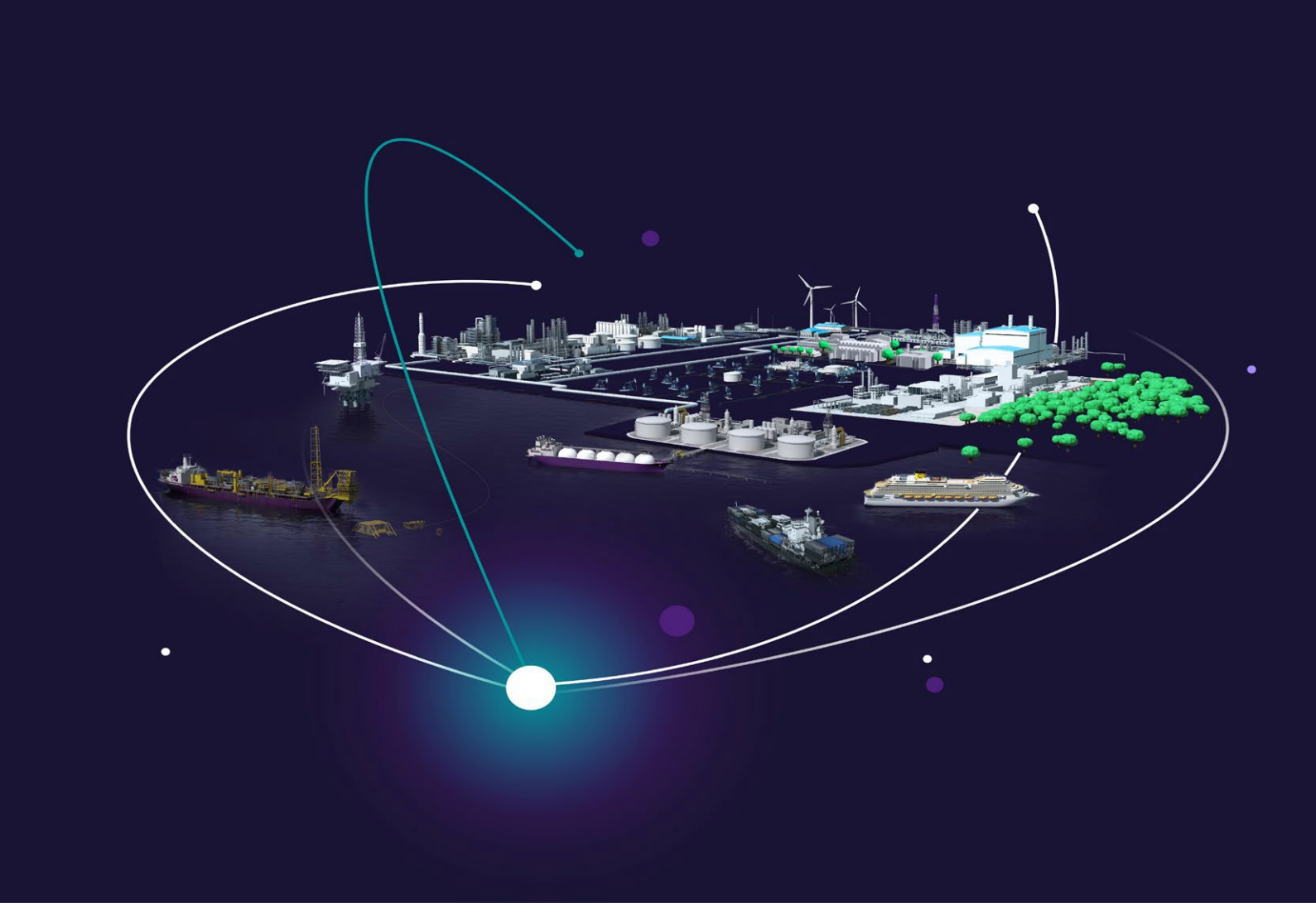


Replacing steam turbines with electric motors

Reducing CO_2 emissions and operating costs through brownfield electrification

siemens-energy.com

SIEMENS energy

01 Foreword
Page 3

02 Petrochemical industry decarbonization challenges
Page 4

03 An alternative to the steam turbine
Page 7

04 The advantages of an electric drive
Page 8

05 The conversion process
Page 9

06 The Siemens Energy portfolio
Page 10

07 The challenges of driver exchange
Page 11

08 The Return on investment (ROI)
Page 12

© 2024 Siemens Energy

1. Foreword

Refiners and chemical producers are under intense pressure to reduce emissions and reach carbon neutrality by 2050. Achieving this will be a difficult task.

