for each inverter unit power supply has not been employed in the alternator. Instead, only main windings have been used, and the power supplies have been built into each inverter unit, meaning that the system is composed of the output of the main winding. This has enabled the alternator to be reduced in size and increased in efficiency.

The completed generator is equipped with an integrated control unit. The centralization of control functions has enabled 2/3 of the electronic components to be eliminated and a liquid crystal monitor to be employed to display information.

Like Honda's previous inverter generators, the newly developed EM7000is employs an electronic governor. In combination with its shroud sound isolation duct structure, this enables the unit to run quietly with high fuel efficiency.

1. Introduction

Portable generators are used throughout the world for leisure, business, domestic applications, and also for emergency. In recent years, they have come into wide use as power sources for electronic equipment, such as computers, which require a high quality source of electric power. They are also required to be compact, lightweight, and easy to use. In order to meet the needs of such customers, a series of compact and lightweight inverter type generators, GENE21, which outputs high quality power and varies the engine speed according to the load was developed^{(1) - (3)}, and currently enjoys a very favorable reputation in the marketplace.

Recently, the proportion of electric power used in IT applications has increased greatly, and the need for a large output inverter type generators is increasing. The maximum output from GENE21 is 3 kVA, and all models output only a single voltage. In the case of a generator of 4 kVA or higher capacity, the equipment connected to the generator is also

correspondingly large, hence large current and voltage are demanded. In other words, there is a need for a dual-voltage type generator that outputs two voltages, such as 120 V and 240 V, for example.

With the conventional synchronous generator, it is possible to obtain two outputs of identical phase by simply arranging the two output windings on the stator winding so that they are in the same phase. Connecting the two output windings in series results in a high-voltage output of 240 V, and connecting them in parallel enables a high-current output of 120 V to be obtained. In the case of the series 240 V output, it is also possible to simultaneously output 120 V between the neutral points. In this way, the conventional synchronous generator can readily provide a dual-voltage output.

This paper describes the issues to be solved in order to obtain a dual-voltage output from an inverter, and also newly developed technology. It also describes the contents of technology employed in the development of the EM7000is (name used in North America and applies to other generators

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as well) dual-voltage inverter generator which is designed to be more compact than the conventional synchronous generator and generate less noise.

2. Technical Issues and Goals

2.1. Inverter

A study of a dual-voltage output type generator was made. As an example, a generator that has an output of 5 kVA and outputs two voltages, 120 V and 240 V is described.

First, a study of an inverter that outputs only one voltage, either 120 V or 240 V, was performed. The output was set to 5 kVA, and the component parts, mainly the power devices, were designed to pass a current of 42 A (5 kVA/120 V) and have a withstand voltage of 120 V in the case of a 120 V output, and were designed to pass a current of 21 A (5 kVA/240 V) and have a withstand voltage of 240 V in the case of a 240 V output. In the latter case, a withstand voltage of twice 120 V is necessary, however the required current carrying capacity is halved.

Next, a study of a single inverter unit that was capable of outputting two voltages of 120 V and 240 V was performed. The output was set to 5 kVA.

First, as (a), a study of the method in which the voltage is switched over by internal control was performed. In this case, the design current must be set to the higher value of the above, in other words to 42 A (5 kVA/120 V), and the design withstand voltage must be set to 240 V. Consequently, compared to the case of the voltage output of a generator that outputs only a single voltage, it is necessary to use power devices that have twice the current handling capacity and twice the withstand voltage even for the same 5 kVA, so it is difficult to make a compact and low cost design.

Also, as (b), a study was performed which involved the use of two 2.5 kVA inverters to produce two voltage outputs by switching them between series connection and parallel connection. In this case, the current is 21 A (2.5 kVA/120 V) and the withstand voltage is 120 V, so the power devices need only half the size. This enables the generator to be designed compactly and at low cost.

The foregoing is summarized in Table 1. For new specifications, (b) was adopted. However, it is necessary to accurately synchronize both inverter units. Therefore, dedicated communication lines were installed between the inverters, and signals were continuously exchanged between them, enabling them to be synchronized accurately with each other. Details are shown in 3.2.

2.2. Alternator

A study of an alternator was also performed.

The alternator for Table 1(a) requires both a large current and a high voltage, necessitating a substantial number of thick windings. This results in a large unit and also difficulty in making the windings.

In contrast, the alternator for Table 1(b) requires two separate systems, but can be made compact compared to (a). For new specifications, (b) was used in addition to the inverter. Details of the alternator are described later in 4.1.

Table 1 Comparison of dual-voltage inverter type

Devices	(a)	(b)
Specification	42A 240V	(21A 120V) × 2
Volume	2	1
Cost	High	Low
Adoption	—	○

2.3. Generator Control

The conventional synchronous generator consists of a large number of units including the ignition unit, timer unit for preventing the starter from double contact, auto throttle unit, battery charging unit, fuel cut solenoid drive unit with remote control interface, and oil alert unit. Also, a mechanical type auto-choke is used. In addition, an operating time integrating meter is being newly demanded, and with this configuration it is unavoidably necessary to install an expensive unit later.

Accordingly, this configuration was integrated and the entire generator was electronically controlled in order to reduce the number of components and realize a generator that could be used easily by the customer. Table 2 shows a system comparison. This unit is called a Generator Control Unit (GCU). By thus configuring the generator as a single unit, it was possible to reduce the number of components to 1/3, and also to add an electronically controlled choke for improved starting performance, as well as an information monitor (i-monitor) that functions as an hour meter, and so on. The detailed functions of the GCU are described later in section 6.

