ALL ELECTRIC

ALL ELECTRIC DRIVES CONTROL BETTER, LONGER, SAFER—AND SAVE MONEY

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ABSTRACT

Reduced environmental impact and greater flexibility are the traditional reasons for using electric drives instead of gas turbines in oil and gas compressor applications. Increased availability, better control, improved energy efficiency, and reduced delivery times are even better reasons and are now well documented. Electric drives cost more initially than conventional gas turbine drives. But when factored in at an early stage in a plant’s design, an All Electric Drive system produces two to three times the savings every operating year. These savings reflect increased production days, lower maintenance costs, increased shaft power efficiency, lower fuel gas consumption, and increased emissions control.

ABB recommends the use of our All Electric Drive system to free up the mutual sizing constraint between the refrigerant compressors and the gas turbines and thereby improve the configuration of power generation and process heating, overall energy efficiency, operational flexibility, and maintainability. ABB’s Power Management System unifies control over the entire power generation system.

The All Electric Drive system delivers benefits for any high energy consuming process within the gas value chain, including processing facilities, compressor stations, LNG liquefaction plants, and CO2 injection.
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MORE EFFICIENCY PLUS LESS DOWNTIME EQUAL HUGE SAVINGS

A modern facility serving a high energy consuming process typically requires rotating shaft power 100 MW or more. This power can be provided either by gas turbines or electrical drives. As shown in Table 1, the two types of drive systems demonstrate some radically different characteristics (data up to end of driving shaft).

Table 1. Comparison of Gas Turbine and Electric Drive Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Gas Turbines</th>
<th>Electric Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight and space</td>
<td>Light unit but space and weight consuming auxiliaries</td>
<td>Similar to that for gas turbines</td>
</tr>
<tr>
<td>Minor maintenance cycle</td>
<td>4,000 hours</td>
<td>25,000 hours</td>
</tr>
<tr>
<td>Major maintenance cycle</td>
<td>20,000 hrs</td>
<td>100,000 hrs</td>
</tr>
<tr>
<td>Minor maintenance duration</td>
<td>6-10 days</td>
<td>1-2 days</td>
</tr>
<tr>
<td>In operation system MTBF</td>
<td>≈ 4,000 hours</td>
<td>&gt; 25,000 hours</td>
</tr>
<tr>
<td>Control Response</td>
<td>Slow</td>
<td>Medium to quick</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Narrow peak range</td>
<td>High over wide range</td>
</tr>
<tr>
<td>Logistics</td>
<td>Delivery time 3-4 years</td>
<td>Delivery 1-2 years</td>
</tr>
<tr>
<td>Average operational efficiency</td>
<td>25%</td>
<td>40%</td>
</tr>
</tbody>
</table>

This article discusses the benefits of the all electric plant in detail and describes the ways those benefits are realized. The initial cost (CAPEX) for an All Electric Drive system for a typical large facility is about U.S. $25 million higher than for a gas turbine system. But, as the examples in this article show, the All Electric Drive system saves between U.S. $86 million and U.S. $97 million annually. Typical payback time for the All Electric Drive system is 3 to 4 months!

Plants throughout the gas value chain are increasing rapidly in size. For example, an LNG plant designed with capacity of 4 MTPA (million tons per annum) has a shaft power requirement of around 35 to 38 MW/MTPA. At 4 MTPA, the daily value of produced LNG is about U.S. $1.5 million. The use of an All Electric Drive system reduces the shaft power requirement, while improving regularity, improving plant safety, and lowering both operational and capital costs.

WHERE DOES THE POWER COME FROM?

The obvious first question is “where does the electric power come from?” For example, LNG liquefaction plants are typically built in remote locations (Russia, the Middle East) where electric power might not seem to be available. However, in some areas of Russia, nuclear power stations have excess capacity because traditional industry power demands have fallen. And in the Middle East, the main problem is the lack of water which is produced in triple cycle thermal power plants, so there might be available electrical power.

Where excess power is not available, it can be produced more efficiently in the plant itself by utilizing large commercial power generation gas turbines in the 100+ MW range, rather than modified aircraft turbines in the 25+ MW range. This power generation is sufficient to cover the needs of an All Electric Drive system. With proper planning, a large plant can be configured for combined cycle generation, raising the efficiency even further.