Among all industrial sectors, the chemicals industry is the largest consumer of energy. Petrochemical feedstock accounts for 12% of global oil demand and that share is expected to increase as the consumption of plastics, fertilizers, and other products grows. In 2022, the chemical sector emitted a total of 935 Mt of carbon dioxide (CO_2). Only the steel and cement industries had a higher carbon footprint.

In addition to the important role of the chemical industry in mitigating climate change and driving a successful energy transition, emissions from petrochemical plants and refineries have profitability implications for operators. In the European Union (EU), the price per tonne of CO_2 emitted exceeded the 100-euro mark in 2023.

It is already clear that this will not be the upper limit. Researchers forecast that to achieve carbon neutrality by 2050, prices in EU emissions trading would have to rise to 130 - 210 euros per tonne of CO_2 for areas covered under the Emissions Trading System (ETS) and between 175 - 350 euros per tonne for those covered by the Effort Sharing Regulation (ESR). Under the European Green Deal, emissions covered by the ETS are reduced by 62% by 2030 compared to 2005 levels.

Electrification of carbon-fired mechanical drivers will be critical to meeting this target.

Siemens Energy has extensive experience with brownfield electrification, including the replacement of steam turbines with electric motors in petrochemical and refining plants. Drive conversion projects can take place during scheduled maintenance outages, thus avoiding any additional facility downtime.

Executing such kind of projects is a challenging task that requires many years of practical know-how and involvement from various types of technical specialties.

In this paper, we discuss the advantages electric motors provide over steam turbines and outline important factors that operators need to consider when evaluating a drive electrification project.

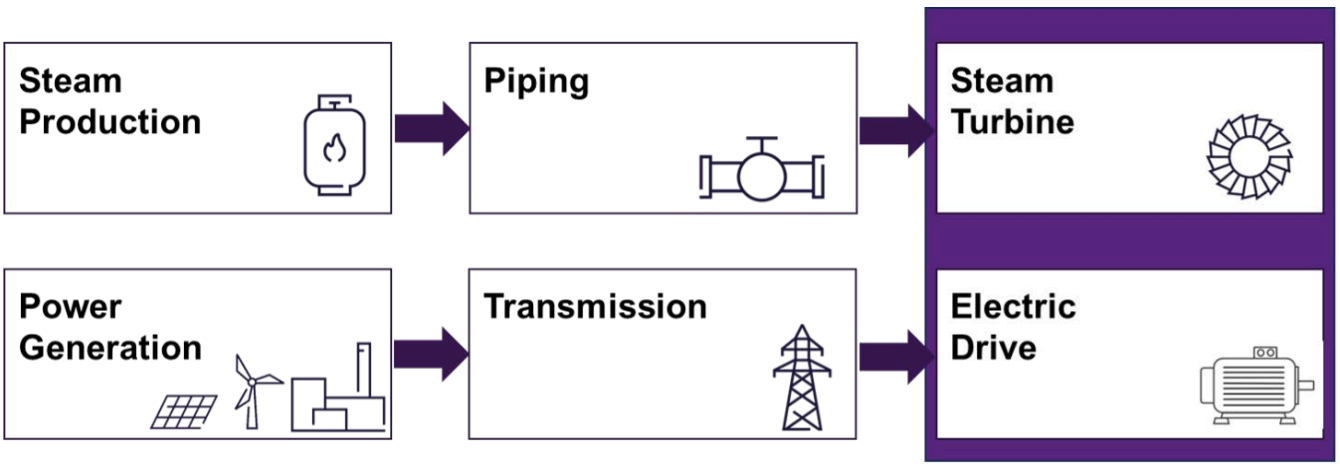
2. Petrochemical industry decarbonization challenges

Steam turbines are a driving force in many industries - and have been for decades. With regular maintenance, industrial steam turbines can last 30 years or more. In many industrial processes, such as power generation and the downstream oil & gas industry, they are integral to facility operation.