Table 2 Comparison of generator control systems

Function	Conventional system	New system	
Ignition system	Ignition unit + Ignition coil	GCU	+ Ignition coil
Automatic choke	Diaphragm vacuum pump		+ Stepping motor
Battery charge	Charge unit		—
Remote control	Interface		
Prevention of double contact of starter motor	Timer unit		
Oil alert	Oil alert unit		
Operating hours display	Total operating hours meter		
Fuel cut system	Power supply + Fuel cut solenoid	Inverter	+ Inverter
Automatic throttle	Automatic throttle unit + solenoid		
Number of parts	12	4	

Except for wire harness and mechanical links

2.4. Power Supply

A method of supplying power for controlling the two inverters and the GCU was studied.

First, the same sub-winding system as that of the conventional GENE21 series generator was studied. In this method, one dedicated winding corresponding to one tooth is used for the power supply of the inverter in the alternator, however the use of this winding in a large alternator results in

poor efficiency, so was abandoned.

Next, a transformer method was studied. The main winding was made the primary side, and the two power supplies for the inverter and also the power supply for the GCU were connected to the secondary side. This method makes for high efficiency, however the input frequency is low, so the transformer cannot be significantly reduced in size. In addition, it is difficult to obtain space to install the transformer in the completed generator. For these reasons, the transformer method was abandoned.

Next, a method was studied in which each of the inverter and GCU units generate their own power supplies from the main winding. For new specifications, this method was adopted. Table 3 shows a brief comparison between each method.

The necessary power supplies for the inverter consist of one positive and one negative power supply, and also three independent FET driver power supplies (H bridge construction, with common lower arm), so these were integrated in a 5-system Ringing Choke Converter (RCC) power supply configuration. This is shown in Fig. 1. Each inverter unit has this configuration, enabling the circuit configuration to be simplified.

Table 3 Comparison of power supply for inverter and GCU

	Sub-winding	Transformer	Built-in to each unit
Efficiency	750W loss	30W loss	30W loss
Volume	Increase volume of alternator	Another space for transformer	A little another space for each unit
Cost	High	Middle	Low
Adoption	—	—	○

Likewise, the power supply for the GCU was also obtained from the main winding. The generator is often used in a completely battery-less condition, and so ignition during recoil starting and the method of obtaining a power supply were important issues. In other words, it was necessary to obtain a power supply from a speed that was lower than that of the inverter. Details of the power supply for the GCU are described later in 6.2.

2.5. Packaging

The targets for the completed generator were 30% miniaturization and reduction of noise level to 7 dB (A)/7 m in the practical load region compared to the conventional synchronous generator. Miniaturization and noise reduction are conflicting requirements, and it is necessary to assess the extent to which both cooling performance and noise reduction can be realized.

One method of reducing noise is a sound isolation box method in which the entire generator is covered with an outer panel. Because this structure involves the use of an outer shell, the volume is increased by 10% as compared to the pipe frame structure (structure of the conventional generator), making it difficult to realize the volume reduction target of 30%.

To overcome this, the completed generator employed a shroud sound isolation duct structure in which the engine was fully covered. Figure 2 shows the shroud sound isolation duct structure.

As a result of using this structure, a 30% volume reduction and also a reduction of noise by 7 dB (A)/7 m in the practical load region compared to the conventional synchronous generator were attained. Details of the structure are described later in section 5.

