Solutions for Oil & Gas Industries under Expansion of Investment Taking Account of Environmental Conservation

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OVERVIEW: Investment in development remains strong in the oil and gas industry due to the long-term augmentation of energy consumption evident in the global market, while the industry also faces urgent issues which include the sustainable and effective use of finite energy resources, new efforts to develop unexploited sources of energy, and the acquiring of interests to these resources. In recent years, the requirements for the oil and gas production plants that support these developments have included reducing life cycle costs and achieving a high level of plant efficiency, moreover minimizing CO_2 emissions for environmental conservation. Hitachi is responding to market needs through initiatives aimed at increasing the value of specific products by measures such as developing technology and improving the efficiency of key equipment and systems and offering total solutions that integrate energy-saving technologies accumulated from past involvement in various different fields, while also contributing to global warming prevention, reducing the burden on the environment, and similar objectives.

INTRODUCTION

THE environment in which the oil and gas market operates has undergone significant changes in recent years. Along with a rapid increase in energy consumption driven by population increase and economic growth in emerging economies in particular (see Fig. 1) have come the vigorous pursuit of resource diplomacy aimed at ring-fencing oil and natural gas resources and, on the supply front, active moves toward objectives such as maximizing the value of finite oil and gas resources and ensuring their sustainable and effective use and an expansion of development and investment in previously unexploited sources of energy.

Meanwhile, the necessity for actions such as preventing global warming and reducing the burden on the environment has created an urgent need for measures aimed at reducing CO_2 (carbon dioxide) emissions and improving energy efficiency in all processes in the oil and gas value chain from upstream resource development to the production and transportation of oil and gas end-products.

Against this background, the equipment, systems, and other products that Hitachi's industrial and social infrastructure business segment supplies to oil and gas plants need to deliver value in a way that solves the conflicting market issues of responding to this growth in energy demand while at the same time reducing the burden on the environment. Hitachi contributes to the oil and gas industry through activities such as the development of product technology and the implementation of solutions that respond to these needs.

Specifically, Hitachi offers a wide range of products and systems that realize reductions in the amount of energy consumption at plants and achieve greater efficiency across all plant equipment by improving design flexibility and optimizing plant capacity, operability, and maintainability.

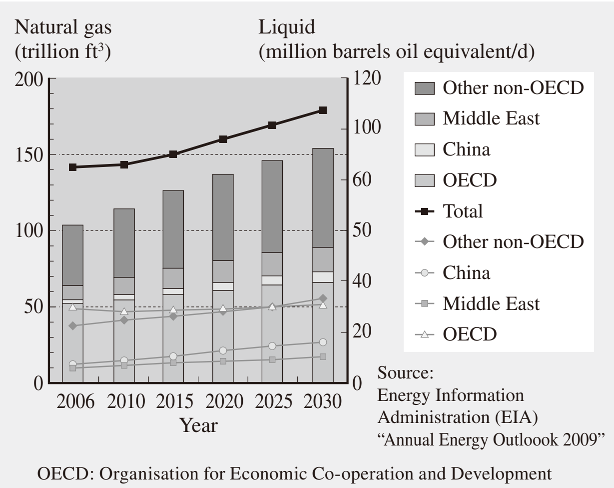


Fig. 1—Worldwide Consumption of Marketed Energy, 2006—2030.
Compared to 2006, demand for both oil and natural gas in 2030 is anticipated to grow by roughly 1.3 to 1.5 times.

This article describes activities such as specific efficiency improvements and technical developments based on market characteristics for Hitachi's main products and systems which include process centrifugal compressors, power generation systems, energy-saving systems, an area in which Hitachi has been involved, and an example of total solutions that take advantage of the combination of these products and systems in collaboration with global partners.

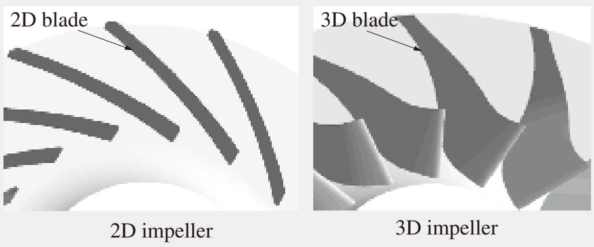
COMPRESSORS FOR OIL AND GAS INDUSTRY THAT AIM TO REDUCE LIFE CYCLE COSTS

Process centrifugal compressors are widely used in gas processing plants and gas pipelines in the oil and gas industry, and these demands are increasing in the wave of recent soaring crude oil and natural gas prices.