Steam turbines perform reliably when it comes to converting heat into mechanical or electrical energy. But heating water to produce steam requires high energy input. In certain instances, biomass or solar energy can be used to generate the necessary energy for steam production.

When industrial steam turbines utilize fossil-fired boilers then is has a significant carbon footprint.





System boundaries for steam and electricity

© 2024 Siemens Energy

According to the World Energy Council, the demand for electricity will increase by 59 percent by 2040. This means that demand will grow twice as fast as primary energy consumption. This describes the energy content of all energy sources used in a country, such as coal, mineral oil or natural gas, which are either used directly or converted into so-called secondary energy sources such as briquettes, fuels or district heating.

According to calculations by the World Energy Council, the production of renewable energies will increase by up to 80 percent by 2040, and their share of primary energy consumption will rise from 14 percent in 2016 to 20 percent in 2040. This means that the consumption of fossil raw materials will remain high. It is true that a 61 percent decrease in coal is reported for the EU. However, the Energy Council expects the share of natural gas in global energy consumption to increase from 22 percent to 25 percent. As early as the 2030s, natural gas will replace coal as the second most important energy source. Oil will remain in first place.

The climate impact associated with fossil-fired steam turbines is only part of the problem. Another is the rising cost of CO_2. In Germany alone, companies in the oil and refining sectors are responsible for about one-fifth of the CO_2 emissions of industry. These environmental burdens must be compensated for by the purchase of CO_2 certificates.

Through an amendment to the Climate Protection Act, the German government has tightened climate protection requirements, seeking to reach net-zero GHG emissions by 2045. By the end of the decade, the goal is to reduce emissions by 65% compared to 1990 levels. The USA is following a similar path after returning to the Paris Agreement in 2021, with plans to achieve 100% carbon-free electricity by 2035 and a net-zero GHG emissions economy by 2050.

Achieving these ambitious targets will require a massive build out of renewable energies and expansion of infrastructure. At the same time, many energy-intensive production processes that rely on fossil fuels will have to be electrified.

The additional burdens from higher energy costs and the costs for CO_2 emissions are leading to price increases on many products - a danger to overall economic development, and also to the competitiveness of many industrial organizations. In addition, production methods that have a high carbon footprint are increasingly being scrutinized by customers, investors, and companies' own employees.

© 2024 Siemens Energy

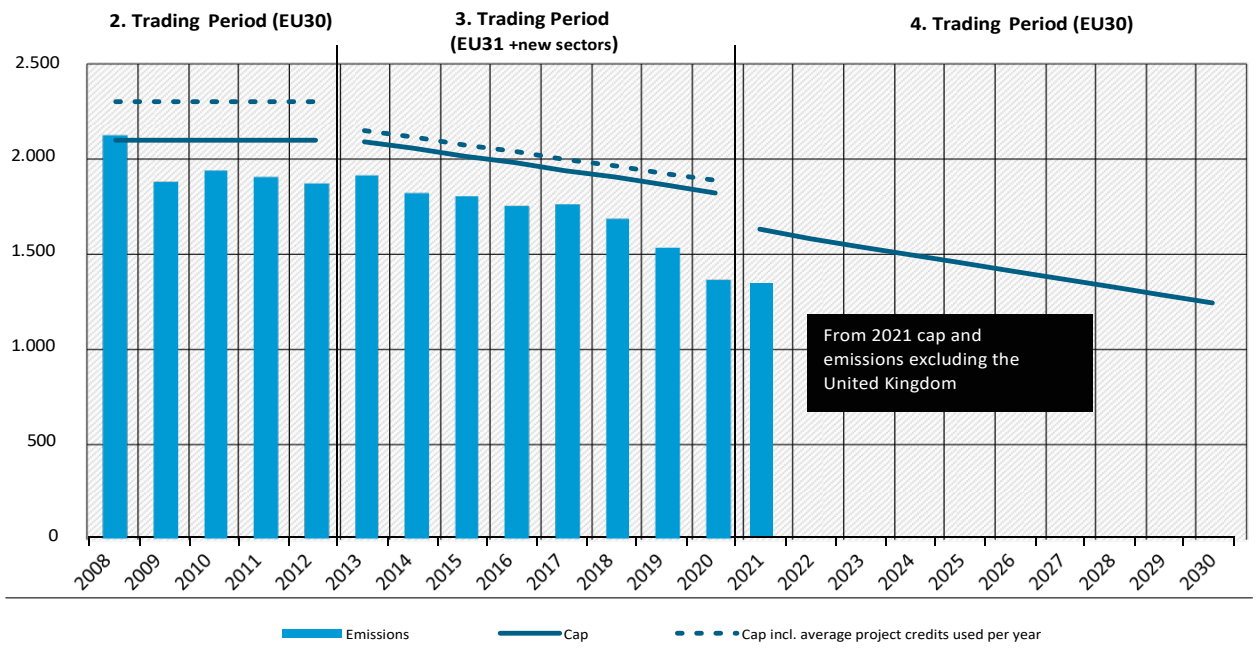
Phase IV (2021-2030) in EU emissions trading

