

# Examples of Electric Drive Solutions and Applied Technologies

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*OVERVIEW: Hitachi has worked on specific solutions for the reduction of CO<sub>2</sub> emissions in the oil and gas field by utilizing energy-saving technologies for rotating machinery. In particular, switching existing steam turbine drive equipment to electric drive has achieved a significant reduction in CO<sub>2</sub> emissions. Some implementation-related considerations apply when converting rotating machinery to electric drive, such as how to deal with resonance and higher harmonics. Hitachi has made efforts to meet these challenges, drawing upon its strength in analysis based on prior simulations and verification technologies.*

## INTRODUCTION

A number of centrifugal compressors with steam turbine drive, delivered during the 1960s, are currently in operation at oil and gas plants in Japan. It is expected that significant energy savings and CO<sub>2</sub> emissions reductions can be achieved by utilizing existing equipment but replacing the steam turbines with drive systems that combine electric motors and inverters. This article outlines specific implementation examples and their supporting simulation technologies in terms of the solution menu stated in another article on the highlight pages, “Hitachi Group’s Involvement in Oil and Gas Industry.”

## COMPRESSOR SYSTEM RETROFIT

The first example is from an oil refinery in Japan and looks at the modification of a centrifugal compressor driven by a steam turbine to use an electric motor and inverter (see Fig. 1). [“Retrofit” refers to

the addition of new components (equipment) to improve older equipment.]

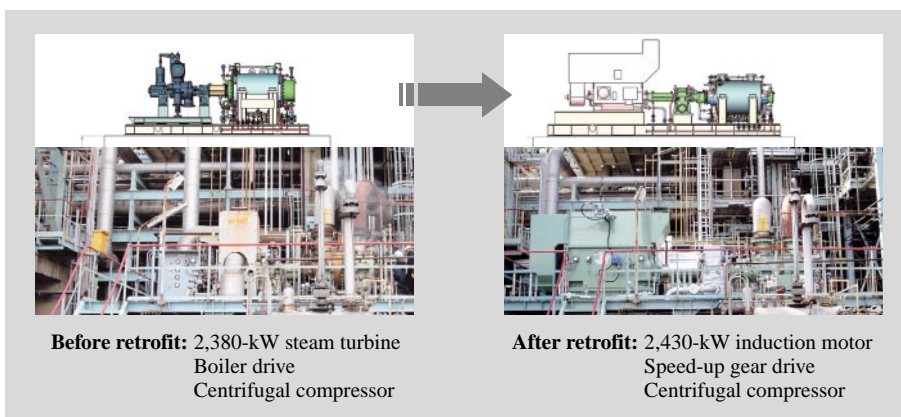
Table 1 shows the major changes from the existing equipment.

The benefits of converting to electric drive include: (1) Annual CO<sub>2</sub> reduction of 40% achieved by converting to an electric motor and inverter drive

TABLE 1. Changes by Retrofitting

*These are the major changes to the existing equipment that resulted from the compressor system retrofit.*

Existing equipment	Work classification	Retrofitting
Centrifugal compressor	Overhaul	Diversion of existing equipment
Steam turbine	Removal	Change to electric motor, speed-up gear
Boiler equipment	Partial suspension, proper operation	Introduction of inverter drive



*Fig. 1—Compressor System Retrofit. The compressor system retrofit shown here achieved a 40% reduction in CO<sub>2</sub> emissions. “Retrofit” means adding new components (equipment) to improve older equipment.*

- (2) Appropriate operation of boiler (One boiler has become a standby unit.)
- (3) Reduced operational costs
- (4) Reduced drive maintenance costs
- (5) Improved control capability through the use of the inverter (acceleration and speed can be controlled independently.)

### Considerations for Conversion to Electric Drive

The following issues need to be considered when converting to electric drive.

- (1) Available space for the installation
- (2) Explosion-proof type of the electric motor
- (3) How to deal with pulsating torque (torque ripple) after installation

Regarding space availability (1), the platform on which the equipment was to be installed needed to be enlarged because the total length of the electric motor and the speed-up gear was longer than the steam turbine.

