Motors and Inverters for Environmentally Friendly Industrial Equipment

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OVERVIEW: Approximately 60% of industrial electricity demand is accounted for by motor systems, so the impact of motors on the environment is enormous. In the development of new products to make motors more energy efficient, a great deal of effort is concentrated on new materials that improve the efficiency and reduce the losses of motors. Rapid advances have also been made improving the functionality and reducing the losses of inverters in the development of compressors featuring variable-speed inverters that optimize loads on motors. These kinds of industrial equipment are seeing very rapid development and deployment to address the growing public need to step up environmental and energy conservation efforts. Meanwhile, the "Mountain Hotaru (firefly) Initiative" advocating and demonstrating the viability of renewable energy for environmental sustainability is gaining momentum, and this is driving the development of inverter technology which is indispensable for implementing small distributed power sources. We are counting on further advances in motors and inverters as fundamental core technologies as we move toward more environmentally friendly and energy-efficient industrial solutions in the years ahead.

INTRODUCTION

WIDESPREAD adoption of inverters is essential to achieve greater energy efficiency and to make motors more environmentally friendly (see Fig. 1). Here we will discuss the use of inverters in compressors and microturbines to reduce losses and optimize control of motors as an environmentally friendly approach that will see widespread adoption in the years ahead.

ENHANCING EFFICIENCY OF MOTORS AND INVERTERS

Energy Saving Effects Through the Use of Inverters

Generally there are two approaches for dealing with

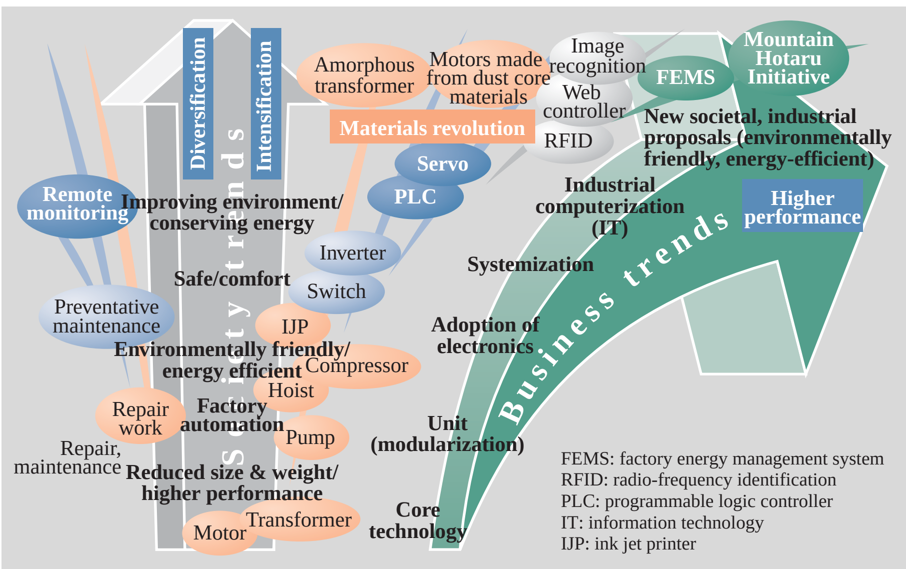

Fig. 1—Prevailing Technology Trends in the Industrial Equipment Sector.
Beyond the challenges of providing ever smaller and better performing electrical equipment, technology enabling variable motor power will play a critical role defining how industry pursues environmentally friendly and energy-efficient solutions.

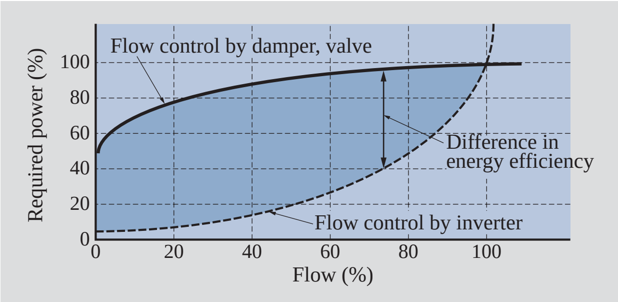

Fig. 2—Relation Between Flow and Required Power.
Performance of fan and pump inverter operation is superior to throttle control.

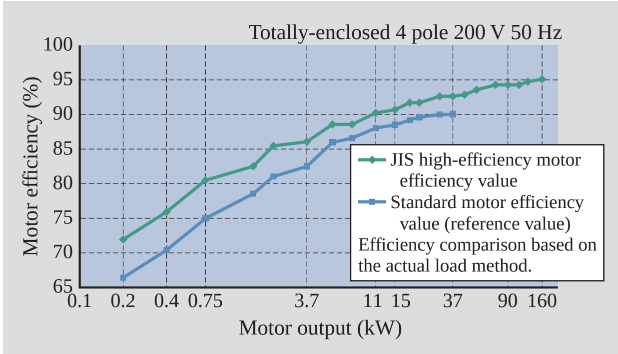

Fig. 3—Comparison of Efficiency of Standard Motor Versus High-efficiency Motor.
The high-efficiency motor is clearly superior to the standard motor.