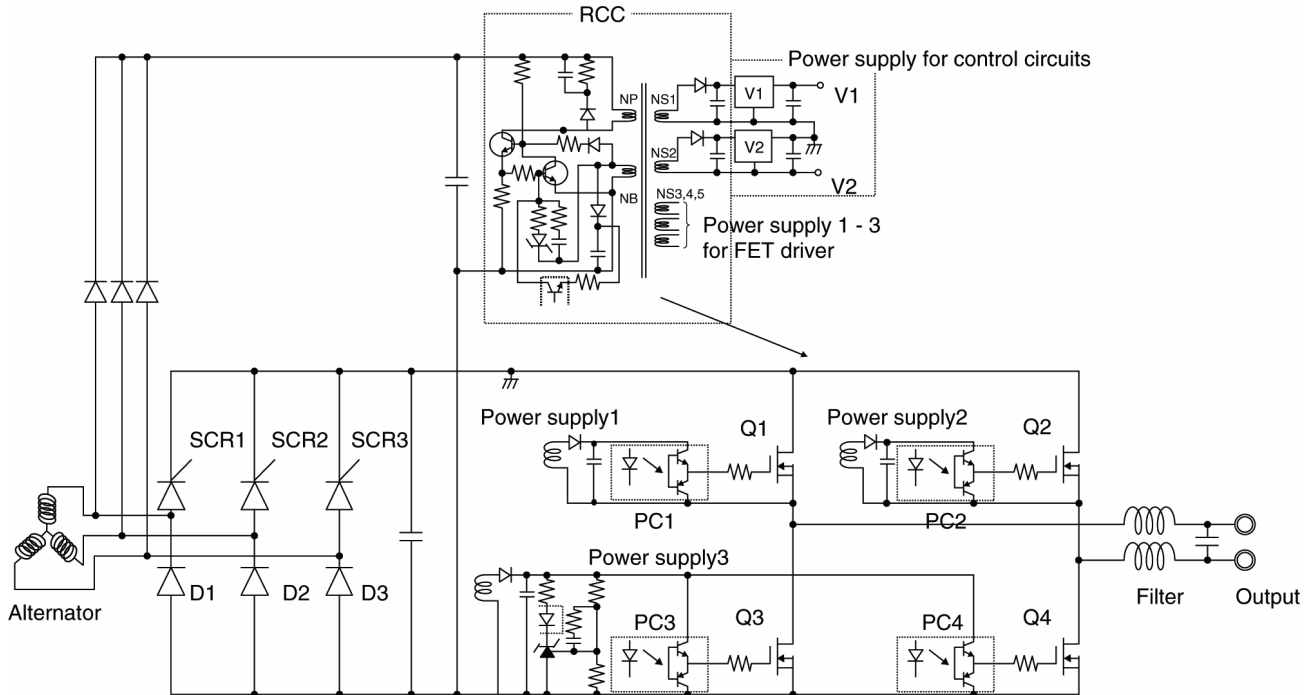


Fig. 1 Power supply system

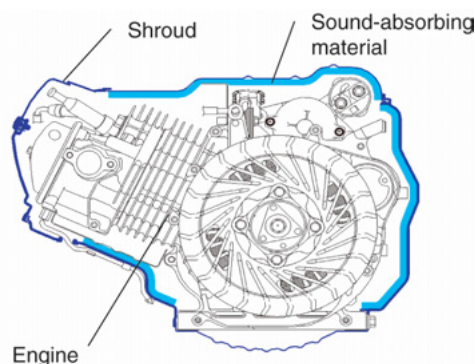


Fig. 2 Shroud sound isolation duct structure

3. Dual-voltage Inverter

3.1. Configuration

The configuration of the dual-voltage inverter is shown in Fig. 3. As mentioned previously, this generator uses two inverters, called master and slave, respectively. When the two outputs are connected in parallel, a 120 V high-current output is obtained, and when they are connected in series, a 240 V single phase three-wire output is obtained. Switchover between series and parallel is done by a toggle switch. This connection method comprises a dual-voltage inverter that outputs two kinds of voltages. The phases of the two inverters must be identical to each other, so it is necessary to synchronize the inverters with each other.

3.2. Synchronization Method

Synchronization is realized by connecting mutually isolated dedicated communication lines between the two inverters. Figure 4 shows the actual control method employed.

Each of the master and slave inverters converts sine waves that it outputs itself, into square waves, and sends them to the opposite inverter. The square waves received from the opposite inverter are compared with the square waves output by the inverter itself. If an inverter judges that the phase of the waves that it outputs is advanced compared to that of the opposite inverter, it adds pulses to decrease the

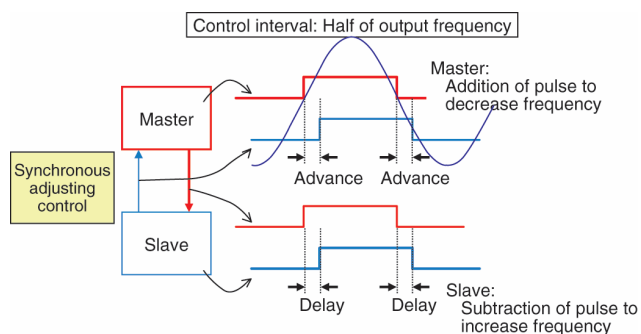


Fig. 4 Synchronous system of inverters

frequency of the sine waves that it outputs, while conversely if it judges that the frequency of the waves that it outputs is delayed compared to that of the opposite inverter, it subtracts pulses to increase the frequency of the sine waves that it outputs.

In this way, both the master and slave adjust their respective phases each half frequency, thus keeping in synchronism with each other. Because the communication lines are isolated from each other, the control operation keeps the inverters in synchronism without problem, for both series and parallel connections.

3.3. Reduction of Residual Harmonic

Like the GENE21 series, Pulse Width Modulation (PWM) is employed for the control system at the output stage. However, the carrier wave, in other words harmonics, remains in the output, and cannot be completely removed by filtering alone.

The dual-voltage inverter is connected as shown in Fig. 5. Here, the inverter was designed in such a way that the waveform of the slave is output 180° out of phase with that of the master, and when both outputs are connected to each other they are in phase. Consequently, the harmonics are connected in reverse phase to each other, enabling the residual harmonic to be significantly reduced. Figure 6 shows the case for an in-phase output. It can be seen that compared to this case, the residual harmonics have been reduced by roughly 6 V.

