Distributed Generation Installed Each Family in 21 Century

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1. Introduction

Mitsubishi Heavy Industries, Ltd. (MHI) has been manufacturing various machines related to power industry in order to meet the needs of customers. “Distributed Generation” is a general term for small-scale power source against large-scale centralized power source that supplies electricity using nuclear, thermal and hydroelectric power plants and the network of power transmissions lines. Easy to install wherever needed as a small-capacity power source, the distributed generation generates only the required amount of power and has high energy efficiency. As a countermeasure against global warming and because of deregulation in energy industry, it has a promising future and is expected to have its market widened.

MHI deals with the distributed generation using high-power diesel engine, gas engine, and gas turbine, the reproducible energy such as wind power generation and solar power generation, and the new energy source fuel cell, etc. This paper, however, describes particularly the product equivalent to the low-capacity distributed generation with power 3.8 MW or under.

2. Past

Fig. 1 shows the horse-power generated by 4 kW - 3.8 MW class MHI engines.

MHI has been producing industrial engines since pre-war time for mounting and using on construction machines. However, with the Fire Service Act revised in 1974 and obligation enforced for buildings to install emergency power supply as a disaster preventing facility, the distributed generation became popular and came to be frequently used as the engines for package generation set.

Further, with the changes brought in energy situation in 1975-1984, there was an increasing market demand for application to continuous power source and cogeneration. Consequently, MHI developed new series

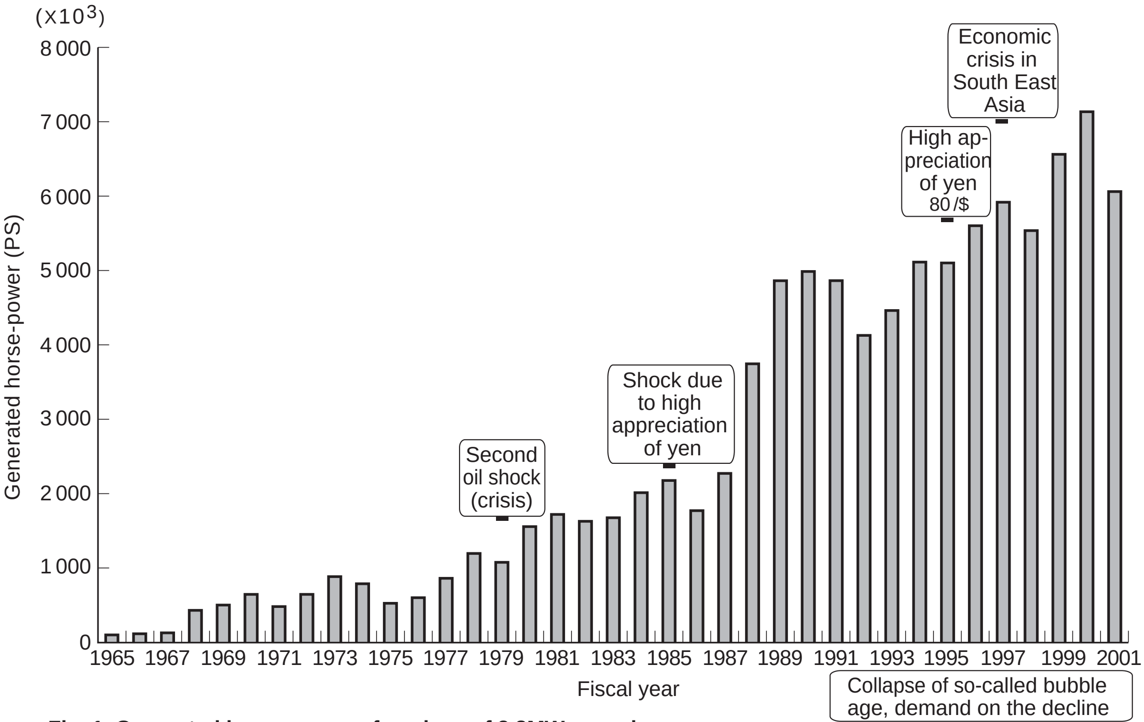


Fig. 1 Generated horse-power of engines of 3.8MW or under
Indicates the transition of generated horse-power of engines ranging in capacity from 4 kW to 3.8 MW since 1965.

of engines with higher performance and durability than the conventional ones, and launched them in the domestic market of distributed generation. Because of the brisk domestic market and increased export during the period of 1985-1994, the generated horse-power has so far enjoyed a rapid growth.