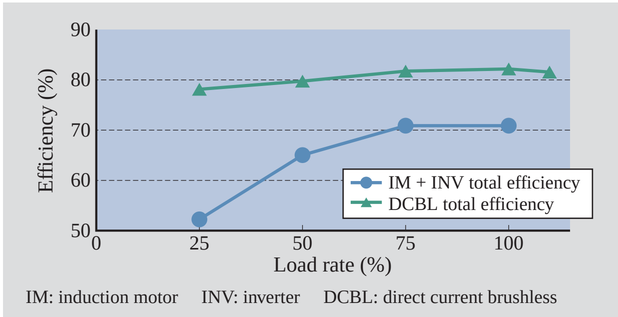

Fig. 4—Total Efficiency Comparison.
Shows the difference in load characteristics between permanent-magnet motor (DCBL) and inductive control.

load variations in equipment such as fans and pumps: either by making mechanical adjustments using a valve or damper, or by controlling the rotational speed of the motor using an inverter. Required power for fans and pumps (*P*) is proportional to the sum of the flow rate (*Q*) and the head (*H*). The flow diminishes in proportion to the rotational speed (frequency), and the head declines in proportion to the square of the flow [rpm (revolutions per minute)]. When control is implemented mechanically with a valve or damper, the flow is reduced but the head is increased, so there is very little reduction in the required power. But when control is implemented with an inverter, the required power is reduced in proportion to the cube of the rotational speed. So as shown in Fig. 2, required power is cut in half, which means the fan or pump rotates in 80% of its full speed, when the output frequency of the inverter is reduced from 50 Hz to 40 Hz, thus achieving a substantial energy-saving effect.

Energy Saving Effects Using High-efficiency Motors

A high-efficiency motor refers to an induction motor with a higher efficiency value than a standard induction motor as defined by Japan's JIS C 4212 standard. A good way of increasing motor efficiency is to reduce losses. There are four basic types of losses that occur in motors:

(1) Mechanical losses: bearing friction losses, cooling fan air losses, etc.

(2) Iron losses: caused by fluctuating magnetic field in the core

(3) Copper losses: caused by induced current in conducting windings that have electrical resistance

(4) Stray load loss: various losses other than the above

There is a range of techniques and strategies for reducing each of these types of loss, but a comprehensive systems approach is required to achieve markedly better efficiency. Fig. 3 compares the efficiency of standard motors with that of high-efficiency motors.

Energy Saving Effects Using Permanent-magnet Motors

Unlike induction motors that employ electrical conductors such as aluminum and copper on the rotor side, in permanent-magnet motors [i.e. DCBL (brushless direct current) motors], the permanent magnets themselves produce magnetic flux. As a result, practically no eddy current losses occur on the rotor side, which enables permanent-magnet motors to run more efficiently than induction motors. Fig. 4 compares the overall efficiency of an induction motor plus inverter with that of a permanent-magnet motor.

Reducing losses also helps hold down the temperature of motors, which enables motors to be implemented more compactly. Incorporating long-running permanent-magnet motors in blowers, pumps, and air compressors not only saves electricity as a result of improved efficiency, but also permits space-saving smaller consumer equipment since the motors can be implemented more compactly.

SCREW COMPRESSORS: ENHANCING EFFICIENCY AND NEW TECHNOLOGIES

Goals of Development

Air compressors are extensively used across the industrial sector as a power source in a wide range of different kinds of equipment for air blowing, pneumatic cylinder driving, and other tasks in plants and factories. Close to 25% of industrial electricity demand is accounted for by this kind of equipment, so improving the energy performance of this equipment is highly significant in terms of reducing CO_2 emissions and mitigating global warming. Building on its competitive edge as the world's leading manufacturer of energy-efficient variable-speed drives and air compressors, Hitachi Industrial Equipment Systems Co., Ltd. developed and brought to market the new series compressors. The 37-kW compressor shown in Fig. 5 and other compressors in the series represent an innovative oil-cooled screw compressor in which all the key components use either brand new or significantly improved technology.

Fig. 5—37-kW Type Compressor.
Schematic shows the all-in-one structure air end enclosed in product enclosure.