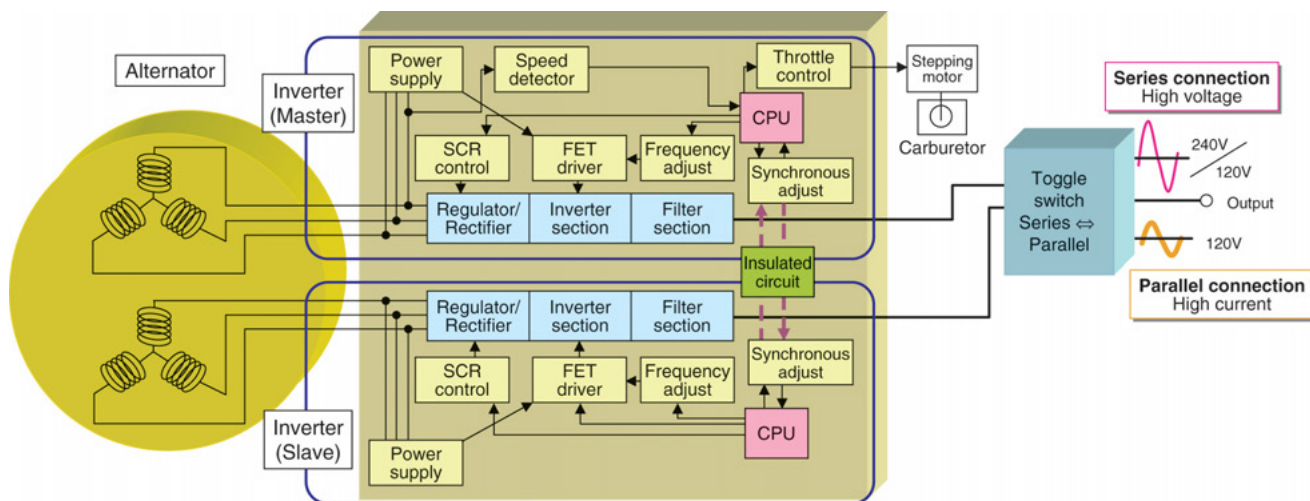


Fig. 3 Structure of dual voltage inverter system

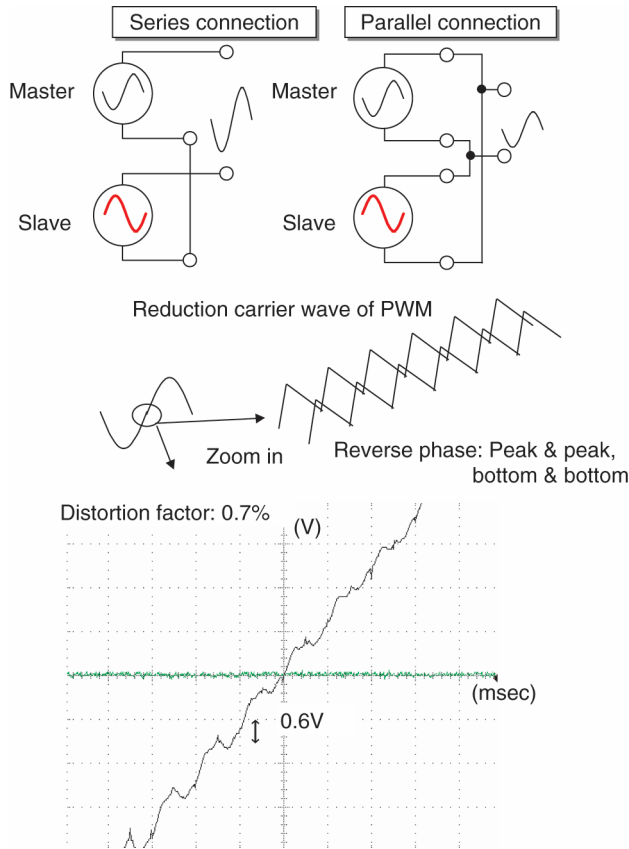


Fig. 5 Reverse connection method of master and slave

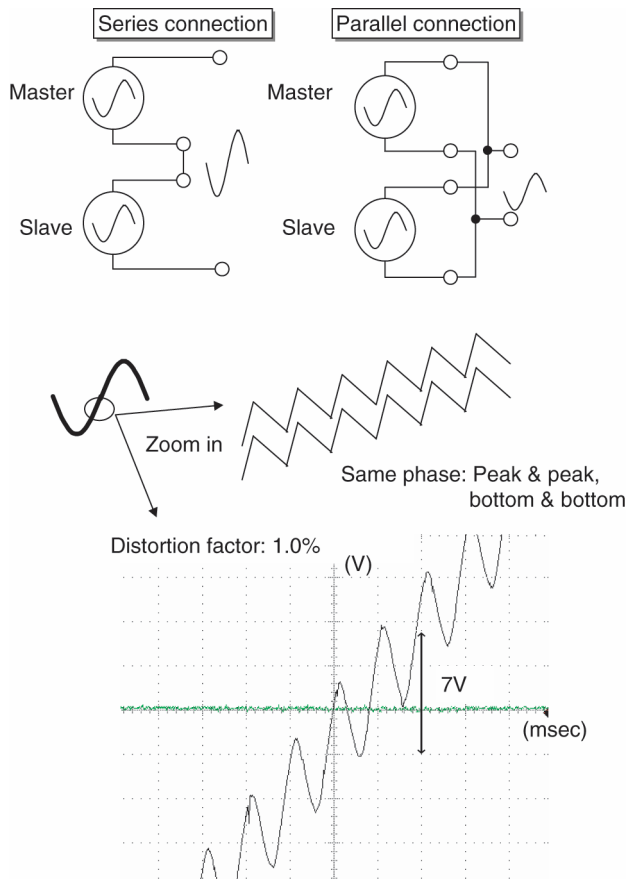


Fig. 6 General connection method of master and slave

4. Alternator

4.1. Structure

The EM7000is dual-voltage alternator was newly developed targeting compact size, high output, and high efficiency. Like the conventional GENE21 series, it is an outer rotor type high-speed multi-pole alternator. As shown in Fig. 7, the independent three-phase windings are configured as two systems. The stator has 30 teeth. Of these, 15 teeth each are used for the master and slave, respectively. There is no sub-winding for the control power supply of the inverter unit that existed in the conventional multi-pole alternator as mentioned previously. In other words, all of the teeth correspond to the main output windings.

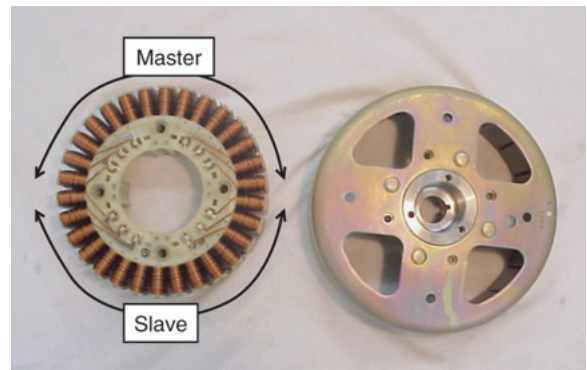


Fig. 7 Alternator for EM7000is

4.2. Comparison with Conventional Multi-pole Alternator

Because all of the teeth correspond to the main output, it was possible to realize a significant degree of miniaturization compared to the conventional multi-pole alternator, on a size-versus-output basis. Compared to the EU1000i, approximately 34% miniaturization was realized, and the output per tooth was increased roughly 5.2-fold. This is shown in Fig. 8.