A 4 MTPA LNG facility has a power requirement equal to an industrialized world city of about 100,000 inhabitants. Thus, it would be attractive for most general utility companies to provide the power by extending their existing (triple cycle) facilities, e.g., with a gas-for-power outsourcing arrangement. In the developing world, the facility can provide electric power to rural areas and emerging industries. This would allow the power requirement to be optimized over more consumers and available sources.

LOWER TAXES, LOWER ENERGY CONSUMPTION

A variable speed industrial gas turbine in the 25MW range driving a compressor train typically has an efficiency of up to 30%. However, this efficiency is reached only at peak performance. Even if trains are stopped to optimize operation, the average operational performance quickly falls to about 25%.

A corresponding electrical drive system achieves an efficiency of around 95% over a quite wide range. In addition, the power generation efficiency is about 47%, but climbs as high as 55% for a combined cycle plant and more than 80% with triple cycle (district heating or water desalination). Thus, even in a not fully
optimized configuration, where the efficiency of the gas turbine is about 25%, an electric drive system achieves 36% (see Figure 1).

![Diagram of gas turbine and electric drive system efficiency](image)

**Figure 1 Efficiency per unit of centrifugal compressor driven by motor and gas turbine**

Indicates total efficiency for motor and gas turbine respectively

In a 200 MW LNG facility, a gas turbine drive consumes 650 million SCM (standard cubic meters) of natural gas annually, whereas an electric drive system consumes just 450 SCM of natural gas. The 30% difference means carbon-dioxide emissions are reduced about 360,000 tons. Under the current European Union quota on carbon dioxide, an All Electric Drive system saves 20 to 25 Euros per ton or U.S $11 million annually. However, an even higher savings comes from the decrease in lost fuel gas. Converted to 225,000 tons of LNG at U.S $200/ton, an All Electric Drive System saves 45 MUSD or 3.6% of annual output.

Therefore, the savings in taxation and consumption of fuel gas at the prevailing market price could add up to as much as third of the system’s CAPEX.

### 10 MORE ONSTREAM DAYS PER YEAR

The average minimum maintenance interval for gas turbines is 6 months or 4000 hours. The turn around time is typically a week for inspection and additional time for actual maintenance work. Further, the in-operation mean time between failure (MTBF) is also in the 4000 hour range. This interval is significantly lower than that required for the compressor or turbo expander. In addition, the compressor requires several utility systems that significantly increase space, weight, operational cost, and maintenance cost. The utility systems include filters, cooling, sound dampers, insulation, lube and seal oil systems, and other turbine auxiliary systems. For our discussion, we can consider the gas turbine drive system the major contributor to unavailability with about three weeks annually required for periodic planned maintenance and another three weeks for unplanned corrective maintenance. The per unit availability is approximately 88%.

A gas turbine driven train configuration is normally N+1: all the drives required for full capacity (N) plus one spare drive. This configuration provides one backup unit in case a primary unit fails or has to be maintained. The CAPEX due to the redundancy is balanced by the gains made from increased uptime. For a 5+1 system this means that at least one train will be in maintenance for about 57% of the time. While planned shutdowns can be delayed, another unplanned shutdown can occur with a probability of about (6%) resulting in a capacity loss of 20% until at least one unit can be brought back on line—in roughly 10 days. The result is about 12 lost stream days per year in total capacity.

The electric drive system typically has a minor maintenance interval of three years or 25,000 hours. The in-operation MTBF is higher than this interval, and also higher than the driven equipment. Thus the electric drive system has a limited contribution to the overall system MTBF, with an availability better than 99.9%. The drive is air or water cooled, and the support systems (lube oil, cooling water, and instrument/purge air) are simpler and less failure prone than those for gas turbine systems. They also require much smaller volumes than support systems for the compressor, so the electric drives can be fed from the compressor...
systems at a minute additional costs. Sound levels, important in the labor safety regulations of some countries, are also much lower.

In addition we must factor in the possibility that power will be interrupted during maintenance of the All Electric Drive system. Also, in this system, we have to factor in unavailability for the entire plant.