In 2021, the fourth phase of EU-wide emissions trading came into effect. To achieve the climate targets, the Kyoto Protocol limits the amount of CO_2 that may be emitted worldwide. In addition, CO_2 may now only be emitted into the air with an allowance. These permits for CO_2 emissions are limited. They are issued in the form of emission rights.

A CO_2 certificate entitles the holder to produce one tonne of CO_2 within a certain period. At the end of the specified period, the company must prove that all its emissions are covered by certificates. It must purchase these certificates through the European Emissions Trading Scheme (EU ETS). With the entry into force of the fourth phase and the associated shortage of CO_2 certificates, the prices rose from 30 to 50 euros, and in 2022 reached the 100-euro mark for one tonne of emitted carbon.

Total cap and emissions in European emissions trading

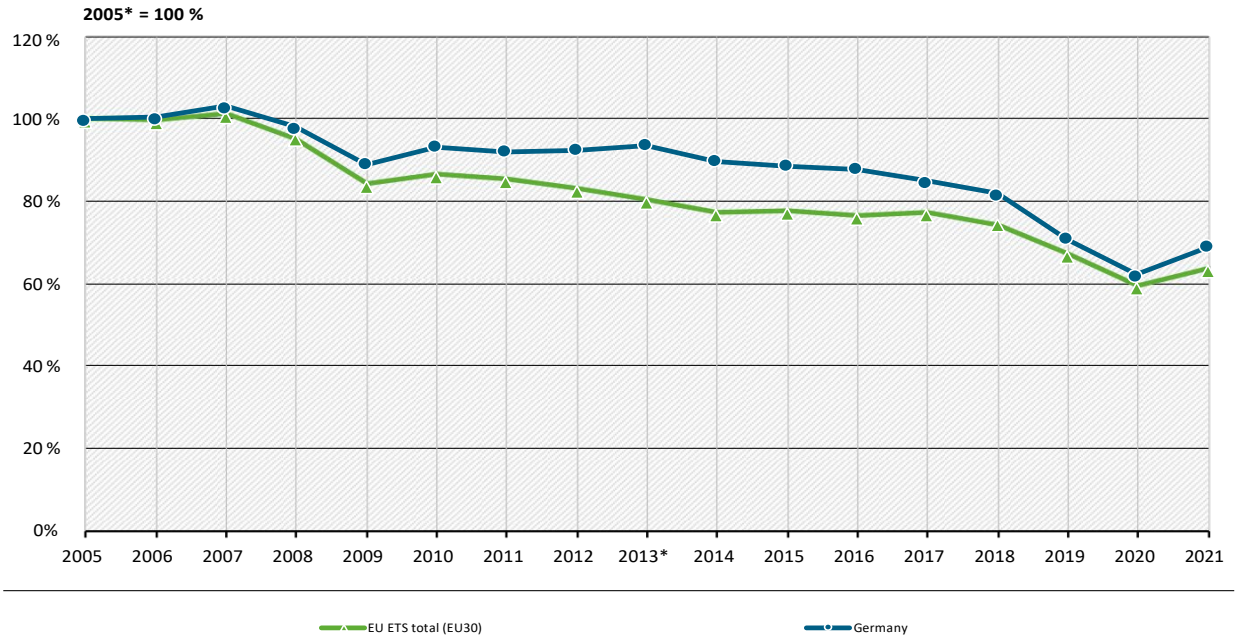
Million metric tons of carbon dioxide



Source: Umweltbundesamt 2022, Deutsche Emissionshandelsstelle, own calculations based on data from the European Environment Agency and the European Commission (2013/448/EU); as of 28.07.2022