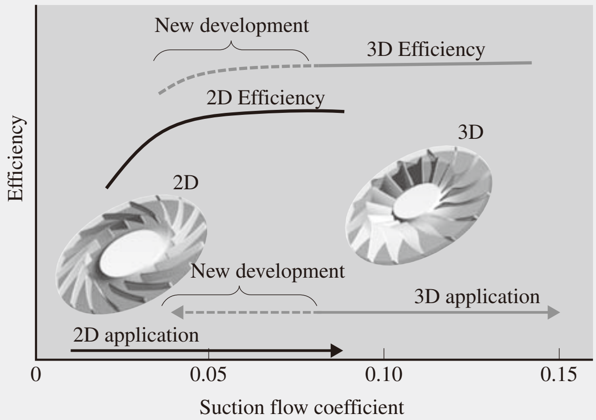
Reduction of life cycle costs is a key issue for compressors used in this application, which are required to have high efficiency and sufficient operating range to be suitable for changes in load including the future demand. In order to satisfy these requirements, an efficient capacity control method needs to be established in addition to the improvement of impellers with higher efficiency and a wider operating range. The following section describes an impeller that was developed to meet the above requirements and a capacity control method by the IGV (inlet guide vane) system.

Development of Highly Efficient Impeller with Wide Operating Range

Many centrifugal compressors in the oil and gas industry are of multistage impellers and it is known



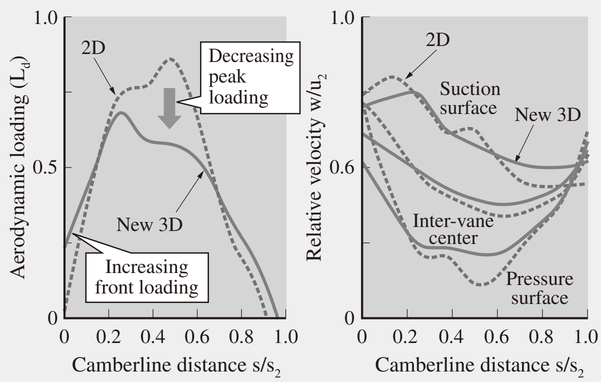
(a) The main difference between 2D and 3D impellers is the blade geometry in the direction of the blade height.



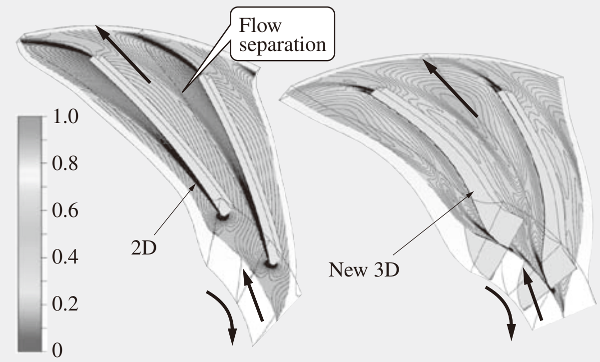
(b) The applicable range of flow coefficient in which the more efficient 3D impeller can be used instead of a 2D impeller has been extended to cover lower flow coefficient.

2D: two-dimensional 3D: three-dimensional

Fig. 2—Blade Geometry and Applicable Range of 2D and 3D Impellers.
Comparisons of the blade geometries (a) and applicable ranges (b) of 2D and 3D impellers are shown.



(a) The blade loading distribution is optimized to achieve higher efficiency by increasing the front loading on the inlet and wider operating range by decreasing peak loading at the mid-span in comparison with a conventional 2D impeller.



(b) In the region near the surge points of the 2D impeller, the significant flow separation observed in the 2D impeller does not occur in the flow pattern for the new 3D impeller.

u_2: peripheral velocity s_2: impeller passage length

Fig. 3—Comparison of Internal Flow Pattern of 2D and New 3D Impellers.
The aerodynamic loading and the relative flow velocity distribution on the shroud side (a) and the relative Mach number distribution at mid-span near surge point on the 2D impeller (b) are shown.

that the overall efficiency is dominated by that of earlier stages and the overall operating range by that of latter stages. Due to the compressibility of the gas nature, the latter stage the gas flows through, the higher its density becomes. Therefore, an impeller in the latter stage handles smaller volume flow and results in a lower flow coefficient. Accordingly, the low flow coefficient impeller characteristics are quite important to determine the wider overall operating range.

For the low and medium flow ranges where 2D (two-dimensional) impellers have conventionally been used, Hitachi has employed CFD (computational fluid dynamics) to develop 3D (three-dimensional) impellers to achieve high efficiency and wide operating range.

Fig. 2 shows the blade profile and scope of application of 2D and 3D impellers. The aerodynamic design concept and fluid performance of the new 3D impellers are described below.

(1) Aerodynamic design

Fig. 3 shows a design concept for the newly developed 3D impellers. Compared to the previous design, a feature of the aerodynamic loading distribution for this new impeller is characterized by a higher front loading at the inlet and lower peak loading at the mid-span. The increasing front loading at the inlet drastically decelerates the flow velocity in the first half and improves the impeller efficiency. In addition, the decreasing peak loading at the mid-span increases the minimum flow velocity on the suction surface, and thus prevents flow separation inside the impeller and enlarges the surge margin.

