When should an Electric Adjustable Speed Drive be used instead of a Gas or Steam Turbine?

Paul Blaiklock, Manish Verma, Stephan Bondy

TMEIC Corporation
Roanoke, VA, and Houston, TX

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Introduction

Large compressors and pumps are the backbone of the oil and gas industry. Compressor systems are found in applications such as gas pipeline boosting stations, refrigeration trains at liquefied natural gas (LNG) plants, and a variety of applications in petrochemical plants, and refineries.

Today, installations that use large centrifugal or axial flow compressors commonly have gas turbines as the prime mover. Gas turbines can run at high speed and have the convenience of using natural gas for fuel, which is often available at the site. Electric helper motors have been used in tandem to start the turbine and to provide additional power when the turbine power declines to less than the process demands.

Trends

In the past, large compression systems utilized only reciprocating engines or steam turbines as the prime movers. The advent of the gas turbine with power ranges of 10 – 100 MW led to today's situation where most compressor systems in this power range have a gas turbine prime mover.

Beginning in the late 1990's designs of Adjustable Speed Drives (ASD) made it practical to use electric motors up to 100MW. Since then, large electric motors with adjustable speed drives have begun replacing gas and steam turbines for driving large compressors. In spite of power, speed, and fuel advantages of turbines as prime movers, the trend to electric motors and drives is accelerating and this paper discusses some reasons why the change makes economic sense.

Summary of ASD plus Electric motor advantages over a Gas Turbine

As highlighted earlier, the past experience of large compression systems has been using mechanical prime movers such as gas turbines. There has to be strong advantage in order to replace a mechanical prime mover in an industry where the operators and engineers have such a long history of mechanical expertise and experience. The advantages must translate into monetary and operational enhancement. The advantages of using electric drives are:

- Reduced downtime because gas turbines require frequent maintenance while electric drives and motors require very little maintenance. This enables more production, lower maintenance expense, and improved productivity.
- Accurate speed control and process control allowing the most optimum plant flow balance to be obtained.
- Lower energy costs because the electric drive and motor has a higher efficiency than most gas turbines, especially at part load.
- Zero CO_2 and NO_X emissions at the operating station and greatly reduced noise. This feature often makes electric prime movers the only selection in applications near urban regions or regions with existing air quality problems.
- Independent of ambient temperature. Gas turbines generate less power when the inlet air temperature rises since the air density is reduced and less oxygen reaches the combustion chambers. Electric drives and motors are not affected by temperature.
- Lower capital equipment, spare parts and maintenance cost.
- Lead times of 9 - 12 months, depending on the motor design. Compared to a mechanical prime mover which can have 18 month lead time, this shorter lead time allows for a quicker production revenue gain.