© 2024 Siemens Energy

Reductions in the EU ETS since 2005 (EU 30 and Germany)



*In 2013, the scope of the EU ETS was expanded. In order to nevertheless make the emissions comparable across the trading periods, an estimation procedure was used. (Source: EEA)

Source: Umweltbundesamt 2022, Deutsche Emissionshandelsstelle, own calculations based on data from the European Environment Agency; as of 28.07.2022

3. An alternative to the steam turbine

Although steam turbines remain important in many areas of industry (i.e., for producing electricity using waste heat from production processes), their use as a mechanical driver of compressors and pumps is becoming increasingly at odds with operators' need (and desire) to decarbonize.

Electric motors represent a more efficient and sustainable alternative to steam turbines. Electric drives are becoming more prevalent in oil & gas applications. Such configurations typically include synchronous motors with Load Commutated Inverters (LCI) or asynchronous motors with Voltage Source Inverters (VCI). The use of electric drives in the liquefied natural gas (LNG) industry is also increasing. To date, motors up to 75 MW have been demonstrated in LNG service. However, motors up to 100 MW are currently being built and tested.

The technical feasibility of a steam turbine conversion project depends on unique factors related to the facility. Several different configurations of electric drives are possible depending on the requirements of the application. For example, with a low-speed motor and associated variable frequency drive (VFD), a gearbox and two couplings are required for high-speed compressor applications. With a high-speed VFD in combination with a high-speed electric motor, no gearboxes are necessary and direct coupling with compressor or pump is possible.

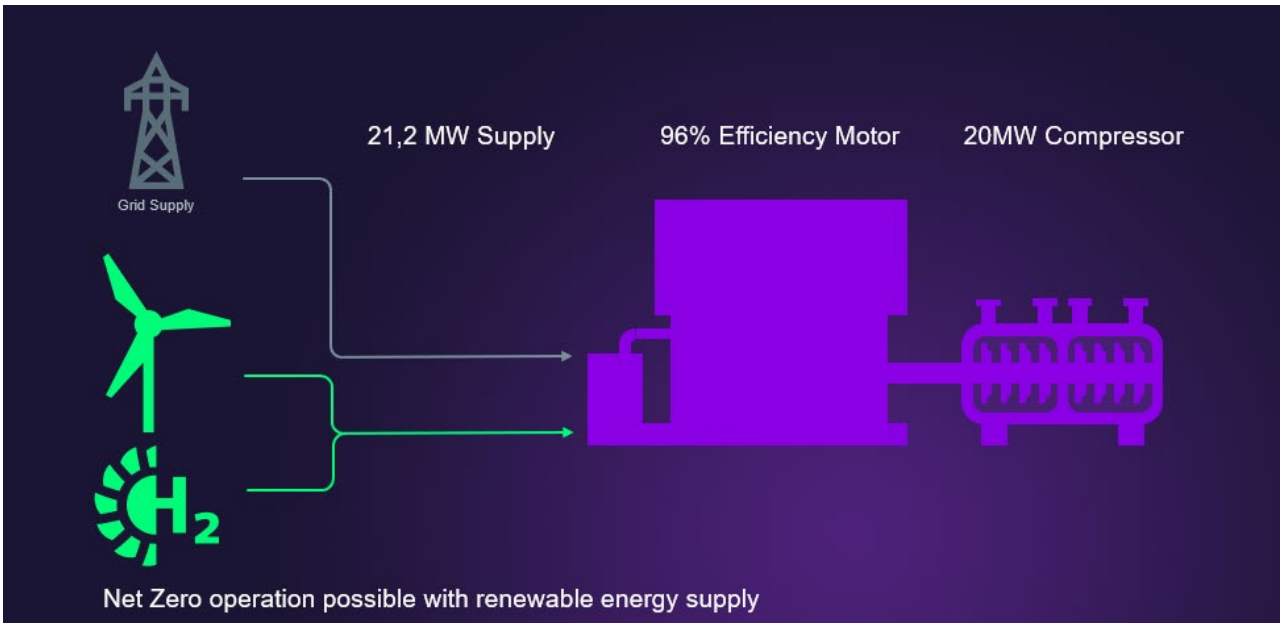
Once an equipment arrangement has been selected, an electrical supply solution must be developed. Conversion cannot be viewed as a simple "driver swap". Large drives, for example, may require a significant modification of the power grid, as well as a comprehensive grid analysis. The electrical system must also be evaluated to ensure safety and availability under all required operational scenarios.