However, the engine generator for camping use did not spread much as the distributed generation for home use.

3. Present

3.1 Diesel engine

The diffusion of cogeneration and the deregulation of energy have led to the distributed generation getting spotlighted and increased.

Fig. 2 shows a line-up of engines used for small-power distributed generation.

Fig. 3 shows the comparison of engines for 1000 kW-class generators, indicating that the new-type engines S12H launched in 1997 is smaller in size and lighter in weight than the conventional type S12N put on sale at about 1975.

Found close to our living, the distributed generation has eventually come to the limelight in recent years with increasing demand for low pollution and energy-saving. In order to meet with these demands, MHI has developed and put on sale diesel engines conforming to emission regulations and low fuel consumption requirements or gas engines using clean city gas as the fuel.

The emission regulations schedule of U.S. Environmental Protection Agency (abbreviated as EPA) for off-load diesel engine is given in **Fig. 4** as an example,

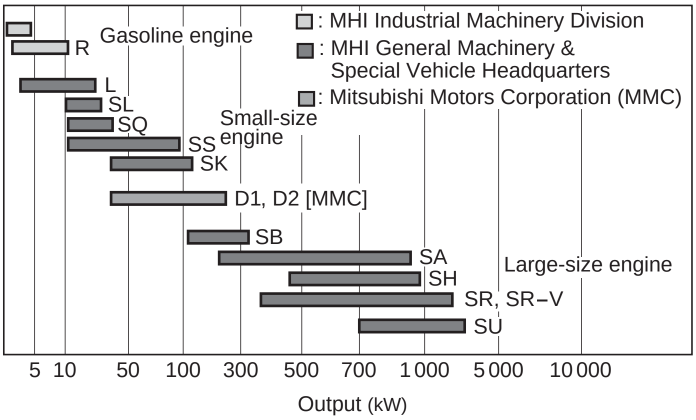


Fig. 2 Line-up of small-power distributed generation engines
Indicates a series of generator engines, covering a wide range from 1 kW to 3.8 MW.

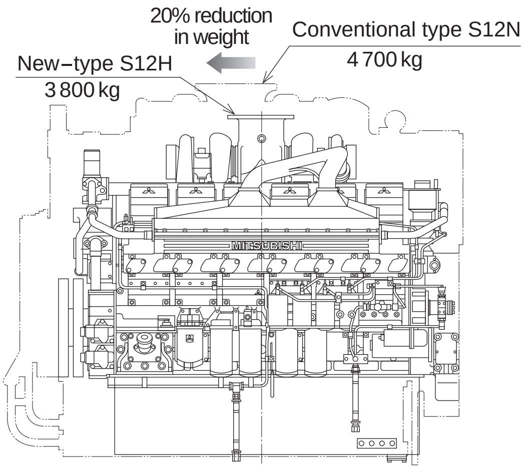


Fig. 3 Comparison of old and new engines
Conventional type S12N for 1 000 kW-class generator is compared with new type S12H in terms of size and weight. The weight is reduced by 20% in the new type.