Gas Turbine Compressor Drive

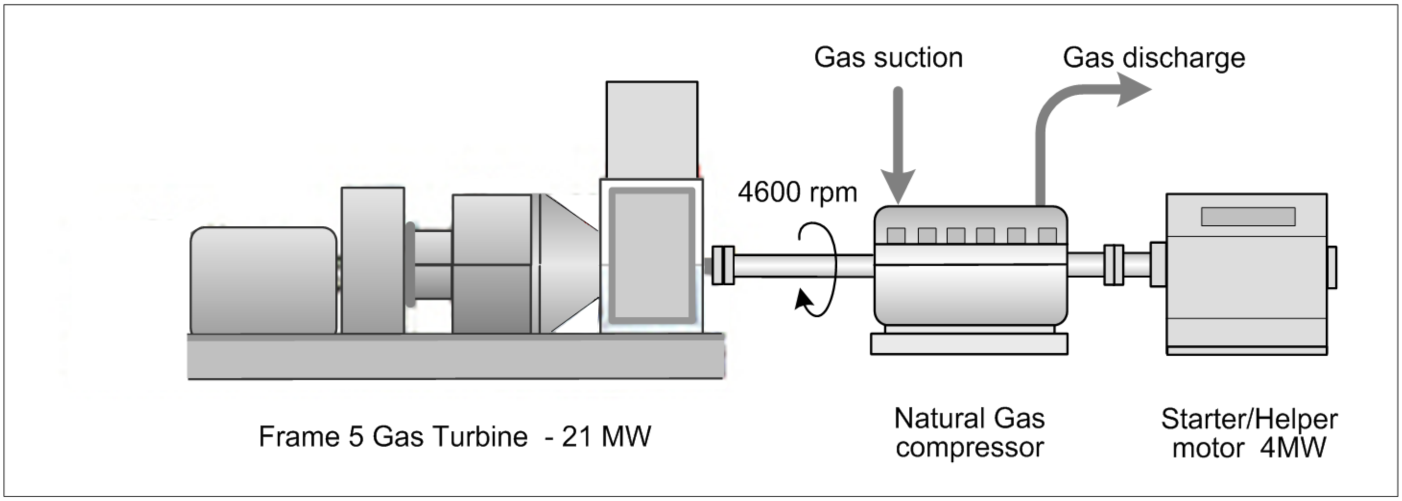


Figure 1. Compressor Drive consisting of Gas Turbine and Electric Starter/Helper Motor

A typical gas turbine driven compressor train is shown in Figure 1. The electric helper motor rotates the turbine up to speed creating pressure in the combustion chambers. The gas burners are ignited and the compressor is loaded up. Power and speed are adjusted by opening and closing the gas valves to regulate fuel. Once the gas turbine has reached rated power, the starter motor is not required. However, the electric motor can be brought online as a helper when the turbine power declines to less than demanded by the process. An ASD, not shown in the figure, is used to smoothly start the helper motor.

Electric Compressor Drive

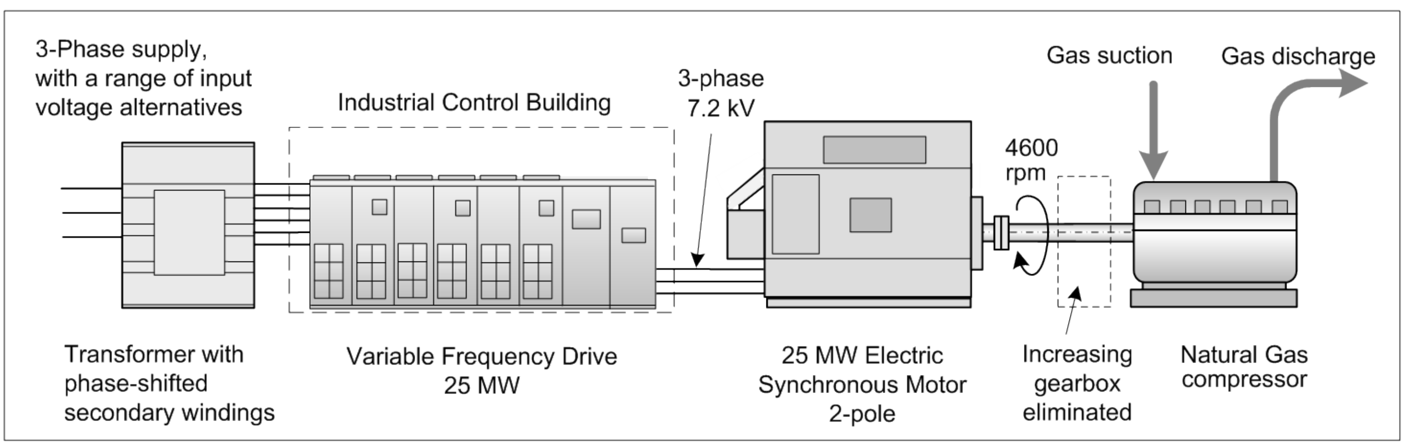


Figure 2. Compressor Drive consisting of an Adjustable Speed Drive and Synchronous Motor

In Figure 2, an electric motor is started and run by an adjustable speed drive. The starting current is controlled so that no large inrush occurs, which can result in overheating in the motor and a dip in the supply voltage. This capability of limiting inrush will save operations significant electrical charges. Generally, synchronous motors are employed for compressor power levels greater than 15 MW, though induction motors now range up to 25 MW. A speed increasing gearbox is typically required for standard speed motors like 1500/1800 rpm or 3000/3600 rpm motors. One of the advantages of using ASDs on motors is that in many cases, the gear box can be eliminated by specifying a super high speed motor. Without a gearbox, the system efficiency increases 2%, however, there are tradeoffs with speed, cost, and power that have to be considered in order to determine if this is the best approach for the application.