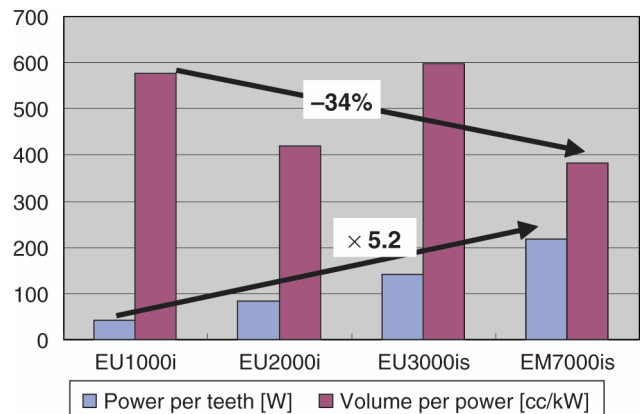


Fig. 8 Comparison of EM7000is with GENE21

5. Packaging

The structure of the completed EM7000i is employed the optimum component layout and also a shroud sound isolation duct structure that fully covers the engine, in order to achieve reduced weight, compactness and cooling performance, while aiming for low noise. (Fig. 2)

5.1. Cooling Ability

As shown in Fig. 9, the various components of the generator were installed in a straight line in sequence from the inverter unit which produced the least heat, followed by the alternator, engine and muffler. The flow of the cooling air was made unidirectional, and the cooling air was made to flow in sequence from the components that generated only a small amount of heat, for improved cooling efficiency. As a result, whereas the conventional synchronous generator had two fans, one to cool the engine and the other to cool the alternator, this generator was able to combine these fans into one, resulting in reduced weight and size. In addition, the generator was constructed in such a way that the hot air emitted as a result of cooling of the engine was isolated from the other electrical equipment, in order to prevent the temperature in the vicinity of the electrical equipment covered by the shroud such as the ignition coil and self-starter motor from rising.

As shown in Figs. 10 and 11, the electrical equipment is partitioned from the engine cylinder by an upper bracket, forming a hot zone and a cool zone. This prevented the temperature of the electrical equipment from rising due to the flow of engine cooling air.

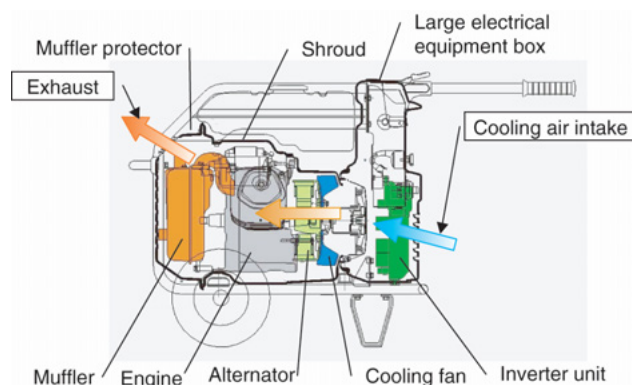


Fig. 9 Structure of complete generator

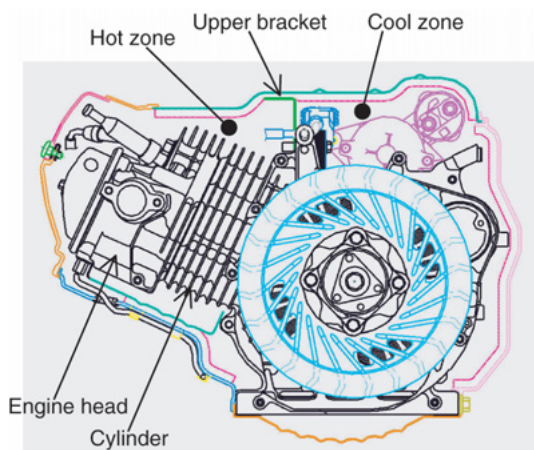


Fig. 10 Front view of engine

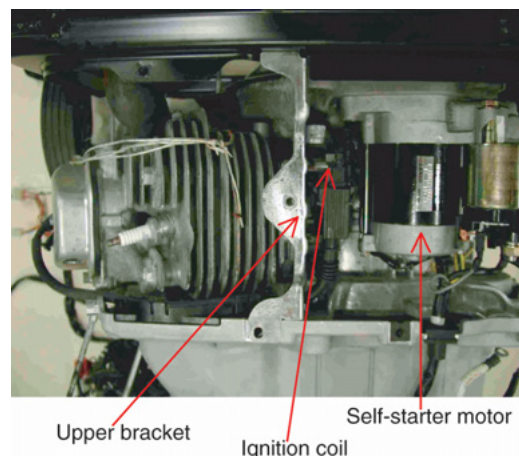


Fig. 11 Upper view of engine

5.2. Reduction of Noise and Fuel Consumption

The cooling mechanism shown in Fig. 9 was configured with the aim of simultaneously reducing noise emitted from the completed generator, which is a conflicting requirement. The large electrical equipment box which contains the inverter, control panel, and other electrical equipment, functions as a large intake chamber for the engine cooling air and the air cleaner. This was intended to reduce fan noise and air cleaner intake noise. The air exhaust section consisted of a large air exhaust chamber containing a long-tail large muffler, which was formed as a muffler protector. In addition, the entire engine was covered with a sound isolation shroud lined with soundproofing material (Fig. 2), aiming at reducing mechanical engine noise.