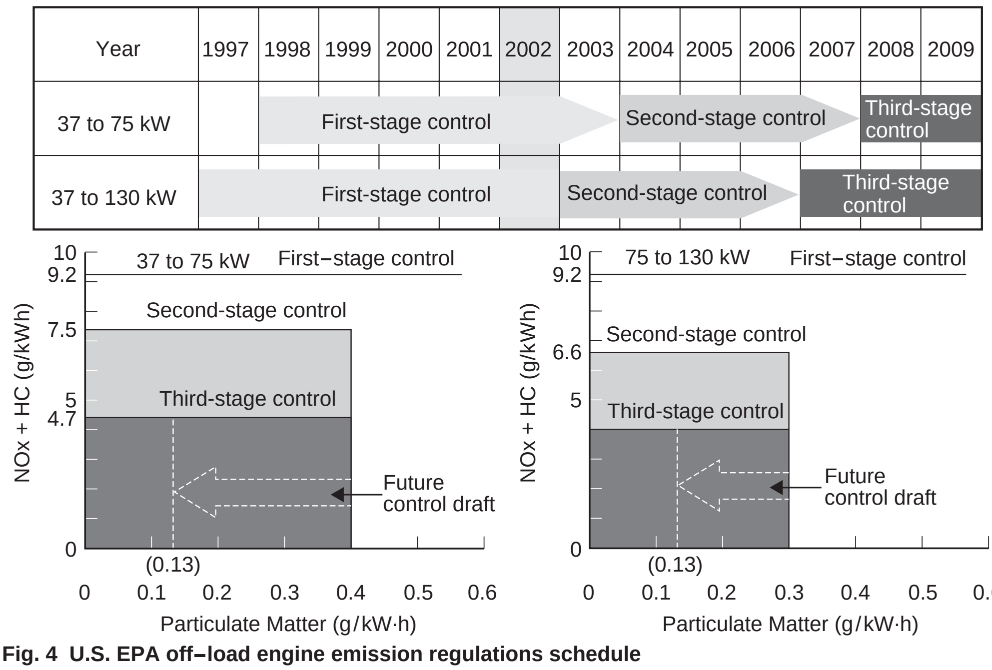


Fig. 4 U.S. EPA off−load engine emission regulations schedule
The example is for 37 kW to 130 kW, with the control getting stricter in second and third stages than in first stage.

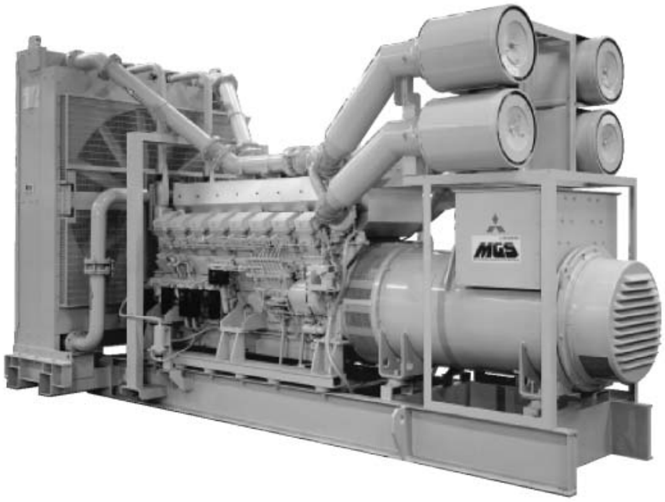


Fig. 5 Diesel engine corresponding to secondary control of exhaust gas (emission)
Indicates the appearance of 2 MW-class S16R generator set corresponding to North American EPA exhaust gas regulatory requirements (control) by adopting large-size air-cooled charge air cooler and high-pressure fuel-injection pump.

Fig. 6 Appearance of miller-cycle gas engine
Indicates the installed GS16R obtained by applying Miller-cycle gas engine for cogeneration to the S16R engine in Fig. 5.

indicating that the schedules and control values both in Japan and abroad are almost same. MHI is currently under consideration of putting new type engines conforming to the second-stage regulatory (control) requirements on sale and developing new engines to meet the more severe third-stage regulatory requirements. In order to clear the second-stage regulatory requirements, the intake temperature was reduced to diminish the NOx emission and the fuel injection pressure was increased to reduce the particulate matter considered harmful to environment and human body, leading to the commercialization of the engine with the appearance shown in **Fig. 5** and conforming to the gas emission regulatory requirements.

3.2 Gas engine

As for the gas engine, MHI launched the Miller cycle gas engine with the highest efficiency in this class of engine in the world in the market in 2000, and has gained high reputation. The appearance of the engine is shown in **Fig. 6**. As is shown in **Fig. 7**, Miller cycle refers to a system where the closing time of intake valve is changed to make the compression stroke shorter than that of a normal engine, causing the expansion ratio to become higher than the compression ratio. The work indicated by the section with dot meshing in the diagram gets increased, causing the thermal efficiency to get improved. MHI has successfully improved the efficiency by 5% as compared with the conventional engine by adopting this system in the