Since higher harmonics from the inverter may cause instability in the shaft voltages, explosion-proof type (2) was addressed by internal pressurization.

### Countermeasures for Dealing with Pulsating Torque (Torque Ripple)

The problem of pulsating torque described in the section above (3) is caused by higher harmonics in the motor current generating torsional vibrations in the drive shaft. If the frequency of the pulsating torque matches the natural torsional resonance frequency of the overall shaft system, resonance may increase the torsional vibration torque and cause damage to the machinery.

To address this problem, Hitachi performed a simulation analysis that covered the machine shaft, electric motor and inverter unit, and developed a

resonance control system that prevents excessive shaft torque by monitoring the inverter output voltage and modifying the voltage if pulsating torque is evident in the current waveform. The new control system was used in this project.

### Verification with Actual Equipment

Fig. 2 shows verification data from the actual system.

The results of an acceleration test from 60% to 100% show that the equipment operates correctly as there was no particular waveform distortion.

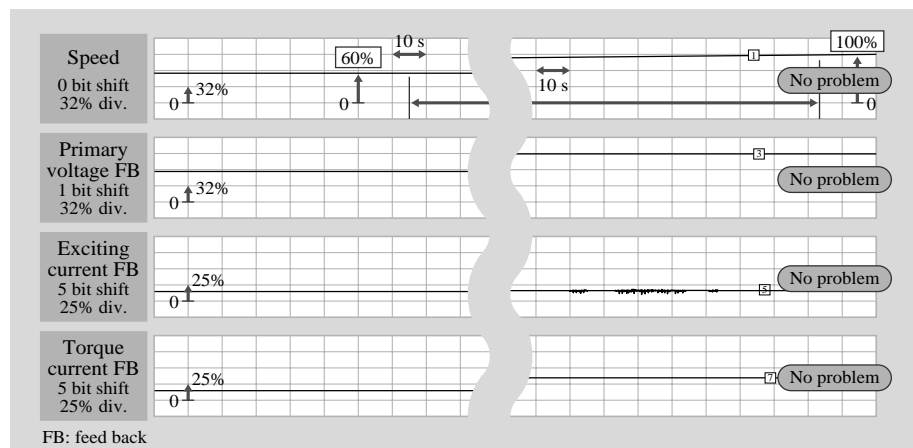
### Evaluation of Electric Drive Conversion Project

Commissioning of the compressor equipment retrofit project to use electric drive went smoothly thanks to a coordinated design that considered the compressor, motor, inverter and control system, as well as by the application of Hitachi's simulation technologies and vibration control technologies to deal with pulsating torque. Hitachi Group manufactures all of this equipment in-house and the success of this project shows that, by utilizing the group's broad-based strengths in areas ranging from control systems to analysis and simulation technology, this approach can be adopted in a wide range of scenarios both in Japan and overseas (see Fig.3). The next section describes an example of Hitachi's simulation technology that models electric drive systems from the drive itself through to the power supply system.

## HITACHI'S SIMULATION TECHNOLOGIES SOLVE PROBLEMS OF OVERALL DRIVE SYSTEM

In recent years, there have been an increasing number of systems that use a VSD (variable speed drive) to drive compressors and fan pumps for energy

Fig. 2—Data from Actual Machine after Retrofitting. The results of testing acceleration from 60% to 100% verify that the equipment worked normally and with no particular waveform distortion.