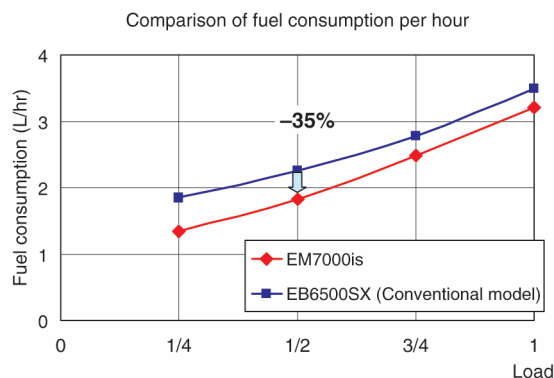


Fig. 12 Fuel consumption

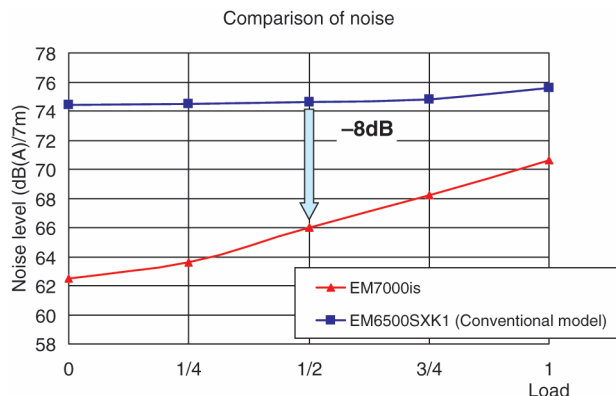


Fig. 13 Noise level

The employment of an electronic governor permitted the engine speed to be reduced in the practical load region, and also reduced both fuel consumption and noise. Compared to the conventional synchronous generator, the fuel consumption was reduced by about 35%, and noise was reduced by 8 dB (A) in the practical load region. The effectiveness in reducing fuel consumption is shown in Fig. 12, and the effectiveness in reducing noise is shown in Fig. 13. Note, however, that the effectiveness in reducing noise includes the noise reduction effectiveness of the completed generator cover.

5.3. Miniaturization and Weight Reduction

A U-shaped integrated pipe frame was employed, and a large plastic electrical equipment box was set at the front face corresponding to the open side of the frame. This is shown in Fig. 14.

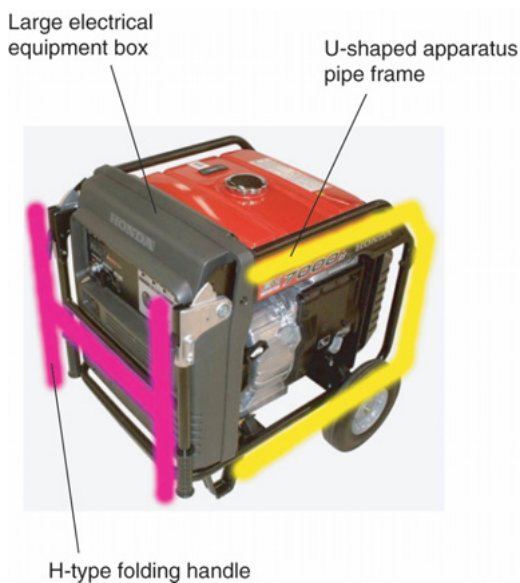


Fig. 14 Structure of a frame

A control valve type small MF battery (YTZ14S) was employed in a large electrical equipment box, instead of the large battery mounted on the outside of the frame of the conventional model.

This together with the use of a single fan mentioned above enabled the volume of the completed generator to be reduced by about 33% (when the handles are retracted) and the weight to be reduced by about 20%, compared to the conventional synchronous generator.

6. Generator Overall Control System

The EM7000is employed a system Generator Control Unit (GCU) that performs overall control of the completed generator. This enabled the number of electrical equipment to be reduced to about 1/3, and also realized a generator that is easy to use.

6.1. System Configuration

Figure 15 shows the configuration of the overall system. The system mainly performs the following kinds of control.

- (1) Ignition timing control
- (2) Choke control
- (3) Starter control
- (4) i-monitor and self-diagnosis
- (5) Inverter communication and monitoring
- (6) Reduction of after-burn when the engine is stopped
- (7) Remote control interface

6.2. Power Supply

As mentioned above, there is no power supply sub-winding because the power supply is installed inside the unit.

Because it is necessary to maintain a high voltage for the main output voltage, it is not possible to use the shorting type thyristor regulator that is normally used. Also, this type of pipe frame generator is often used in a completely battery-less condition, so the full-transistor ignitor for recoil starting and also the power supply were major issues.