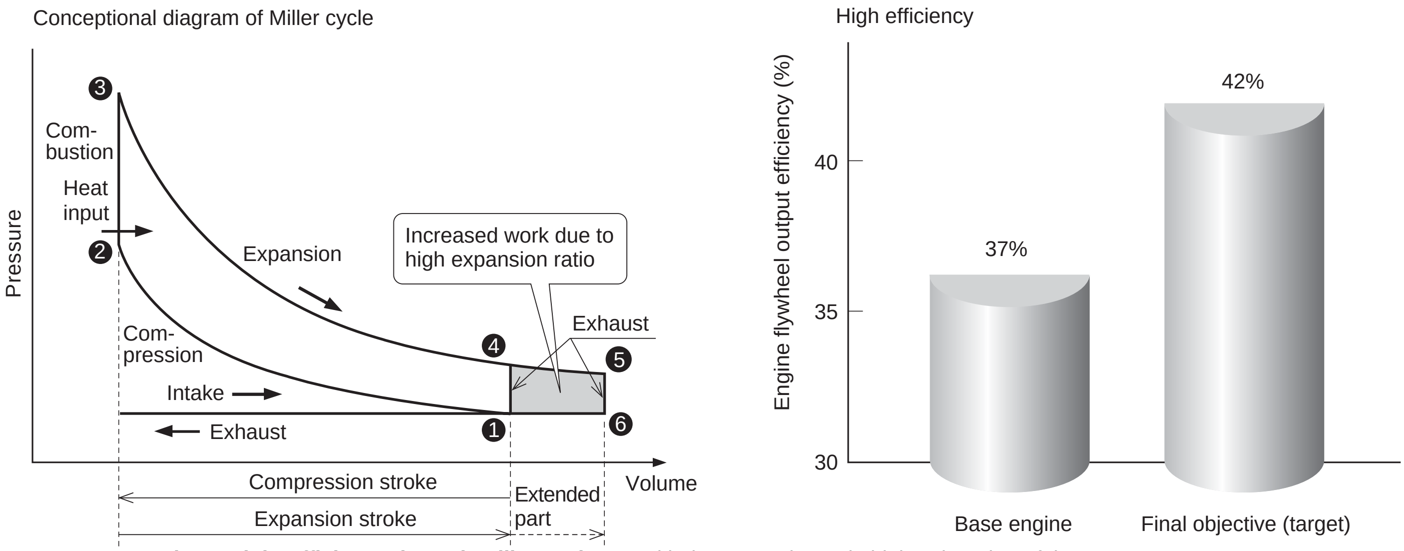


Fig. 7 High−efficiency through miller-cycle With the expansion ratio higher than that of the conventional engine, the work done got increased with the efficiency improved by 5% against the base engine.

Outline of equipment

1. Main specification of gas engine

Engine type	GS 16 R
Number of cylinders–Bore x Stroke	16–ϕ170 × 180
Output	845 kWe/1 500 rpm
Power generation efficiency	40%
NOx	1 20 ppm (O_2 0%)

2. Operating record
   (1) Operation started: July 1999
   (2) Total operating time: 7 600 hr

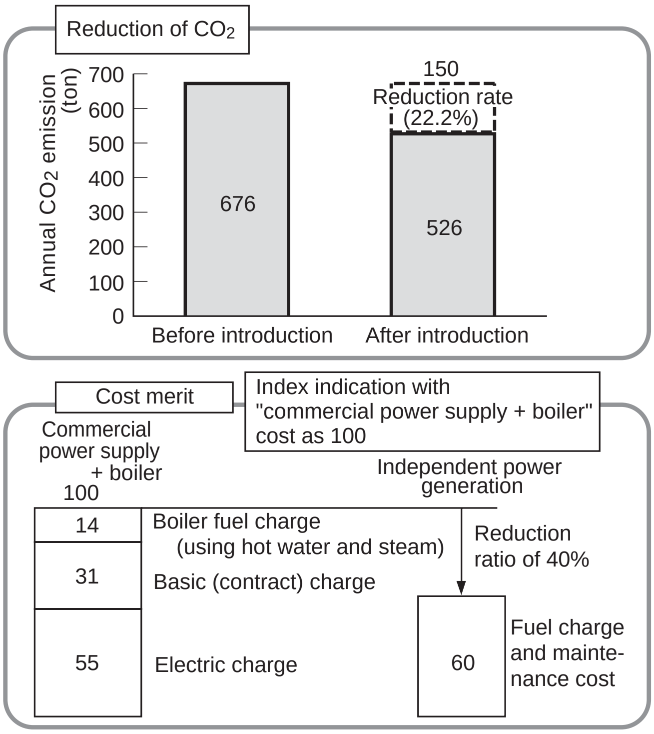


Fig. 8 Example of gas cogeneration engine installation Shows an example of independent power plant in Sagamihara Machinery Works of General Machinery & Special Vehicle Headquarters, indicating a drastic improvement in CO_2 emission and operating cost as compared with before the adoption of the plant.

lean-burn engine. **Fig. 8** shows an example of the gas cogeneration used for independent power generation in MHI Sagamihara Machinery Works, with the CO_2 reduced by approximately 20% as compared with prior to its adoption and the operating cost by approximately 40% as compared when the works had used commercial power supply and boiler.