(2) Test results

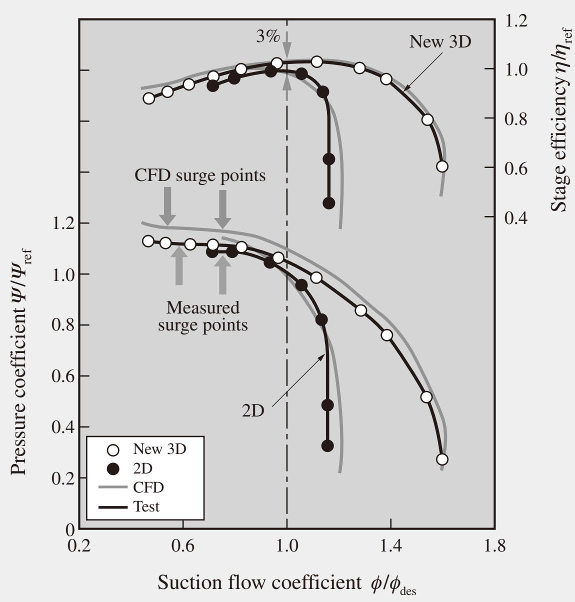
Fig. 4 shows a comparison of the performance test results of the 2D and 3D impellers with prediction by CFD. The efficiency η and pressure coefficient ψ are normalized by those of the 2D impeller at the design flow coefficient.

As shown in the figure, the design-point efficiency of the newly developed 3D impeller is 3% higher than that of the previous 2D impeller and the operating range has been enlarged by 2.8 times. The combined effect of changing the 2D impeller to a 3D design and optimizing the aerodynamic loading distribution can achieve significantly improved efficiency and a wider operating range.

Also, the efficiency and pressure coefficient characteristics predicted by CFD show very close agreement with actual measurements.

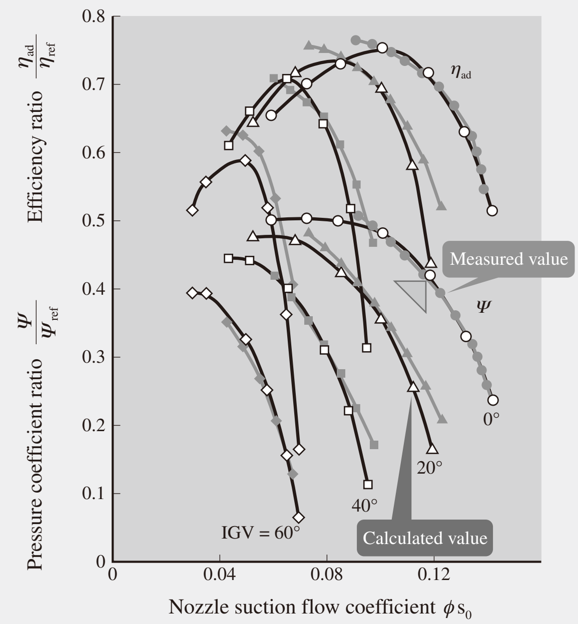
IGV Control System

An IGV control system is one of the capacity



CFD: computational fluid dynamics

Fig. 4—Test Results and Performance Predictions Obtained Using CFD for 2D and New 3D Impellers.
The new 3D impeller achieved 3% higher efficiency and 2.8 times wider operating range compared with the 2D impeller. The prediction accuracy by using CFD for these impellers is within ±5%.



IGV: inlet guide vane

Fig. 5—Prediction and Actual Measurement of Fluid Performance of Compressor with IGV.
Influence of changes in IGV angle on performance is shown. The predictions are in close agreement with actual measurement.

control methods in turbomachinery. This method has the following characteristics:

(1) Capacity can be regulated without a significant decrease in compressor head.

(2) A wider operating range at low flow rates can be achieved compared to variable speed control.

(3) Losses are lower compared to using suction throttling.

(4) Higher power saving is achievable at constant discharge pressure compared with variable speed control.

The CFD analysis was made for optimizing the inlet flow path including IGV's, predicting the downstream flow angles and total pressure losses. Then, IGV characteristics were tested using a single-stage compressor. Fig. 5 shows the results of this testing. Good agreement was obtained between the predicted and actual partial load performance and the accuracy of the pre-whirl angle prediction was verified.