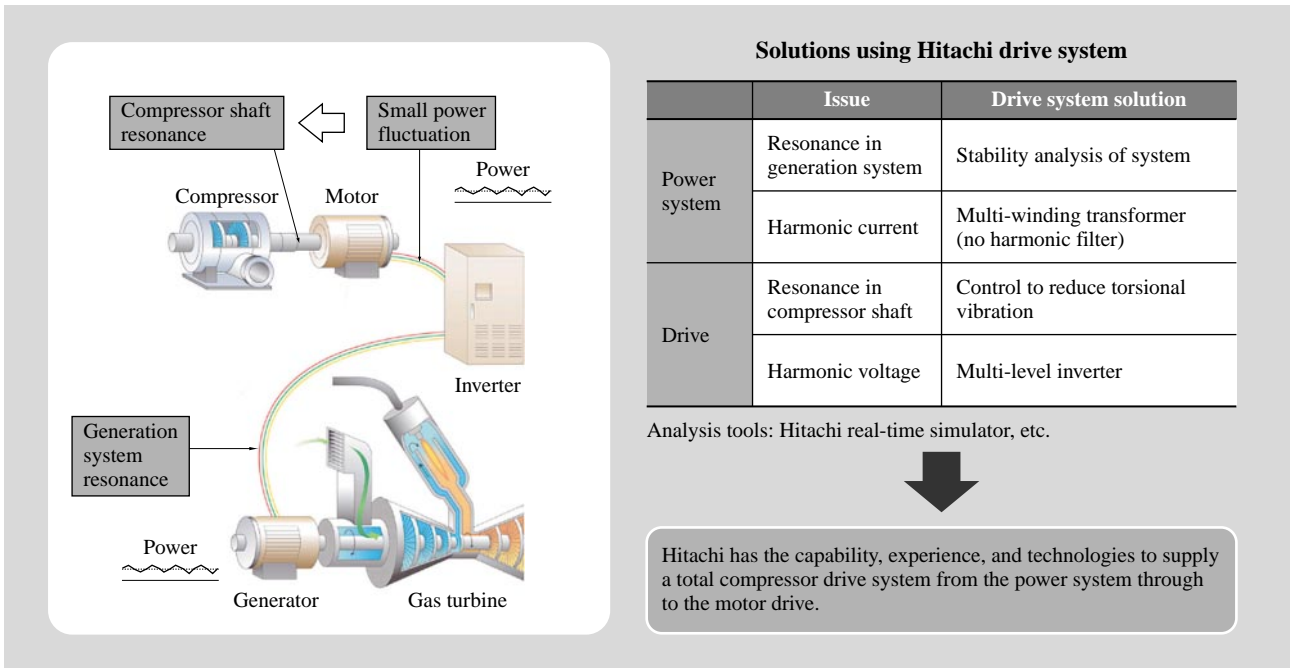


Fig. 3—Solutions Using Hitachi Drive System  
Problems and solutions for both power side and drive side in drive system are shown.

and power saving. As stated in the previous section, the VSD systems are prone to drive shaft damage caused by excessive torsional vibration torque in the shaft if the low-level pulsating torque generated by the VSD happens to match the mechanical resonance frequency of the drive shaft. Other problems include excessive distortion of the incoming voltage and instability in the power supply system caused by the interaction between the higher harmonic currents generated by the VSD and the power supply impedance.

Therefore, the design needs to consider the total system to ensure the stability of all system components including the power supply, drive and load. The following section details the simulation technologies used to solve this problem.

### Shaft Resonance Analysis Technology

As shown in Fig. 4, shaft torsional vibration means torsional resonance in the shaft generated when the frequency of the pulsating torque generated by the VSD or rotating machinery matches the mechanical resonance frequency of the drive shaft.

Analyzing the shaft torsional vibration requires a lengthy analysis of the stability under acceleration and deceleration and multiple simulations where different operating speeds and load conditions are tested. However, it is difficult to conduct these analyses with

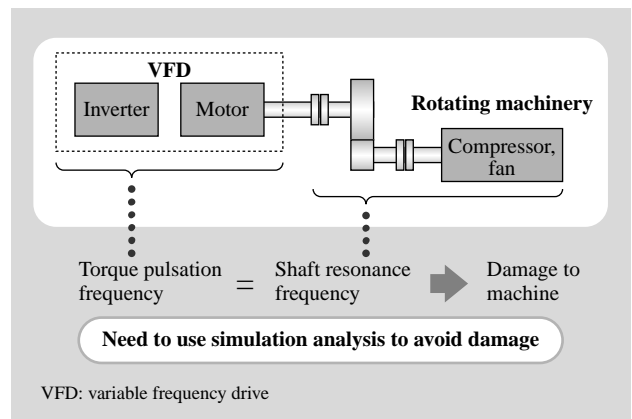


Fig. 4—Shaft Torsional Vibration.  
Shaft torsional vibration is generated under the condition that the frequency of the pulsating torque created by the VSD (variable speed drive) or rotating machinery matches the mechanical resonance frequency of the drive shaft.

conventional simulators that have a long calculation time. In order to solve this problem, Hitachi Group uses real-time simulation technology.