These engines are operating at the customers' places and, like continuous generation system, are controlled through a 24-hour remote monitoring system to minimize the failure chance caused by trouble.

4. Future

4.1 Future of distributed generation

The demand for electric power is estimated to increase in Japan until the middle of 21st century. However, the centralized power generation is expected to face a drag on the new installation of nuclear power plant, making the construction of large-scale plants more and more difficult in the future. This is likely to increase the need of distributed generation all the more.

Further, because of the augmentation of equipment to match with the maximum power, the centralized generation is incapable of precise correspondence (to situation) such as load leveling, etc., so that the system has excessive equipment (facility), releasing about 60% of the input primary energy as waste heat. As a result, towards the middle of 21st century, when the equipment is expected to get superannuated needing renewal, it is considered to be partially replaced with the distributed generation and the small and medium size centralized generation with excellent efficiency.

Fig. 9 shows the possibility of the distributed generation getting widely spread in the future. The distributed generation adopting micro-gas turbine used in a convenience store has become a topic of conversation in newspaper, etc. in recent years, and is expected to spread in future for small-scale facility such as houses with less demand of heat and electricity. It is also expected that the power source for distributed generation will become optimum for each pattern of power demand.

Further, the distributed generation is indispensable to the plant facilities where installation of transmission line (cable) is not easy, and eventually, its demand (need) is considered to be increasing.

MHI is mustering efforts in the development of future-generation products, such as high-efficiency gas engines and high-efficiency continuous diesel engines for distributed generation, and such as micro-gas turbines and fuel cells for small stores and home use.

4.2 High-efficiency gas engine

As for the high-efficiency gas engine, the development of engine employing the cylinder-wise, independent optimum electronic control adopted in MACH series for high-power distributed generation