Future Applications

Optimizing the aerodynamic load distribution through the utilization of CFD has achieved a world-class improvement in the impeller efficiency (+3% compared to the conventional model) and a significantly better operating range (2.8 times the conventional model). Hitachi has established and utilized its own compressor automated design system which makes up preliminary model selection at proposal stage and detail design of components including manufacturing drawings. The results from this new development have already been incorporated into this system which enables the quick compressor selection to meet the customer requirements. Hitachi has also established a design methodology for IGV system capable of achieving an even wider operating range. By utilizing the results of this development, Hitachi intends to supply centrifugal compressors with high efficiency and wide operating range in a timely manner, with the applications to the oil and gas market as well as CCS (carbon dioxide capture and storage) at power plant which requires a wide operating range to cope with varying electrical loads.

H-25 GAS TURBINE APPLICATIONS IN OIL AND GAS MARKET

Gas turbine market has expanded rapidly in recent years due to growing demands for energy saving and environmentally conscious power plant.

This is a consequence of the advantages of gas turbines (high efficiency, expandability, environmental compatibility, fuel flexibility and ease of operation). However, market needs in large units for electrical companies and small- / medium-sized units in oil and gas market are different.

This section describes the H-25 gas turbine which has rapidly increased in sales volume in the oil and gas market.

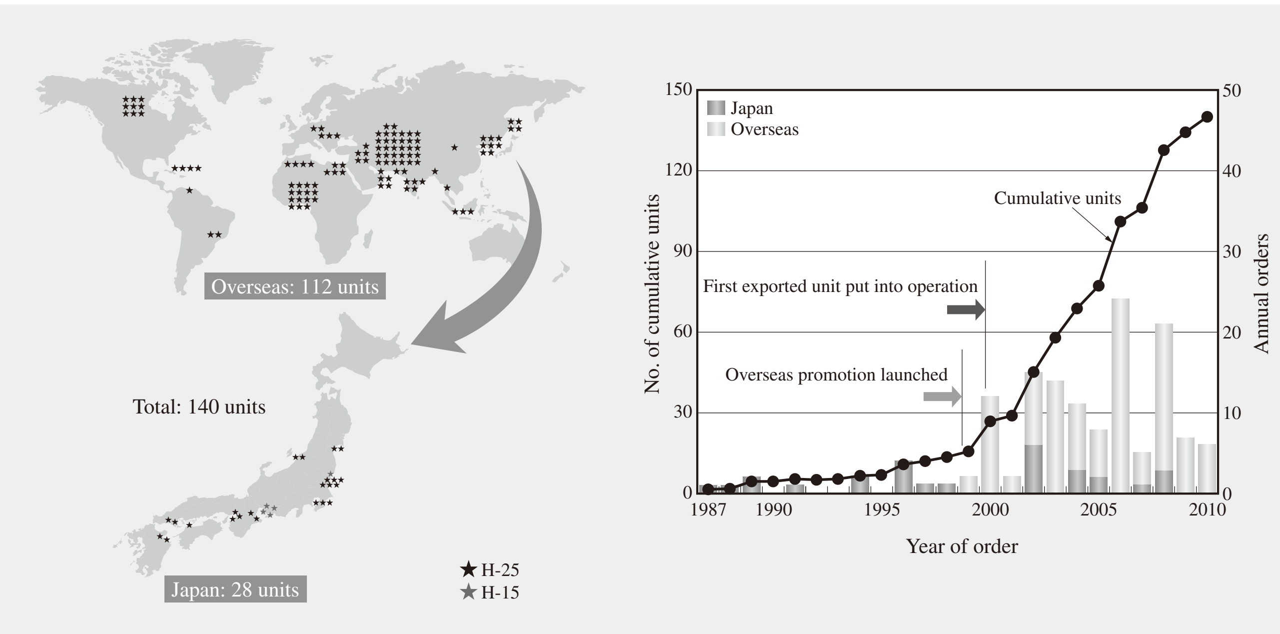


Fig. 6—Sales of H-25 Gas Turbine.
A total of 140 units have been delivered since the first order was received in 1987.

Features of the Oil and Gas Market

Reliability and special standards

The consequences of an outage on a gas turbine at on oil refinery or petrochemical plant are greater than just a shortage of electric power and may result in the shutdown of associated plants leading to significant losses. Accordingly, the most important factor in the oil and gas industry is reliability. No matter how excellent in performance, equipment will only be adopted after reliability is proved in the field. This is a major point of difference with large commercial gas turbines where the competition is to develop units with large output and high efficiency. This philosophy, "never shut down the units with accidental troubles" is reflected in the plant design. The required number of gas turbines is determined based on operating them under partial load and additional backup units are provided. As a result, sites with four or five gas turbines are common.

It is rare to perform load tests at the factory before delivery because gas turbines have a fully standardized package design. However, it is common in the oil and gas industry to perform load tests at the factory as a minimum there is a requirement to perform no-load tests. The reason for this practice is to avoid bringing faults to the site. Naturally, this idea is also reflected in the equipment design. Meanwhile, instrumentation systems are often required ultimate redundancies and monitoring functions to secure the total system. It is also necessary to comply with the stringent specifications such as API (American Petroleum Institute) standards.