The real-time simulator performs simulation calculations in real time. Fig. 5 shows the structures of a real-time simulator and a conventional simulator.

Although conventional simulators implement models of the speed control circuit, converter, and load internally, the calculation time is tens or hundreds of

times longer than real time because the simulations require the use of small calculation steps.

In contrast, a real-time simulator performs

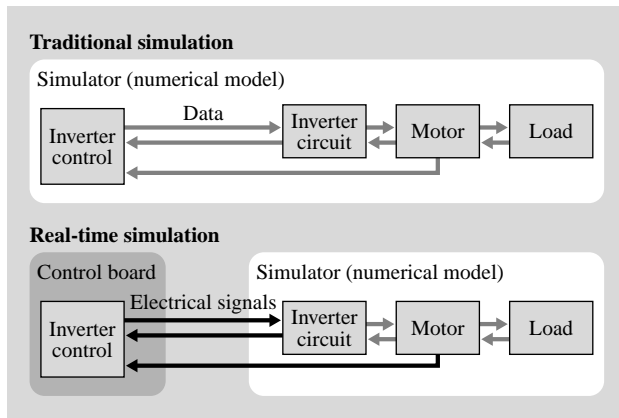


Fig. 5—Difference in Structure of Conventional Simulation and Real-time Simulation.

The calculation time for real-time simulations is much faster than conventional simulations.

simulations in real time using the actual VSD rather than a simulation model of the speed controller and then links this with the simulation models of the converter and other parts of the system that run in the computer. For this reason, the calculation time takes the same time as the analysis time (real-time operation) and means that all the necessary patterns can be simulated. In addition, since the actual control device is used, errors associated with a simulated model of the control system do not occur. Therefore, use of real-time simulation allows simulation of more analysis conditions than ever with greater accuracy, and so can be used to prevent or solve problems proactively.

Fig. 6 shows simulation calculation results and measurement results from actual machine operation.

### Power Supply System Analysis Technology

In a power supply system, the inductance in components such as power lines and transformers and

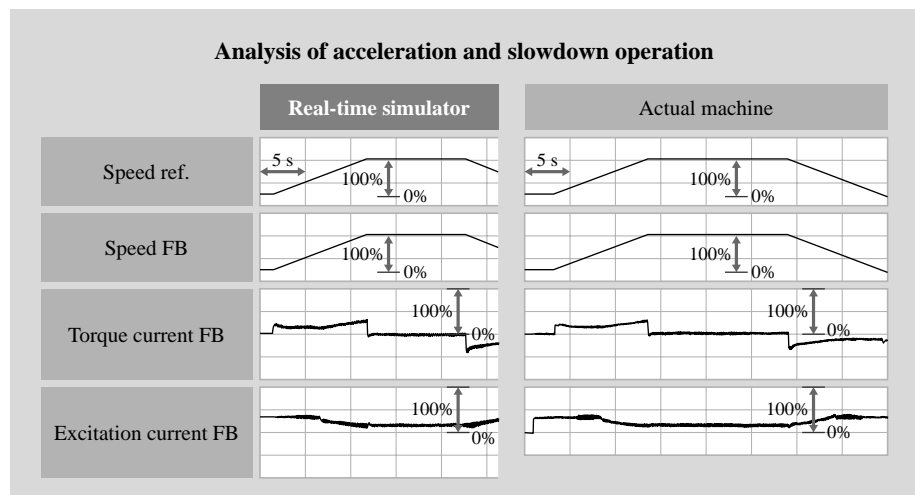


Fig. 6—Comparison of Results from Simulation and Actual Measurement. The graphs show the results from the simulation and from measurement of actual machine operation.