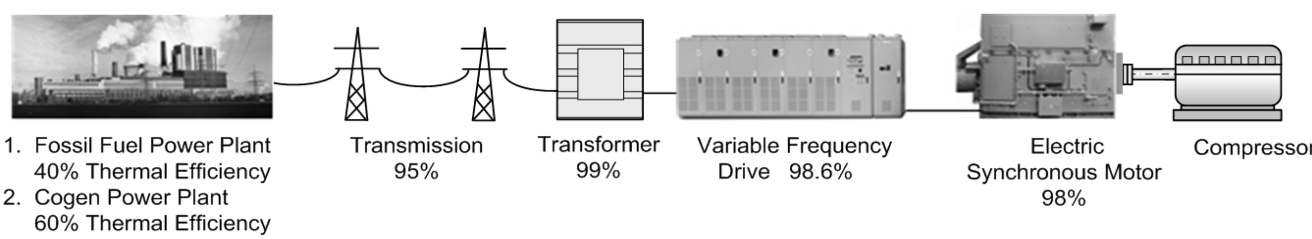
The two-pole motor shown in Figure 2 has a rated maximum speed of 4600 rpm for a 76.7 Hz input frequency, and is a direct drive solution with no gearbox. By using a high speed motor design with an ASD, motor speeds of up to 12,000 rpm can be achieved. Because the ASD controls the output speed, voltage, and motor torque, optimum control of the process is possible. Also, because the ASD has complete control of the load torque across the entire speed range, it is possible to start the process under loaded conditions. This enables the end user to avoid the gas being recycled, flared, or released in the atmosphere while the system is being started up. Sometimes these savings can be several hundred thousand dollars.

Energy Consumption

The main operating expense of the plant is the cost of fuel. This can be illustrated by comparing the thermal efficiencies of the turbine and the electric motor drive system as shown below in case 1 and 4. The electric drive system has a 95% efficiency and the industrial gas turbine has a 36% efficiency. The higher the efficiency, the lower the fuel expense.

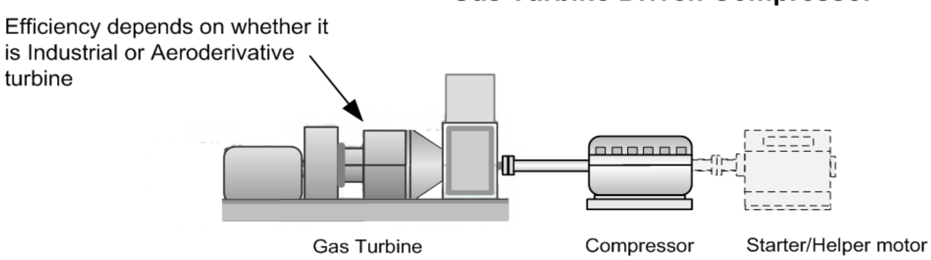
When the energy efficiency of the electric power supply is included, the overall energy efficiencies are more equal, as shown in cases 2 and 4. If, on the other hand, the power is supplied by a co-gen plant then the electric drive system has a much higher overall efficiency of 55%, see case 3.

Electric Motor Driven Compressor



1. Drive, Transformer and Motor - Overall Thermal Efficiency = 0.99 x 0.986 x 0.98 = 95 %
2. Electric System with Standard Power Plant - Overall Thermal Efficiency = 0.40 x 0.95 x 0.99 x 0.986 x 0.98 = 36 %
3. Electric System with Cogen Power Plant - Overall Thermal Efficiency = 0.60 x 0.95 x 0.99 x 0.986 x 0.98 = 55 %

Gas Turbine Driven Compressor



Example: Industrial Turbine, not including starter motor

4. Turbine System at Best Conditions [-40 Degree C] and full load Thermal Efficiency = 36 %
5. Turbine System at High Temperature [+40 Degree C] and Part Load Thermal Efficiency = 19.4 %

Figure 3. Drive Efficiencies

Turbine Temperature and Load Effects

Gas turbines are sensitive to ambient temperatures. When the air temperature rises the efficiency and power decreases as shown in Figure 4. Turbines also lose efficiency at part load.