Fuel flexibility and environmental features

For environmental and efficiency reasons, DLNCs (dry low NO*x* combustors) fueled by natural gas are dominant in large combined systems. Natural gas has become more common as fuel in recent times in the oil and gas industry, still needs to burn light oil, natural gas/light oil dual-fuel, off gas and etc. are active. For these fuels, water injection and steam injection systems are sometimes used with standard diffusion combustors as well as DLNC for environmental reasons. Because gas turbines are directly powered by combustion gas, many potential problems such as corrosion lie in the fuel and its combustion system. Therefore, for the gas turbine in the oil and gas industry, a high level of engineering skills is required for fuel evaluation and design of fuel systems.

TABLE 1. H-25 Gas Turbine Orders by Sector

The oil and gas market accounts for more than half of all orders.

Oil & gas	74 (53%)
Electric companies and IPPs	48 (34%)
Other industries	8 (6%)
Regional heat and power	7 (5%)
Research and development	3 (2%)
Total	140 (100%)

IPP: independent power producer

TABLE 2. Main H-25 Gas Turbine Specifications

The H-25 gas turbine is a heavy-duty model designed for long-term continuous operation.

Component	Design
Gas turbine	Heavy-duty, simple cycle, single-shaft
Compressor	17-stage axial type Pressure ratio: 14.7
Turbine	3-stage impulse type Air-cooled 1st and 2nd stage nozzle and bucket
Combustor	Reverse flow type, 10-chamber Conventional combustor or DLNC

DLNC: dry low-nitrogen-oxide combustor

H-25 Gas Turbine

History of H-25 gas turbine

Total orders for the gas turbine have reached 140 units since the first order was received in 1987 (including five of the smaller H-15 model gas turbines) (see Fig. 6).

Table 1 shows a breakdown of H-25 gas turbine orders by market. As indicated by the table, the oil and gas industry accounts for more than half of all orders.

Features of H-25 gas turbine

The H-25 is a heavy-duty, single-shaft, for 30-MW-class gas turbine with the highest level of efficiency and reliability in its class.

Table 2 lists the main specifications of the H-25 gas turbine and Fig. 7 shows a cross section.

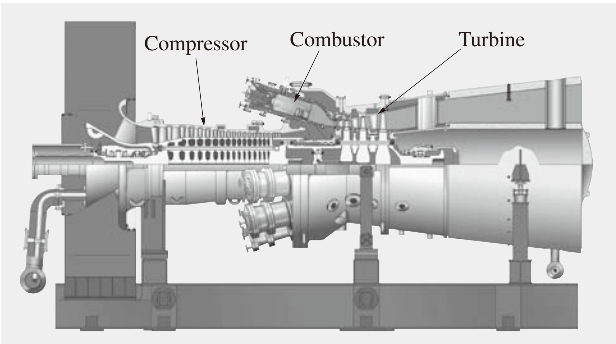


Fig. 7—H-25 Cross Section.
The cross section shows that the H-25 is a single-shaft gas turbine suitable for power generation.

Example of H-25 Gas Turbine Applications

Fig. 8 shows the H-25 gas turbine supplied to the Sakhalin II Project, one of the natural resource development projects underway in Russia's Sakhalin Sea. Operating in an environment where the air temperature can fall as low as -42°C, the unit not only supplies electricity to the plant, it also achieves a high overall efficiency by supplying heat to a WHRU (waste heat recovery unit). When gas turbines are used in a cold climate area, where electricity and heat are required, co-generation system with an HRSG (heat recovery steam generator) is used in place of a WHRU, achieving overall efficiency in excess of 80%.

Fig. 8—H-25 Gas Turbine at Sakhalin II Project.
An overview of the H-25 gas turbine that contributes to stable supply of LNG (liquefied natural gas).

Future Development

The high performance and reliability of the H-25 gas turbine have led to strong growth in orders. The gas turbine has a wide range of applications that are not limited to the oil and gas market and also include district heating and cooling systems and cogeneration systems for general industry. Hitachi intends to continue working hard to achieve even better efficiency and reliability to satisfy the needs of these applications.

SOLUTIONS FOR ENERGY CONSERVATION AND CO_2 EMISSIONS REDUCTION USING HIGH-VOLTAGE INVERTERS

In addition to major items of equipment for the oil and gas industry such as process centrifugal compressors and gas turbine generators described above, Hitachi is also working actively to encourage the adoption of energy-saving solutions for existing equipment in oil and gas plants by taking advantage of its extensive know-how and experiences in offering energy-saving services to various different sectors of manufacturing industry that it has built up through their past activities. These are described below.