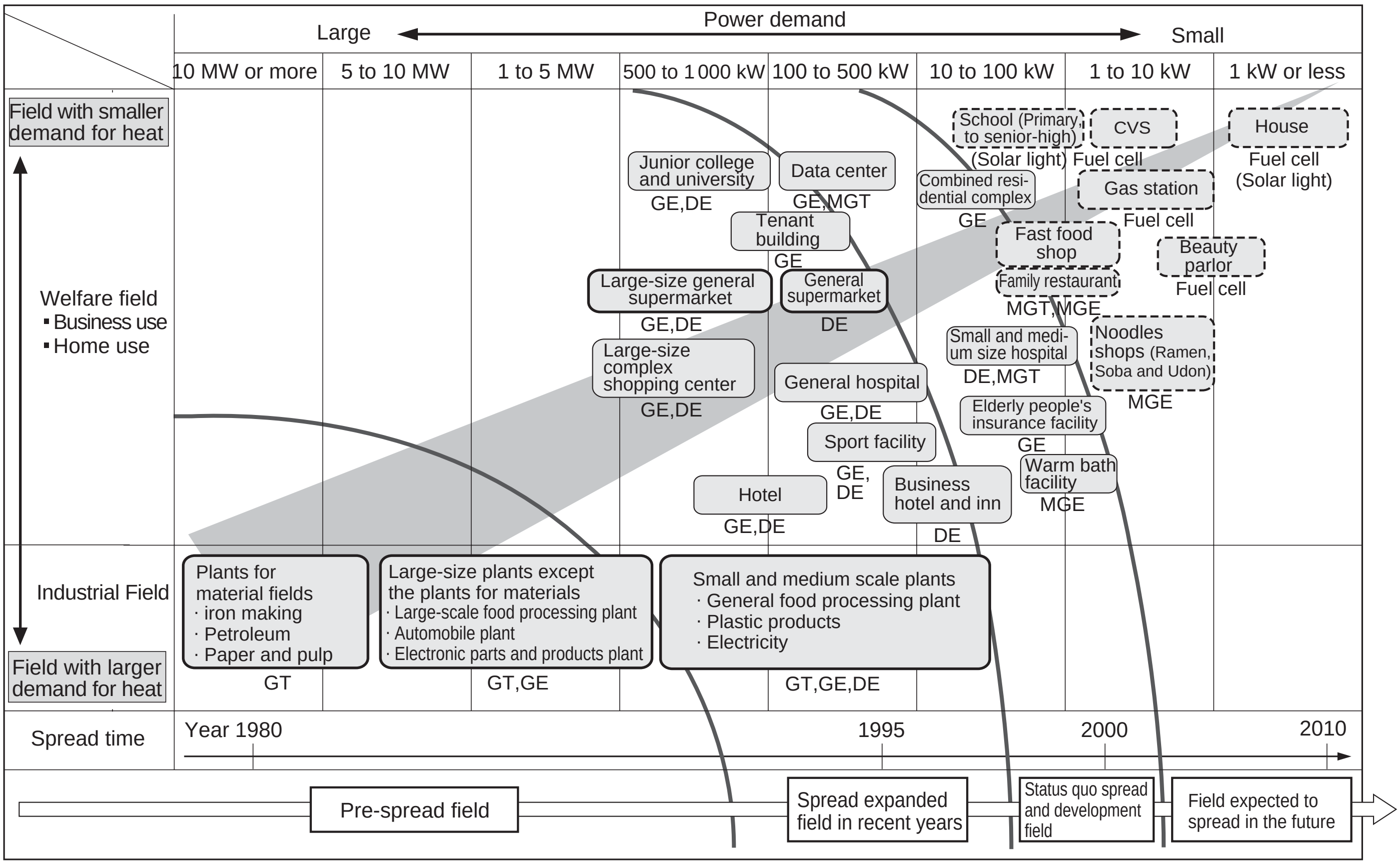


Fig. 9 Prospect of expansion in spread of distributed generation in future It is expected that the distributed generation with conveniently operable power source will spread in future for small-scale facility such as houses with less demand of heat and electricity.

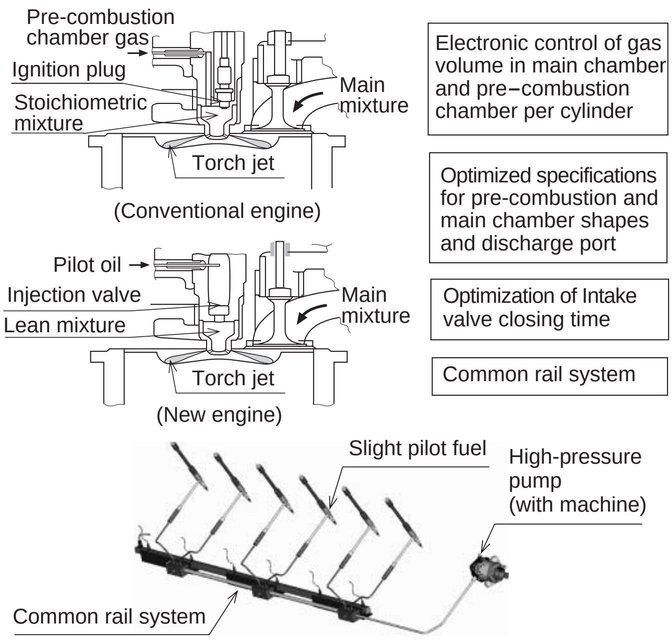


Fig. 10 Development of high-efficiency gas engine
Indicates the concept of development of MACH series, with the efficiency of 42% achieved by adopting the elements in the figure.

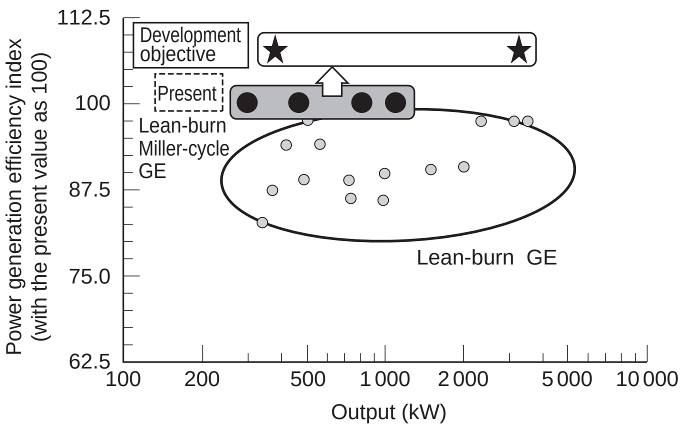


Fig. 11 Development objective of high−efficiency gas engine
Improved power generation efficiency and substantial series are obtained by partially applying the development factors of Miller-cycle and MACH series.

as shown **Fig. 10**, the lean-burn system of pilot ignition to control NOx emission and making partial use of the Miller cycle development factor is under way. The development objective (target) is given in **Fig. 11**.