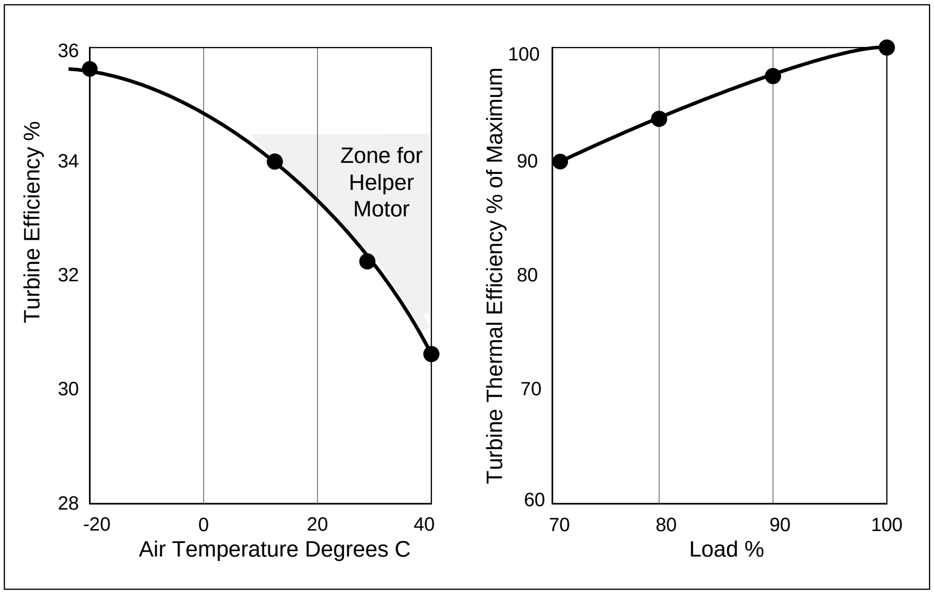


Figure 4. Temperature and Load Effects

Application Considerations when Selecting a Drive

When a major capital equipment purchase is being considered, the important considerations are:

- Process and equipment to be driven – power levels, speed range, controllability
- Plant location – availability of utility or gas power, ambient conditions, environmental regulations
- Target plant availability – expected level of production and revenues based on the equipment MTBF and MTTR
- Flexibility of operation
- Capital expense – equipment, site construction, installation
- Operating expense – electric or gas power, maintenance, spares

When making an equipment choice, the above factors are considered for the main alternatives, and the Return-On-Investment (ROI) is calculated over a 20 year period to find the most promising solution. Table 1 shows the important consideration factors.

Table 1. Comparison of Gas Turbine Drive with an Electric Adjustable Speed Drive

Decision Factor	Gas Turbine	Electric Adjustable Speed Drive	Electric Drive Advantages
Minor maintenance schedule and duration	Every 4,000-8,000 hrs. 6 -10 days downtime	Every 25,000 hours, half day downtime	Less downtime, more production Lower maintenance expense
Major over haul schedule and duration	Every 20 -30,000 hours. 30 days downtime	No major overhaul required	Less downtime, more production Lower maintenance expense
Reliability – MTBF hours	4,000 to 10,000 hours	28 years	Less downtime, more production Lower maintenance expense

Repair time - MTTR	0.5 to 3 days	0.5 hours	Less downtime, more production Lower maintenance expense
Maximum speed	Typically 6,100 rpm	3,600 rpm to as high as 12,000 rpm without a gearbox	No need of additional lube oil system, can use the compressor lube oil system
Variable speed	Narrow speed range; large gas turbines range is 96-101% speed	Wide, accurate variable speed control range, 69% to 105% speed	Better process control Better flow balance in process
Speed control	Slow speed control response. Narrow speed control range	Faster control response. Good energy efficiency at lower speeds	Better speed control & plant flow balance bringing operating savings
Starting	Electric starter motor usually required, turbine start takes time	Short starting time using the ASD. No bad effect on the power system.	Shorter starting time. Increased production.
Overall thermal energy efficiency	Industrial Gas turbine 28-38%, Aeroderivative gas turbine 36-42%	With power from utility plant - 36%. With power from co-gen plant - 55%	Usually lower energy costs. Lower operating cost
Variation in energy efficiency & power	Efficiency & power drops with rising temperature, with falling speed; efficiency drops with decreasing load	Efficiency is constant with temperature, speed, and load	Helper motor is not required. Lower operating cost
Power output level	Up to 150,000 HP	Up to 135,000 HP	-
Power supply	Power source required to start turbine	Reliable grid connection required	-
Emissions and noise	High local CO_2, CO, NO_X emissions, and noise. May have to pay penalties	Drive & motor have no emissions. Utility station controls its emissions	No emissions. Smooth permitting process. Avoid complaints and penalties
Initial equipment cost	Turbine, piping and installation cost	Drive cost somewhat lower than turbine cost	Lower capital cost than turbine (Higher cost if power plant is built)
Delivery time	18 months	ASD has 8-12 months. Motor has 9-15 months	Earlier delivery can provide project cost savings and earlier cash flow