Accordingly, the power supply shown in Fig. 16 was developed and incorporated in the generator. The

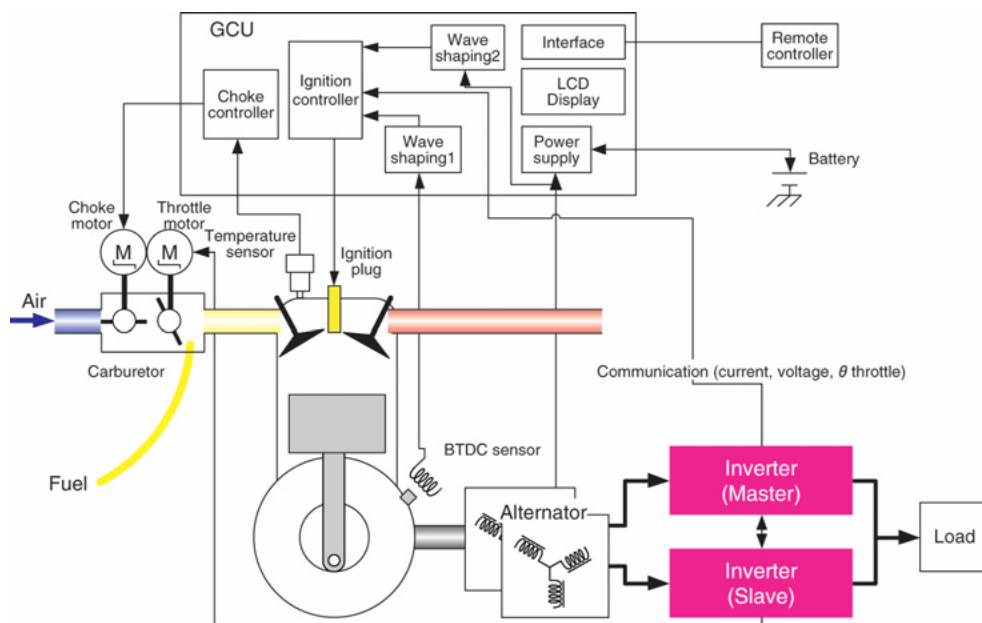


Fig. 15 Structure of GCU

specifications of this power supply are shown in Table 4.

Figure 17 shows the input versus output characteristics of this power supply during startup. Both outputs start to be generated at 125 rpm, and the system starts up, however in this speed region, the effect of kick-back during startup is large, so ignition is prevented from occurring below 180 rpm. The voltage of 5 V is obtained by voltage-dropping from the 15 V output using a 3-terminal regulator. The voltage boosting action of the 15 V system takes place to about 200 rpm, and that of the 17 V system to about 250 rpm.

Table 4 Specification of power supply

Input voltage	DC 10 - 400V
Output voltage 1	DC 15V $\pm$ 0.5V
Output current 1	MAX 2A
Output voltage 2	DC 17V $\pm$ 1V
Output current 2	MAX 0.8A

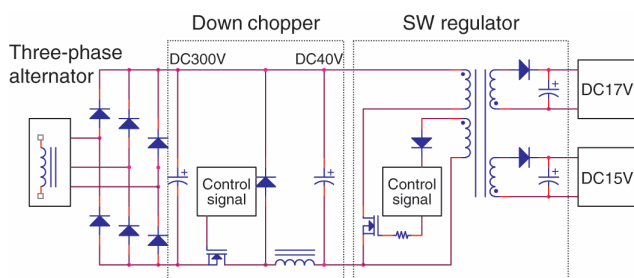


Fig. 16 Schematic diagram of power supply

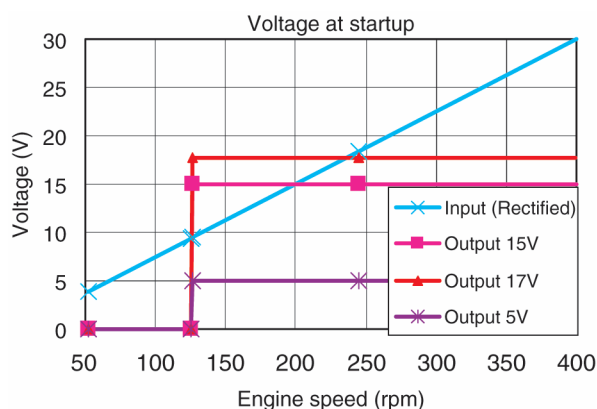


Fig. 17 Voltage of startup

6.3. Ignition System

A general-purpose product is often used in a battery-less condition, so the ignition method generally employs a transistorized magneto or a CDI which consumes relatively little power. In the case of this generator, however, the way became clear to obtaining power supply capacity for recoil starting, so a simple full-transistor ignitor method was used. A full-transistor ignitor method necessitates energization period control, so a crank angle sensor is necessary in addition to a TDC sensor. In this system, a 10-pulse/revolution pulse which is obtained by rectifying the alternator waveform is used instead of a crank angle sensor,

rendering the crank angle sensor unnecessary. The timing for this is shown in Fig. 18.

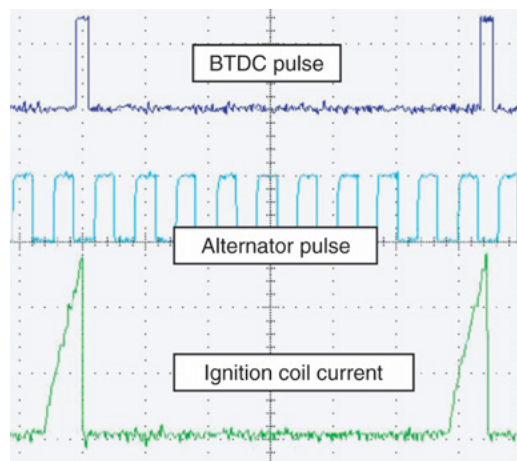


Fig. 18 Timing chart of ignition

6.4. Choke Control

Figure 19 shows the carburetor of this generator. On the left is the governor stepping motor, and on the right is the choke opening control stepping motor. The specifications of both of these motors are identical. Detection of the warm-up condition of the engine is done by using the cooling water temperature in the case of a fuel injection type water-cooled engine. In the case of an air-cooled engine, there are reported cases concerning motorcycles in which the temperature of the engine oil is used⁽⁴⁾. Both types employ injection period control in which the engine temperature is detected continuously, and combustion is regulated according to the temperature at that time. Although the engine of this generator is an air-cooled type, it does not have an oil circuit around the head, like the case of a motorcycle. Lubrication is performed only inside the crankcase, so it was not possible to use oil temperature to measure the engine temperature. For this reason, it was decided to install a thermistor on the head to directly detect the temperature of the head.