4.3 High-efficiency diesel engine

Development of new series of high-efficiency diesel engine for continuous use conforming to the much stricter regulatory requirements for exhaust gas expected in the future is under way. In order to achieve simultaneously both the correspondence to exhaust gas regulatory requirements and the improvement in thermal efficiency, the engine is designed to have high stiffness (rigidity) to withstand the increasingly high maximum pressure inside the cylinder in addition to the adoption of high-pressure injection of fuel and electronic control, with

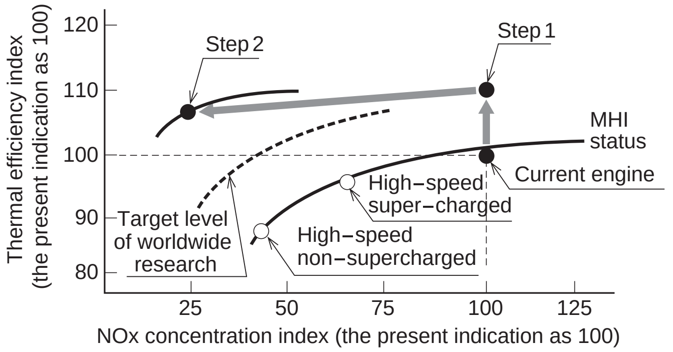


Fig. 12 Development objective (1) of high-efficiency diesel engine
The development objective is expressed by the relationship between NOx and thermal efficiency, with the thermal efficiency improved at the present level of NOx before reducing NOx emission drastically in the next step.

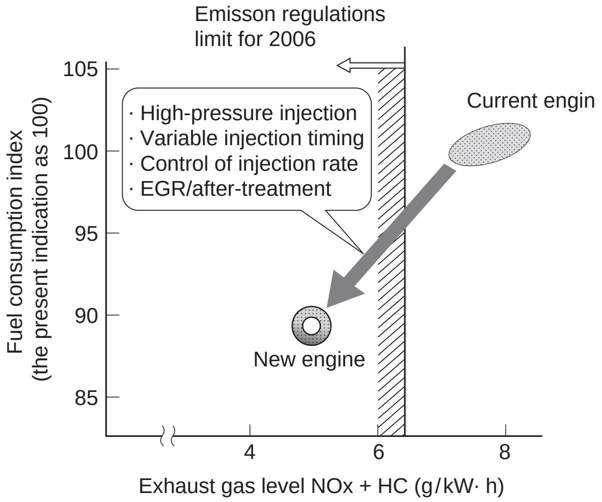


Fig. 13 Development objective (2) of high-efficiency diesel engine
Low emission of exhaust gas and drastic reduction in fuel consumption are set as the development objective (target) by applying the development factors (elements) in the figure.

the target values shown in **Fig. 12** and **Fig. 13**. In order to achieve the final target, development of unique MHI after-treatment device and the conventional technology for meeting the exhaust gas regulatory requirements such as water injection inside the cylinder as well as the correspondence to the engine performance are to be effectively used.

4.4 New distributed generation

Fig. 14 shows the micro-gas turbine generator. Though there is no detailed description in the figure, the generator is put to commercialization with the following 3 "E's" as the sales points.

(1) Efficiency: Small-size generator with efficiency 30% or above
(2) Environment friendly: Urban-type generator with low NOx emission and low noise
(3) Easy to operate: Generator capable of starting, loading, and stopping by means of a single button

Fig. 15 shows the polymer electrolyte fuel cell. The know-how of the research carried out jointly with Mitsubishi Motors Corporation is to be applied to the development of the fuel cell for distributed generation. Development of 1 kW-class distributed generation for home use is also under way.

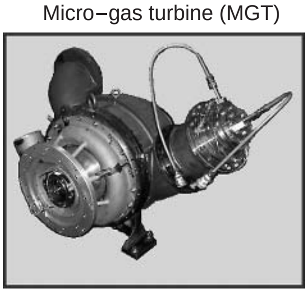
The expansion of spread of the distributed generation depends largely on external environmental factors (such as power rates, fuel cost, and environmental control). MHI is developing gas turbine and fuel cell in addition to diesel and gas engines to correspond to whatever change might occur in the environment.