For example, a loss of power can create overpressure in the process. Developing a safe and application-optimized solution ultimately requires the evaluation of many different variables across the entire electromechanical system, including available footprint, torsional analysis, vibrations, the foundation, available power, etc.

© 2024 Siemens Energy

4. The advantages of an electric drive

Electric motor drives offer several advantages over steam turbines. The typical efficiency of a steam turbine ranges from 30 – 40%.
State-of-the-art electric motors, on the other hand, offer efficiencies up to 96%. In addition, motors usually are more flexible in operation, require less maintenance, have higher availability, and most importantly, generate no onsite emissions. True zero-emission drive operation is possible if the source of electricity generation is from renewable energy, such as solar, wind, nuclear or hydro.



Enables net zero operations with renewable electricity.

In terms of maintenance requirements for electric drives, a comprehensive motor inspection is required approximately once every four years. This usually includes an insulation resistance test of critical components such as the rotor, stator, cooling system, and other components, along with an endoscopy.
Although the duration of maintenance varies from motor to motor, this work can normally be done within the maintenance window of the driven equipment.

Typically, electric drives only need a major overhaul every 20 - 25 years. However, this time span is influenced by numerous variables, especially environmental and operation conditions. Major overhauls on steam turbines are usually required every 6 – 10 years.
When overhauling an electric drive, inspection and maintenance can usually be carried out within a few days. This contrasts with steam turbines, where the process can take weeks.

Advances in digitalization and data analytics also enable in-depth analysis of the entire electric powertrain in real-time as part of digital service offering. Operators can use digital solution offerings to plan activities more intelligently and shift maintenance approaches from reactive and scheduled to a more condition-based service. With such an approach, it is possible for powertrains to operate for up to five years without a single shutdown.

The inclusion of drive analytics to monitor operational data also enables predictive functions where anomalies and indications of potential faults can be detected and reported. Early analytics from electrical motor analysis can provide insights into process efficiency and potential upsets which enable the operator to reduce unplanned downtime.

All these advanced features and digital service offerings significantly reduce operational costs over the life of the drive and lead to higher availability and production.

© 2024 Siemens Energy

Operating costs are also a decisive factor when considering a steam turbine conversion. For steam turbines, the largest operating expenses are typically the fuel costs for the boiler and maintenance, whereas for electric drives it is the purchase price of electricity. As discussed previously, carbon emissions taxes are also becoming a material expense. For electric drives, maintenance costs are comparatively low. However, it is still important to look at service schedules and costs for both types of drivers, electrical drive and steam turbine. This can be done by evaluating long-term service agreements (LTSAs), as they encompass factors such as maintenance frequency, manpower requirements, and spare parts.

The technical details at a glance:

- By using an electric drive instead of a steam turbine, CO_2 emission can be reduced to zero if the source of electricity generation is green (e.g., solar, wind, hydro or nuclear). In terms of onsite emissions, the replacement of a 5 MW steam turbine with an electric motor drive can save around 25,000 tonnes of CO_2 per year.
- The efficiency of an electric motor is usually around 95-96% compared to 30-40% for a steam turbine*.
- Maintenance requirements for electric drives can potentially be reduced by up to two-thirds versus steam turbines.
- Electric motors can potentially run up to five years without downtime.
- Electric motor drives are less affected by changes in ambient conditions and provide high efficiency across the entire operating cycle.