With all these factors considered, the net gain is approximately 10 stream days for the All Electrical over the gas turbine drive system, producing savings as high as U.S. $36 million annually.

ABB also offers a thermal and electrical power management system and an asset management system to monitor and diagnose the condition of equipment. Together, these systems move maintenance from periodic/preventive to predictive. An all electrical system is well suited to predictive maintenance, which has been demonstrated to lower maintenance costs by up to 80% (ARC strategies, October 2000) and decrease downtime due to planned and corrective maintenance by about 75% (ABB Benchmarking).

BETTER SURGE PERFORMANCE, SAFETY

The main operating parameters for a compressor are the flow and pressure differential. At lower flow, there is a minimum pressure differential before the compressor surges. Recirculation is used if variations in flow are expected or if there’s a difference between common shaft compressors. The surge response is determined by the volume of the recirculation system, the surge loop response, and the overall system response time. A faster speed control response time improves surge performance and allows the system to operate with less recirculation.

An electric drive system significantly increases the response time and offers a much wider efficient operating speed range than a gas turbine. As a result, the electric drive system balances power requirements faster and better between different sections of the process. Tighter control means higher overall process efficiency and safer operation, with increased overall efficiency and less wear on equipment due to excessive stress. In addition, gas turbines cause energy loss and increased fuel consumption due to recirculation. The All Electric Drive system can significantly reduce recirculation. Considering a 5 train operating scenario where two trains are out of balance, and one of two compressors on three trains is out of balance. Considering recirculation in this case is 5% the savings in fuel consumption using an All Electric Drive system is 3.5% or another U.S. $5 million per year. Because the All Electric Drive system eliminates recirculation, the savings in fuel consumption using an All Electric Drive system is about 3.5% or another U.S. $5 million per year.

ABB has patented a “no surge” principle whereby compressors can be safely controlled in surge even without recirculation facilities. While the no surge principle is not currently operating in any plant, the information gained from ABB’s research is currently enhancing control over surge, helping to avoid recirculation during normal operation, and opening up opportunities for reduced anti-surge equipment costs and operation in subsea applications.

UNIFIED POWER MANAGEMENT

ABB has enhanced the All Electric Drive system with a Power Management System (PMS) that handles dynamic electric load balancing, rotating reserve, and fault restart. The Power Management System unifies control over the entire power generation system, including compressor, motor, and transformer. This unified system simultaneously balances and controls these critical systems within the optimum process envelope, achieving increased productivity, stability, and safety.

A full shutdown in an LNG plant creates both a safety hazard and a major loss of production. It takes up to 48 hours to come back on line, or more than U.S. $7 million in lost production. The Power Management System uses a network matrix representing its “knowledge” of the electrical network topology and dynamic state and a network determination function to calculate the electrical network contingencies. This calculation is performed within milliseconds to adjust power control, load shedding, and re-synchronization/restart functions and to prevent a full shutdown.

The power exchange with an external utility company is optimized based on a sliding 15-minute power demand forecast, that predicts imported (or exported) power with respect to contractual agreements, time of day, average and peak demand, etc., and then adjusts internal power generation or consumption accordingly.

OPEX SAVINGS OF 70% OR MORE
A straightforward replacement of electrical drives for gas turbines is valuable. But even more value is gained if the plant configuration takes full advantage of the characteristics of electric drives.

For example, gas turbines are generally available either in two sizes: less than 30 MW variable speed units or large 100 MW or more fixed shaft speed units. Electrical drives are available in a wide power and speed ranges, up to 100MW. Thus, the All Electric Drive system has much wider design flexibility in terms of size of trains, compressors per train shaft, and the possibility to separate smaller essential units. The plant design should take advantage of the opportunities presented by the All Electric Drive system.

- The average size of each train can be increased and the number of trains can be reduced. This change is possible because electric drives increase the overall uptime and reliability of trains significantly.
- Safe and stable operation can be maintained over a wider range of process states. Because electric drives have a wider control range and because the number of shafts and compressors per shaft are reduced, plant stability and uptime both improve. Most plants do not allow emergency shutdown in operation, as this represents a safety hazard. Also the plant restart time would be 50 hours or more. With electric drives, the plant can go to a production hold idle recirculation mode.
- Low manned, remote, or unmanned operation can be considered, because electric drives have a service interval that's about 6 times longer and can operate for 100,000 hours without the need for a major overhaul. As a result, fixed and variable costs are further reduced.
- The possible sources of power are wider. The plant can generate its own electric power or use outsourced electrical energy. Power surpluses and demands in the area should be studied to take advantage of rotating reserves and off peak times. The All Electric Drive system can get power from hydro, nuclear, or triple cycle grid power.