Energy-saving for Utilities Equipment

Hitachi conducts evaluations of the energy savings available by adopting inverters to auxiliary equipment for utilities such as fans, pumps, and blowers. The installation of an inverter in auxiliary equipment can often be done with only a partial shutdown of the equipment involved, and without having to wait for a regular plant maintenance shutdown, and because the disturbance to systems such as heat-source equipment and electrical distribution equipment is minimal, the scope for using inverters in existing oil and gas plants is wide.

The first step is to select which items of equipment in the plant are suitable for conversion to inverter-based operation and to investigate their actual operating conditions to evaluate the energy savings, CO_2 emissions reduction, and return on investment that installation of an inverter will achieve. In addition to determining the direct effects of installation, Hitachi's evaluation also considers technical issues of concern associated with installation of an inverter (such as the consequences and countermeasures in the event of an inverter trip causing a variation in airflow, for example) and can produce an overall proposal for improving energy savings.

Adoption of Electric Drive for Compressors

This section describes the process of evaluations and proposals based on estimating the benefits of replacing steam turbine drive with motor drive for compressors that are the main consumers of energy in oil and gas plants. Although the potential energy savings and CO_2 reduction are large compared to the utilities equipment described above, there is a need to investigate and evaluate the overall energy balance including the augmentation of electricity supply equipment and centralization of heat generation equipment.

Hitachi estimates energy savings by taking account of how electrification will change the steam balance based on the steam flow in the plant and the operating conditions (see Fig. 9).

Evaluation of CO_2 Emissions Reduction

As the CO_2 emission factors for energy sources such as electricity, gas, and fuel oil are often undetermined in overseas oil and gas plants, an understanding of the

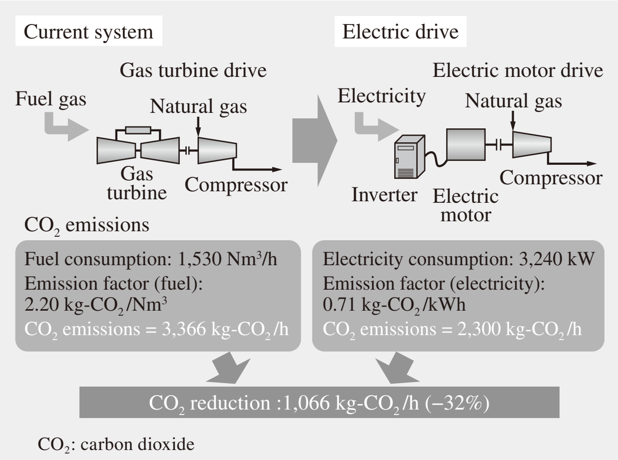


Fig. 9—Concept of CO_2 Emissions Reduction by Electrification of Turbine-driven Compressors.
CO_2 emissions can be reduced through the appropriate selection of motor capacity to improve operating efficiency and by switching to electrical energy which has a lower CO_2 emission factor.

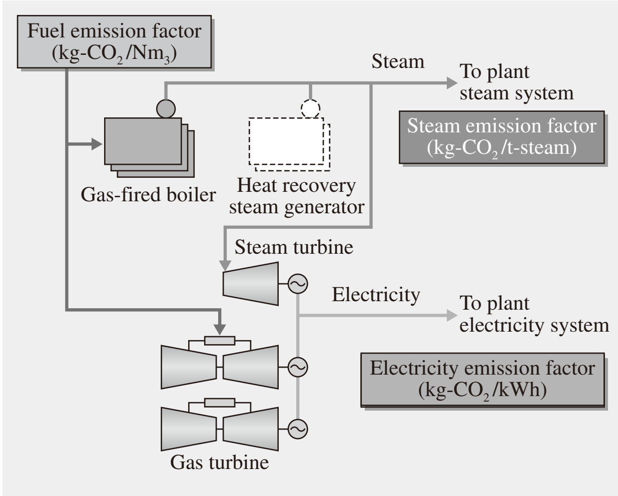


Fig. 10—Overview of CO_2 Emission Factor Calculation.
CO_2 emission factors are calculated from the fuel composition and the configuration and operating conditions for the heat sources and electricity generation equipment in the plant.

individual energy systems in the plant is needed to calculate the potential CO_2 emissions reduction.

To calculate and evaluate potential CO_2 reduction for an oil and gas plant, Hitachi conducts a survey to determine the characteristics of the heat source and electricity generation systems in the plant including their configuration, operating conditions, and fuel composition (see Fig. 10).

Future Development

When conducting large-scale energy savings and electrification programs in an existing plant, it is necessary to keep in mind the resulting changes in the electric power and steam balance of the plant. Hitachi plans to continue working actively to develop improvement solutions for all energy supply equipment including gas turbine generators and steam systems.