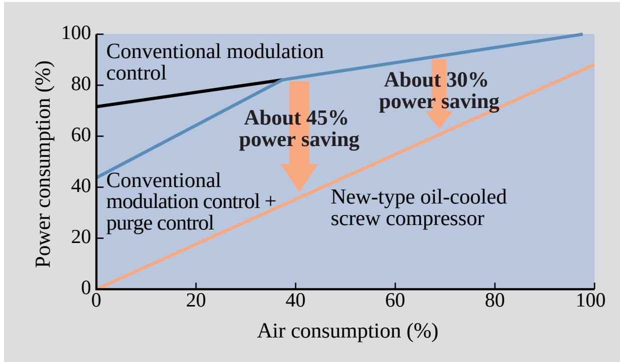

Fig. 6—Energy-saving Effects.
Energy-saving effects of the 37-kW compressor for different amounts of air consumption are shown.

Energy Saving Effects

The excellent performance of Hitachi's air compressor has been further enhanced with a proprietary design, compact and highly efficient DCBL drive system. By implementing rotational speed control that can be optimally adjusted to the amount of air taken into the compressor, the Hitachi drive system uses 45% less electrical power than a conventional modulation control at 40% air consumption (see Fig. 6).

Technical Features

All-in-one configuration air end

The power transmission losses due to belt acceleration and other factors have been cut to zero in the air end shown in Fig. 7 by coupling a high-efficiency DCBL motor to a high-performance screw compressor. And by integrating an oil separator and other key components right in the screw compressor housing, the piping to interconnect the different parts has been eliminated, and pressure losses have been substantially reduced.

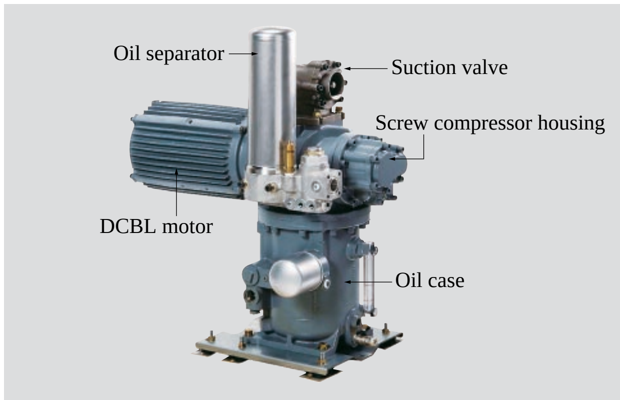

Fig. 7—All-in-one Configuration Air End.
Appearance of the integrated air end with DCBL motor coupled to a screw compressor is shown.

DCBL controller

Recently we developed a 2-stage DCBL motor driven air compressor that, first in the industry, implements cascade vector control in addition to conventional phase and torque control in parallel (i.e. cascaded), that delivers very high efficiency and reliability no matter what the operating state is.

Other technologies

Also incorporated in the controls of the line of air compressors are (1) a "PQ wide mode" that extends the operating range of the compressor by automatically adjusting the maximum rotating speed of the compressor, and (2) an operating pressure control capability that maintains the proper set pressure even when running under low loads.

In the area of auxiliary equipment as well, we have made excellent progress improving energy efficiency across the full range of systems that use air compressors including inverter-based optimized control for low-noise high-efficiency turbo fans and an all-stainless heat exchanger for air dryers that practically eliminates pressure losses.

HARNESSING NEW ENERGY BY APPLYING INVERTER CONTROL TO A MICROTURBINE GENERATOR

Applying Inverter Control to a Microturbine Generator

The untapped potential energy from water heat-storage type air-conditioning systems in high-rise buildings and cooling water circulators in factories can be recovered using microturbine generators. A major challenge has been that the amount of water circulating in these systems varies, and since microturbine generators are so small and have such little output, they employ fixed guide vanes which has made them unable to deal with variable flows. Another problem is that the amount of untapped potential water energy from building water heat-storage type air-conditioning systems and factory cooling water circulators also varies depending on outside temperatures and cooling loads.

Hitachi's energy back system (microturbine) effectively addresses these problems by incorporating inverter technology in the turbine controller that enables the system to accommodate varying flows by applying variable speed control to the turbine. Essentially, the turbine controller regulates the PWM (pulse width modulation) of the AC (alternative current) generator, and thereby adjusts the rotational speed. Although the frequency of the generator and that of the power source are different, the frequency is output by the power conditioner as AC after it is converted to DC (direct current) by the turbine controller (see Fig. 8).

Variable-speed Optimum Running Control and DC Transmission

The relationship between rotational speed, flow, and turbine efficiency is shown in Fig. 9. As one can see, turbine efficiency is represented as a series of peaks with respect to the rotational speed. Note that the rotational speed at point a (the point of maximum efficiency) diminishes corresponding to reduced flow at points b and c. The energy back system automatically tracks and follows points a, b, and c, a capability called variable-speed optimum running control.