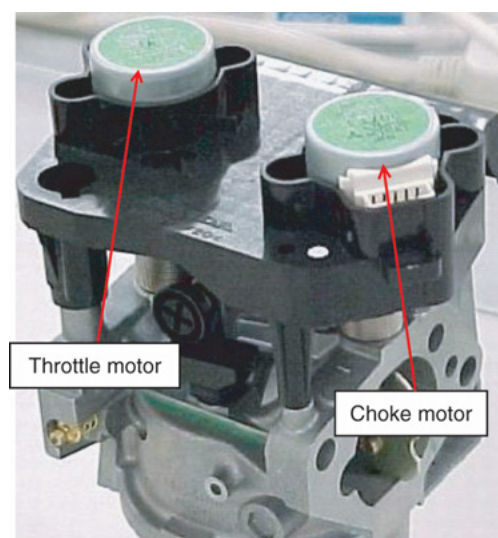


Fig. 19 Carburetor

6.5. i-monitor

Figure 20 shows the GCU. The liquid crystal display repeatedly displays the contents of Table 5 in the numbered sequence when the button at the right side of the display window is pressed. This is called an i-monitor. The default is an hour-meter display, which displays the data once every hour. However, internal integration is performed at 1-minute intervals so as to reduce the integration error.

If an error occurs in the system, a red LED flashes and an error code appears on the LCD display, as shown in Fig. 20. The display shown here is an example in which the engine temperature sensor is abnormal. The monitor communicates continuously with the master and slave inverters, and if an error occurs on the inverter side, the GCU immediately executes fail-safe action such as stopping the engine.

Table 5 i-Monitor display

	Mode	Unit
1	Total operating hours	hour (1 hour)
2	Power output	VA (50VA)
3	Engine speed	rpm (10rpm)
4	Battery voltage	V (0.1V)



Fig. 20 GCU

6.6. After-burn Reduction Control

When the temperature inside the muffler is high, and the ignition is stopped by turning OFF the engine switch, raw gas inside the muffler sometimes burns in a rush after the engine stops. This is called after-burn. A conventional generator has a solenoid valve beneath the carburetor for cutting off the supply of fuel the instant that ignition stops, thus preventing after-burn. As shown in Fig. 21, in this generator, after the engine switch is turned OFF, ignition is continued until the engine speed falls to the designated value or below, and is stopped once the engine speed falls below the value, reducing blow-out of raw gas. This, together with the fact that the cooling performance of the muffler is improved, enables after-burn to be reduced.

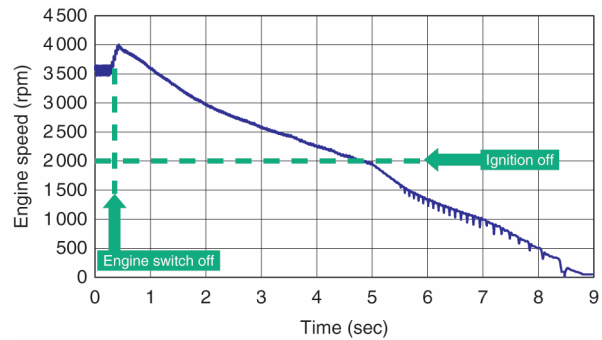


Fig. 21 Engine-stop control and engine speed

7. Completed Generator

The EM7000is generator that employs the technologies introduced above is shown in Fig. 22, and a specification comparison is shown in Table 6.

Table 6 Specification of EM7000is

		EM7000is
Engine	Displacement (cm ³)	389
	Speed (rpm)	* 2400 - 3600 ☆ 3300 - 3600
	Operating noise level (dB(A)at7m)	69
Generator	Type	Multi-pole field rotary
	Excitation method	Magneto
	Voltage regulation method	※ PWM
	AC voltage (V)	120/240
	AC frequency (Hz)	60
	Max. AC output	6500
	Rated AC output	5500
	Voltage variation rate	Momentary 10% max. Stability 6% max.
	Frequency variation rate	Momentary 1% max. Stability 1% max.
	Waveform distortion	5% max.
Dimensions	Generating efficiency	85%
	Dimensions L × W × H (mm)	1155 × 670 × 710
	Dry weight (kg)	95

* : Eco SW ON ※ PWM = Pulse width modulation
☆ : Eco SW OFF



Fig. 22 EM7000is

8. Conclusion

The EM7000is, a dual-voltage inverter generator that has a larger output than the GENE21 series, was developed.

- (1) Two inverters were used, and two kinds of voltages were obtained by connecting these inverters in series or parallel. Also, a control system that accurately synchronizes these inverters was developed.
- (2) A power supply was incorporated in each unit, realizing a compact, highly efficient alternator that produces a high output.
- (3) The completed generator employs a shroud sound isolation duct structure that completely covers the engine. As a result, a 30% volume reduction compared to the conventional synchronous generator and also a reduction of noise to 8 dB (A)/7 m in the practical load region were attained.
- (4) The use of a GCU enabled the number of electrical components to be reduced to 1/3 of that of a conventional synchronous generator, and also realized an information display with self-diagnostic function.

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