TOTAL SOLUTION FOR COMPACT MOTOR-DRIVEN LNG PLANTS

Traditional LNG (liquefied natural gas) projects have been planned for the development of large scale gas fields with production in the 3-million-t/year range or larger. Medium and small size gas fields, on the other hand, are currently being treated as a lower priority and dropped from development due to their low commercial availability. In collaboration with global partners, Hitachi is working on the development of commercially viable LNG plants with high production efficiency which have a production capacity of 0.5- to 2-million-t/year.

Proposal for Compact Motor-driven LNG Plant

Fig.11 shows a flow chart of an LNG plant being proposed jointly with an engineering company.

Hitachi proposes total solutions of mechanical and electrical systems including centrifugal compressors for liquefaction process and drivers for those compressors, power generation systems, and substation facilities supplying electricity to the plant, monitoring and control systems for liquefaction process and other facilities.

The refrigerant system can be downsized by adopting motor-driven compressor. This allows modularization of the facilities to reduce the total cost in ways of improving plant construction workability and shortening construction period.

As motor-driven system also requires fewer of the periodic maintenance shutdowns that are a feature of gas turbine-driven system, the operation availability per year can be increased compared with gas turbine-driven system. Thus, the life cycle cost of the LNG plant can be reduced and the cost competitiveness of the LNG produced by the plant can be increased.

Also, by variable-speed control of the motor with the inverter, a compressor drive system with good start-up performance and operability can be realized. As this system is easy to follow the variable change of operation, the reductions of power consumption from full loading is expected as the contribution to the energy-saving when the liquefaction process is operated in lower consumption.

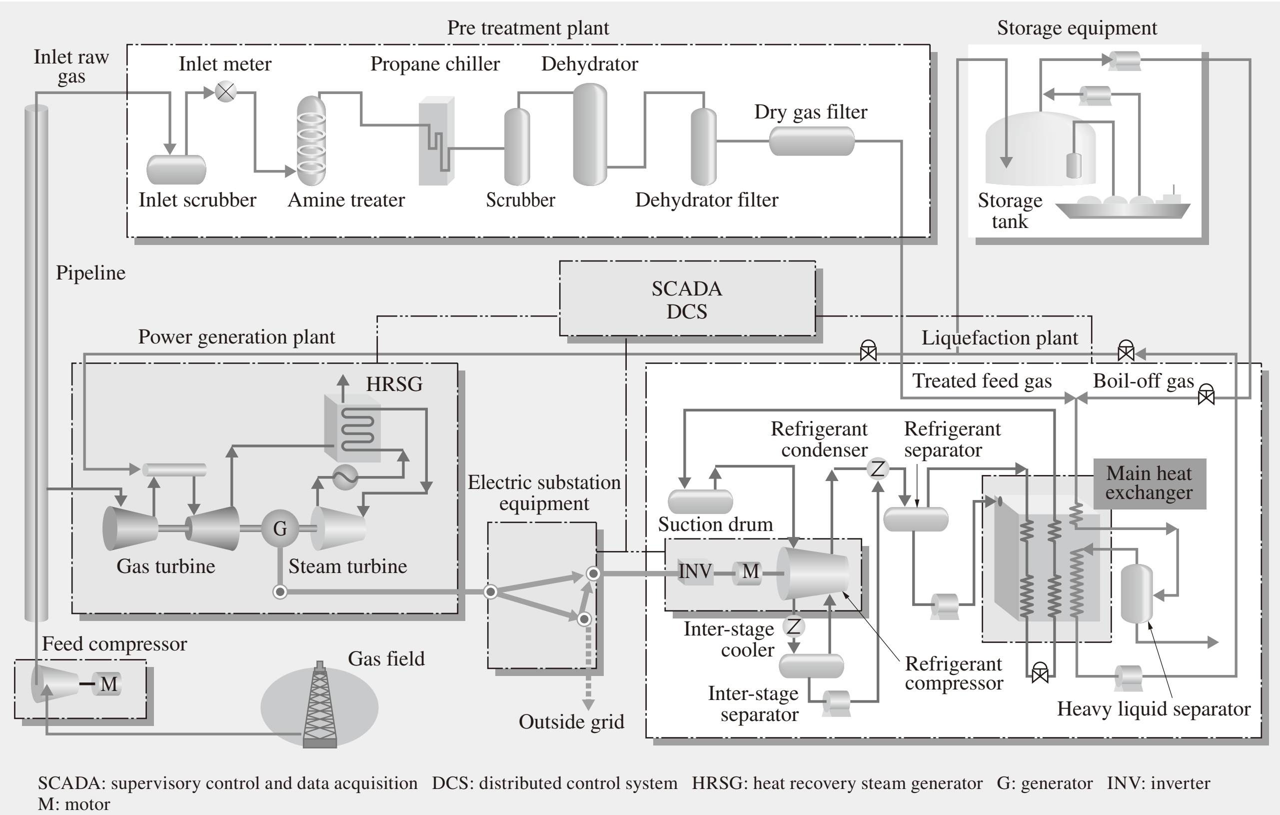


Fig. 11—Flow Diagram of Compact Motor-driven LNG Plant.
Hitachi proposes total solutions of mechanical and electrical systems including centrifugal compressors for liquefaction process and drivers for those compressors, power generation systems and substation facilities, and monitoring and control systems.