When current is output as AC by a power conditioner, losses occur in the DC-to-AC conversion. The efficiency of most equipment is quite high at around 90%, but of course elimination of all losses would be preferable. Hitachi's energy back system transmits DC power directly from the turbine controller to the inverter that drives the loads of pumps, fans, and other equipment, so no DC-to-AC conversion losses occur. In this case, however, the load power consumption decreases, and when generated power declines, this causes the DC voltage to increase which could cause the equipment fail. To address this problem, the energy back system implements double protection: the turbine controller regulates the power to ensure that the DC voltage never exceeds a specified upper value, and it temporarily stops generating when it detects sudden voltage spikes.

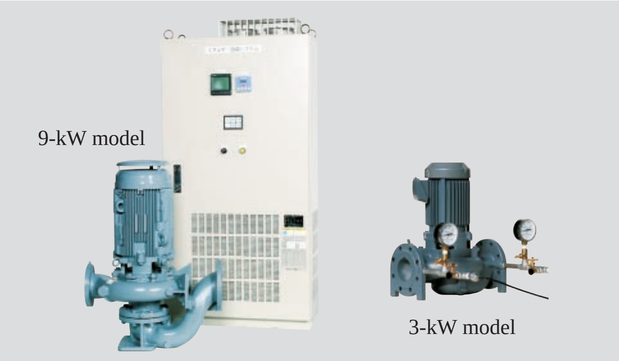

Fig. 8—Appearance of the Hitachi Energy Back System.
The microturbine generator (both models) and control panel are shown.

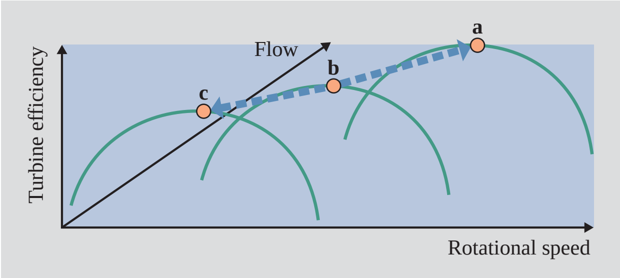

Fig. 9—Variable-speed Optimum Running Control.
Highest efficiency point is controlled by microturbine inverter technology.

Running Status of Installed Systems

Hitachi has now delivered 20 of its AC output by power conditioner type energy back systems since the first system was shipped in 2003, and all installations continue to run smoothly and reliably. Most recent installations have been deployed to exploit the high efficiency turbine, and use DC output as auxiliary power for the inverter. In January 2008, we deployed a system that delivers DC power generated by a turbine connected to three cooling water return pipes to a printing machine to the water supply pump inverter, and the system continues to work perfectly just as designed.

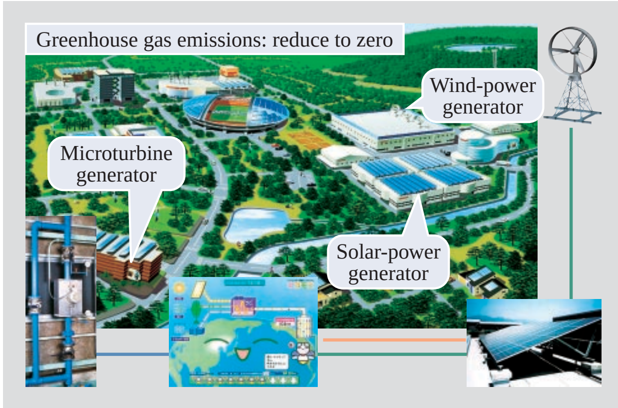

Fig. 10—Mountain Hotaru Initiative.
Mountain Hotaru (firefly) Initiative is a project devoted to developing advanced environmentally friendly solutions that fully exploit renewable energy such as solar, wind, and water power. The end goal is to achieve wide-spread deployment of small distributed sources of power based on renewable energy.

CONCLUSIONS

Here we presented actual examples showing that the application of inverters to compressors and microturbines is highly effective for reducing losses and optimizing control of motors. The Hitachi Group is committed to wide-ranging efforts to mitigate global warming. We are developing and deploying more efficient environmentally friendly motors and inverters for industrial equipment that save substantial energy, while also seeking to save energy by incorporating high-efficiency motors and inverters in fluid equipment and machinery.

In addition to conserving energy, there has also been a major push in recent years to harness renewable energy such as solar, water power, and wind power. However, renewable energy sources tends to be unstable, and stabilizing small capacity energy so it can be used effectively remains a challenge. Motor and inverter technologies obviously have a crucial role to play in developing and exploiting these small distributed power sources. While continuing to pursue better efficiency, we must also continue to develop and deploy actual pilot installations to figure out how these technologies can be harnessed to reduce losses from conventional system interconnections and also conversion losses associated with DC power transmission. Fig. 10 shows a schematic overview of the Mountain Hotaru (firefly) Initiative, a major cross-sectional project now in progress to investigate the full potential of renewable energy.

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