Conclusions

In summary, the advantages of using an electric motor and adjustable speed drive instead of a gas turbine are as follows:

1. The ASD has a 28 year MTBF, and only half day of downtime is required every 25,000 hours. The electric motor has a very high reliability (MTBF) and can run for years without maintenance. A gas turbine on the other hand requires maintenance every 4-8,000 hours and time consuming periodic major overhaul every three years. Therefore the electric drive enables overall higher plant availability, greater gas throughput, and lower maintenance expense.

2. Gas turbines vary in energy efficiency from 28% for industrial turbines up to 42% for aero-derivatives. The electric motor drive has an energy efficiency of 94.5% and if the power station source has an efficiency of 40%, and the transmission 95%, then the overall electric drive efficiency is 36%. If the power station has a 60% efficiency (Co-gen plant) then the electric drive overall efficiency is 55%.

Therefore, depending on the type of gas turbine used and the type of grid power used, the electric drive can reduce energy costs. In addition, unlike a gas turbine, the power delivered by the electric drive is not affected by a rise in ambient air temperature so a helper motor is not required.

3. Delivery of a gas turbine is about 18 months whereas delivery of an ASD and synchronous motor is 9 -15 months. Delivery of a large high-speed two pole synchronous motor is about 15 months, and delivery of a 4-pole motor is 9 months. Therefore an electric drive can be delivered in a shorter time than a gas turbine, which reduces the overall construction schedule.

4. There are no local air quality issues created by an electric drive, whereas the gas turbine generates CO_2, CO, NOx, and other emissions, including noise. Noise from the electric drive is low, less than 80 dBA.

The most important advantage of an all-electric solution is high reliability and efficiency. Lower environmental impact is also becoming an increasingly important parameter during the permitting process which could kill a certain project if gas turbines are employed.

Appendix A. Comparison of Steam Turbine Drive with an Electric Adjustable Speed Drive

Generally the electric drive also has some advantages over a steam turbine. Use of a steam turbine is dependent on whether the plant needs a steam supply for the process. This steam might be required, for example, for heating crude oil or running a distillation column. A boiler with its associated condenser and feed water system will be required, and if the boiler has sufficient size then steam is available for the turbine. These situations may occur on shore, off shore, or on floating platforms. Again, the steam turbine will not be economic if a boiler and auxiliaries have to be built just to run the turbine. The following Table 2 outlines the comparison.

Table 2. Comparison of Steam Turbine Drive with an Electric Adjustable Speed Drive

Decision Factor	Steam Turbine	Electric Adjustable Speed Drive	Electric Drive Advantages
Minor maintenance schedule and duration	No minor maintenance downtime required	Every 25,000 hours, half day duration	-
Major maintenance schedule and duration	Every 35,000 hours. 30 days duration	No major maintenance	-
Reliability – MTBF hours	175,000 hours	28 years	-
Repair Time - MTTR	1 day to as long as 30 days	0.5 hours	-
Maximum speed	Typically 3,600 rpm, smaller sizes up to 26,000 rpm	3,600 rpm to as high as 12,000 rpm without a gearbox	-
Variable speed	Yes, variable speed	Yes, accurate variable speed	-
Speed control	Medium speed control response time	Fast speed control response time	-
Starting	No starting power required	Variable speed drive required for starting, short starting time	-

Average operating thermal efficiency	Approx 30-35%	Power from utility plant 36%. Power from cogen plant 55%	Lower energy costs Lower operating cost
Plant size	Large with boiler, condenser, and feedwater system	Compact, packaged solution	Depends whether steam is required for the associated process
Power output level	Up to over 150,000 HP	Up to 135,000 HP	-
Power supply	Steam from boiler system	Reliable grid connection required	-
Emissions and noise	Boiler generates local emissions	Utility station controls its emissions	No local emissions
Ambient temperature effect on output	Small temperature effect	No temperature effect	-
Initial equipment cost	Competitive, but much higher cost with boiler, condenser and feedwater system	Lower than the steam turbine only	Much lower cost, unless steam required for the associated process
Delivery time	2 to 4 years	1 to 1.5 years	Earlier delivery brings project cost savings and cash flow