Dealing with Resonance Problems Resulting from Inverter Control

In case of a motor-driven compressor system with inverter control and a power generation system composed of gas turbines and generators being integrally controlled, the following types of resonance can occur (see Fig. 12).

(1) Shaft torsional vibration between compressor and motor

Since the motor current includes a harmonics wave, if the frequency of the torque ripple in the motor torque matches the natural torsional frequency of the mechanical shaft system, the resonance may increase the torsional vibration torque and can cause damage to the mechanical shaft system such as damages of couplings.

(2) Resonance within power supply system

A resonance circuit may in some cases be formed by power lines, transformers, static capacitors and harmonics filters. When this resonance frequency matches the frequency of higher harmonics output by the inverter, the distortion of the incoming voltage is created and this distortion can adversely affect the other equipment connected to the power supply system.

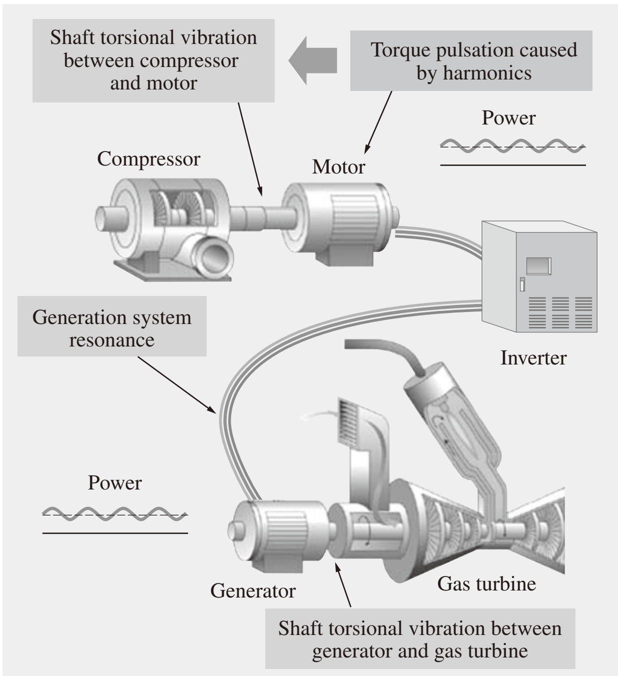


Fig. 12—Examples of Resonance due to Inverter Control.
This shows Hitachi's proprietary vibration suppression and control technologies to suppress the resonance which can occur in case of a motor-driven compressor system with inverter control and a power generation system composed of gas turbines and generators being integrally controlled.

(3) Shaft torsional vibration between gas turbine and generator

Shaft torsional vibration can occur between a gas turbine and generator in a power generation system due to a failure of the line composed of motor-driven compressor.

There is possibility that this shaft torsional vibration is amplified by interaction between the inverter and power generation system and this amplified vibration adversely affects the system such as shaft damage and life shortening.

Hitachi takes account of the potential for these problems and conducts simulation analysis precisely at the design stage so that it can produce optimum designs that use proprietary vibration suppression and control technology based on the results of this analysis and thereby offer systems that suppress resonance and prevent serious damage.

Future Developments

LNG plants of these scales are contributing to the acceleration of the commercialization of medium- and small-sized gas fields and also contributing to the exploitation of limited energy resources due to their suitability for the development of unconventional gas resources such as CBM (coalbed methane)/CSG (coal seam gas) in Australia and Asia. Hitachi is actively promoting these compact motor-driven LNG plants with high production efficiency having started with a joint proposal in partnership with an engineering company and has already started Feasibility Study in Australia. Hitachi also intends to continue seeking to supply its distinctive optimized designs and value across the entire system from power generation system to the liquefaction process by bringing together technologies from throughout the Hitachi group.

CONCLUSIONS

This article has given an overview of the products and solutions that Hitachi proposes to the oil and gas industry market which is characterized by growing investment in development and an awareness of environmental concerns.

Long-term partnership between manufacturers and with customers, engineering companies and others have an important role in the oil and gas industry extending from comprehending on-site needs through to the development of technology and also the supply and operation of products and systems. Hitachi will take proactive action to respond to future market needs in various areas from individual products through to the supply of total solutions by bringing together the capabilities of its social and industrial infrastructure divisions so as to make an even greater contribution.

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