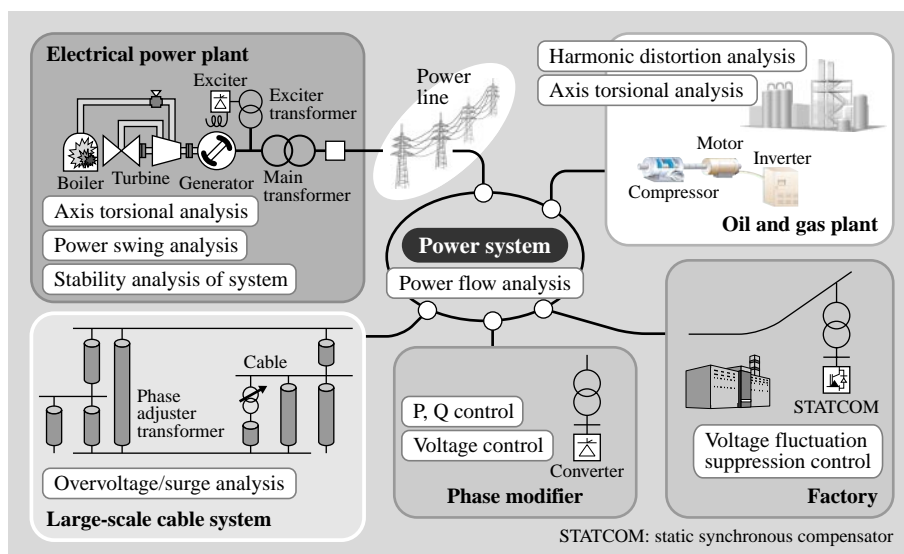


Fig. 7—Schematic Diagram of Transmission System. There is various phenomenon in the transmission system. The power supply system has a number of elements that need to be considered and this requires a complicated analysis model.

STATCOM: static synchronous compensator

the capacitance of components such as static capacitors, higher harmonics filters, and series capacitors can form a resonance circuit. In the case of parallel resonance of inductance and capacitance, equipment connected to the power supply system may be adversely affected by the distortion of the incoming voltage that results when this resonance frequency matches the frequency of higher harmonics output by the VFD (variable frequency drive). In the case of series resonance of inductance and capacitance, on the other hand, problems such as shaft damage and life shortening may be caused by shaft torsional resonance in generator systems if the resonance frequency is close to the shaft torsional resonance frequency of the generator and its power source. In addition, shaft torsional resonance in the generator system requires caution because it is known that, depending on system conditions, the resonance may be enhanced by interaction between power conversion devices such as VSDs and the generator system. Furthermore, the incoming voltage may become unstable due to interference between load control in the VSD and the voltage control in the generator.

For this reason, it is necessary to verify the system stability with a combined simulation of the VSD and power supply system. As shown in Fig. 7, however, the power supply system has a number of elements that need to be considered, such as the load from other equipment and stray capacitance, and may require a

complicated analysis model to cover all the elements depending on the phenomenon to be analyzed.

In terms of analysis time, the analyzed time domain varies significantly, ranging from hundreds of microseconds when analyzing switching surges in the VSD to the order of seconds when analyzing the stability between the generator and VSD.