Micro−gas turbine generation set

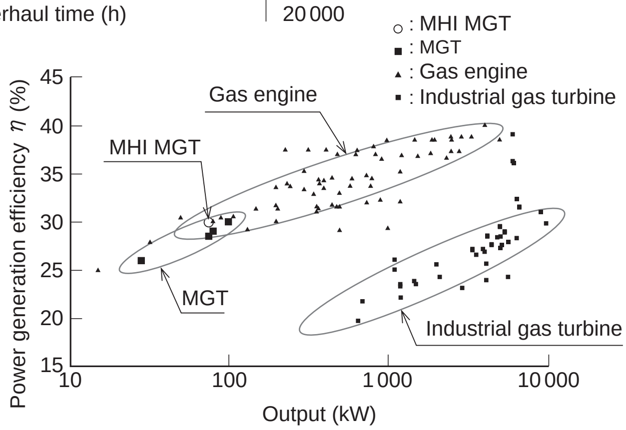
[Specifications]

Output (kW)	80
Rotational frequency (rpm)	65 000
Power generation efficiency (%)	30
NOx (ppm)	25 or more
Overhaul time (h)	20 000

Micro−gas turbine (MGT)



High−speed generator



Output and efficiency of MGT and gas engine

Fig. 14 Micro-gas turbine generator With the output 80 kW, the power generation efficiency of 30% has been achieved, so that the generator is placed at the top level in the world.

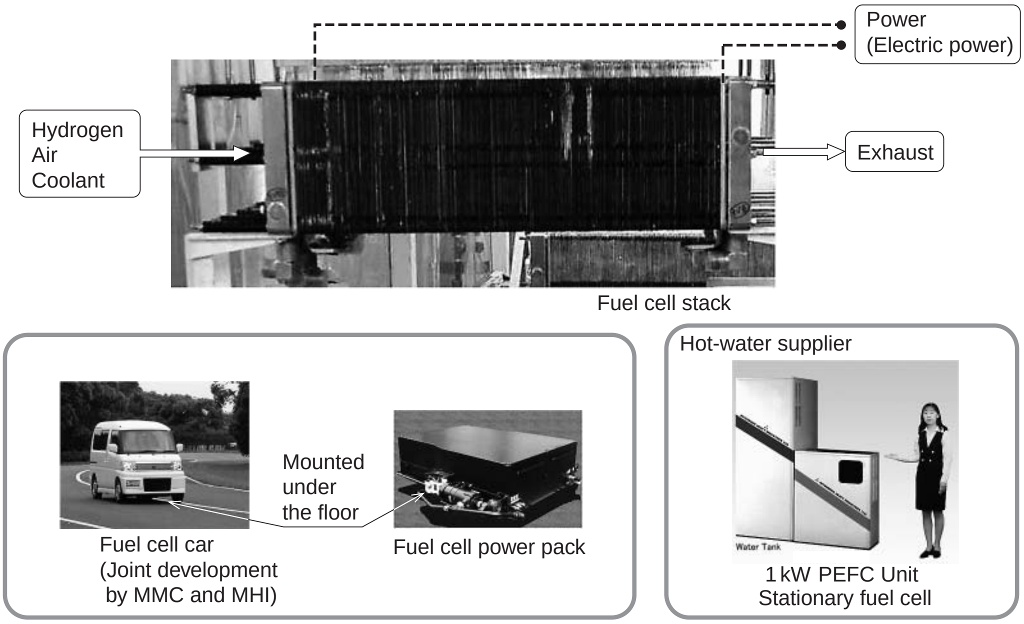


Fig. 15 Appearance of polymer electrolyte fuel cell Describes the outline of the fuel cell and the fuel cell under development, with the photograph at the bottom right showing 1 kW fuel cell for home use.

5. Conclusion

With the diffusion of distributed generation to the extent that one unit is used in each family, each family will start to own a heat accumulating system, bringing a drastic change in the pattern of energy utilization. Then the present power system from upstream to downstream will not work, calling for the optimization of energy operation of the whole community. This is likely to result in the revolution of energy business, giving rise to a rich life with less pollution. MHI is determined to continue making efforts to develop and spread distributed generation meeting individual requirements in order to realize such world.

References

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