The overall efficiency of such a plant can lead to OPEX savings of more than 70% for the scope of work discussed in this paper.

**TYPICAL DESIGN CASE: SAVINGS OF U.S. $97 MILLION/YEAR**

Figure 2 shows a simplified diagram of the main components of a conventional gas turbine system and an All Electric Drive system. The following discussion assumes a requirement of 150 MW for the main trains and 50 MW of electrical power, including smaller electrical drives with an annual shaft energy requirement of 1.75 TWh.

The conventional gas turbine system has six 30 MW gas turbine driven trains in a 5+1 configuration plus two 30 MW electrical power generation units. The All Electric Drive configuration has four 40 MW trains, fed by a 200 MW power plant that's designed to capitalize on the efficiencies of electric drives. In addition, we
have included three 10 MW smaller drives for both systems. The calculations in Table 2 are based on the maintenance cycles and efficiencies given previously and on standard values for gas energy content and emissions. The plant is an LNG plant with a capacity of 32 MW/MTPA. The effect of tighter control and better balance results in lower recirculation losses with an estimated benefit of U.S. $5 million per year. Maintenance, unavailability, and reduced downtime benefits typically gives 10 additional production days equal to U.S. $36 million per year. Figures are indicative and provided to show the relative impact of benefits; they will vary based on the actual design and various constraints. The cost of gas turbines is currently volatile and highly influenced by delivery times. It can be significantly higher than shown.

Table 2. Annual Savings Using an All Electric Drive System (MUSD=U.S. $million)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>A. Electric Drive</th>
<th>B. Gas Turbines</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX system cost (main drives, auxiliary drives and power generation)</td>
<td>30 MUSD main drives 35 MUSD power plant 7 MUSD auxiliary drive</td>
<td>25 MUSD main GT 14 MUSD power plant 7 MUSD auxiliary drive</td>
<td>(26 MUSD)</td>
</tr>
<tr>
<td>LNG production</td>
<td>6,250,000 tons/year</td>
<td>6,250,000 tons/year</td>
<td></td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>5 MUSD/year</td>
<td>10 MUSD/year</td>
<td>5 MUSD</td>
</tr>
<tr>
<td>Shaft power efficiency</td>
<td>36%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Fuel gas consumption</td>
<td>450 mmSCM</td>
<td>648 mmSCM</td>
<td>200 mmSCM</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>800,000 tons</td>
<td>1,160,000 tons</td>
<td>360,000 tons</td>
</tr>
<tr>
<td>CO2 tax (EU where applicable)</td>
<td>24 MUSD</td>
<td>35 MUSD</td>
<td>11 MUSD</td>
</tr>
<tr>
<td>Value of fuel gas</td>
<td>100 MUSD</td>
<td>145 MUSD</td>
<td>45 MUSD</td>
</tr>
<tr>
<td>10 additional production days</td>
<td>36 MUSD</td>
<td>0</td>
<td>36 MUSD</td>
</tr>
<tr>
<td>Recirculation losses</td>
<td>0</td>
<td>5 MUSD</td>
<td>5 MUSD</td>
</tr>
<tr>
<td><strong>Annual savings</strong></td>
<td></td>
<td></td>
<td>≈ 91-102 MUSD</td>
</tr>
</tbody>
</table>

This calculation clearly demonstrates the value of an All Electric Drive system. For LNG plants, for example, industry goals are currently to reach a 7.2% ratio of field gas consumption to LNG production. An All Electric Drive system is the only way to reach that ratio. Indeed, ABB has achieved a target closer to 6%.

With the added operational safety and operational benefits, as well as shorter delivery times and flexible design parameters, an All Electric Drive system is easily the logical choice, with a payback time of only 3 to 4 months. In this context the environmental impact becomes an important added benefit, but is not critical to the economical analysis.