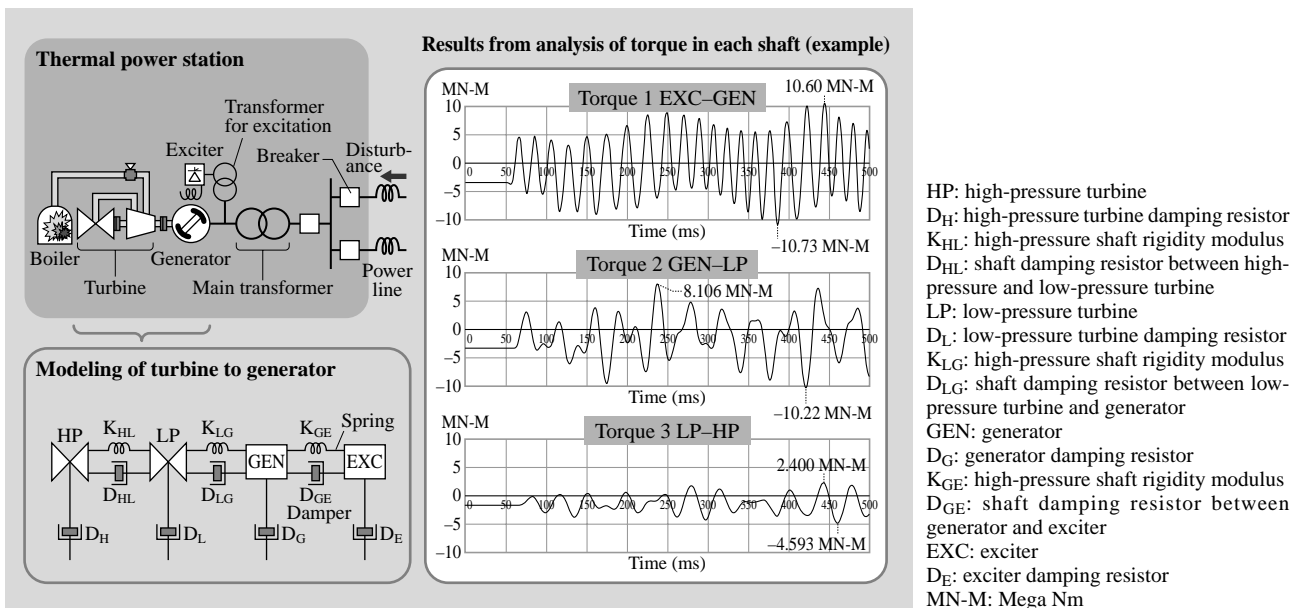
As stated above, the required model size and the

TABLE 2. Types and Characteristics of Simulation Tools  
The table lists the types of simulation tools and their characteristics.

Category	Features	Hitachi tools	Commercial tools
Digital program (Effective value analysis)	Flow analysis, steady analysis of frequency analysis Transient phenomenon analysis for electric phenomena (large-scale analysis)	TSAP VSAP SHAFTOR	PSS/E ETAP
Digital program (Instantaneous value analysis)	Inrush current analysis for surges or transformers Analysis based on the VED waveform (small/medium-scale analysis)	HARMO	PSCAD/ EMTDC MATLAB
Analog simulator	Performs analysis under conditions close to actual phenomenon (smaller-scale analysis).	Factory simulator	
Digital simulator	Analysis utilizing external equipment (small-scale analysis)		HYPERSIM RTDS

Fig. 8—Results from Generator Shaft Torsion Analysis.

The figure shows results from a shaft torsion analysis of the generator based on simulations of a load disturbance (system failure) in a system where power lines have series capacitance.



time domain vary greatly depending on the phenomenon being analyzed but there is no common simulation tool that can handle all the phenomena collectively. Therefore, it is necessary to perform analyses and reviews by selecting different simulation tools for each target phenomenon.

Table 2 lists the characteristics of the major simulation tools used by Hitachi Group. Hitachi has technology to appropriately select and utilize all these simulation tools according to the analysis target's size, phenomenon, time scale, and customer demand.

In addition, as an example of this simulation analysis, Fig. 8 shows results from a shaft torsion analysis of a generator when a load disturbance (system failure) is caused in a system where power lines have a series capacitance.

### Future Efforts

In this chapter, the simulation analysis technologies owned by Hitachi Group were discussed. For energy and power saving, rotating machinery that uses VSD for applications such as compressors and fans is likely to become even more common. Hitachi Group will utilize simulation analysis technologies to contribute to preventing and solving problems caused by the application of VSD.

### CONCLUSIONS

Specific examples of electric drive solutions and applied simulation technologies were described in this article.

The scope for saving energy through the use of

inverter drives is not limited to oil and gas plants and significant benefits can also be expected in other air and fluid powered equipment such as fans, pumps, and blowers.

Hitachi Group will improve the reliability of its overall drive products particularly in the field of rotating machinery as stated above, and will take a systematic approach to the global roll out of solutions for energy saving and CO<sub>2</sub> emissions reduction in oil and gas plants.

### ABOUT THE AUTHORS

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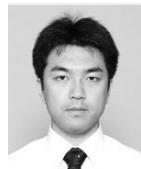
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