5. The conversion process

To carry out a drive conversion project efficiently and maximize the use of existing plant equipment, a great deal of expertise and detailed planning is required. All relevant mechanical, structural, and electrical interfaces need to be analyzed to confirm technical feasibility. The project consists of a team of Siemens Energy experts from a wide range of disciplines, including project managers, design engineers, installation experts. Including the time for the detailed planning and construction, the project usually takes around 18 months to complete. The installation and commissioning process can be completed in roughly 3 – 4 weeks. To avoid extended production downtimes and associated financial losses, the work is typically carried out during a scheduled maintenance outage. There are also examples where careful planning and collaboration with the operator allow for the exchange to be completed in a shorter window, without major disruption to production schedules.



*) efficiency of electrical motor only, efficiency of power generation depends on energy source and is not considered

© 2024 Siemens Energy

Case study: Electrification of an integrated petrochemical complex in Europe

An integrated refining and petrochemical facility in Western Europe was converted to full CO_2 neutral production. The plant's steam turbine was replaced with a low-frequency electric motor powered 100% by renewable energy. In the feasibility study performed by Siemens Energy, the effects on the electrical grid, foundation, process safety, and steam balance were examined in detail. Siemens Energy was responsible for the complete implementation of the electric drive, including engineering, procurement, construction, installation, and commissioning. With the newly installed drive train, the operator will save about 25,000 tonnes of CO_2 annually.

6. The Siemens Energy portfolio

Siemens Energy is a strong partner and highly qualified in helping petrochemical plants execute complex steam turbine electrification projects.
With a solutions portfolio that covers virtually the entire spectrum of engineering services and equipment supply required for converting the drive train, we can support operators from the very early inception and feasibility phase through to implementation and lifecycle support.

Process Modeling and Analysis
Siemens Energy's engineering services portfolio includes in-depth capabilities for process modeling and analysis of the drive train, as well as adjacent process areas. We provide a holistic view of the overall change in the facility as a result of the electrification of steam turbines. This can include critical process analysis, such as overall steam balance and heat consumption studies, with recommendations for optimization as a result of the electrification.

Electrical Studies and Network Analysis
One of our key competencies lies is electrical study and network analysis. These studies provide an in-depth analysis of the electrical supply grid and infrastructure (that either already exists or would need to be implemented to supply electrical power to the motor). In addition, the electrical studies model the impact of the additional load in the upstream supply network by providing analysis of parameters, such as power factor correction and harmonic filtering requirements. These studies can be provided as either a basic verification or as high-fidelity dynamic models.

Feasibility Studies and Business Case Evaluation
Based on our in-house expertise and engineering services portfolio, Siemens Energy is able to offer comprehensive feasibility, pre-FEED and FEED services to support determining the viability of electrification projects. We are intimately familiar with emissions and legislative requirements which could be included in feasibility studies to support the decision-making process for steam turbine electrification.

Equipment and Engineering
Siemens Energy can provide the complete portfolio of equipment required for the electrification of steam turbines, including key equipment such as electrical switchgear, transformers, VFD, and motor, either component based or as fully integrated modular offerings. This is complemented by our expertise in automation and digitalization and comprehensive portfolio of control and monitoring solutions.

A key differentiator lies in our ability to provide a fully integrated electrification solution, including all the studies, engineering, and implementation services for the project, and the electrical equipment for the drive. This enables optimization of the entire train -- from the discharge flange of the compressor, all the way to the electrical substation.

Having a single supplier for the entire project benefits the customer by avoiding multiple complex vendor interfaces, which reduces implementation and execution risk. It also benefits that technical integration challenges are addressed early on in the project timeline, including potential issues related to torsional dynamics or harmonics.

In addition, Siemens Energy provides digital solutions, Dynamic modeling and analysis that allow operators to simulate operation of the production plant with the electric drive before it is installed. A single supervisory system can be employed to monitor and optimize the production process and various components of the drivetrain. Through digitalization, operators can shift from regular maintenance to a more condition-based service. Realtime data driven predictive analysis can also be applied to.

© 2024 Siemens Energy

7. The challenges of driver exchange

Replacing a steam turbine with an electric motor is a complex undertaking that presents many challenges. One of the significant is plant downtime, which can occur if there is unexpected interface challenges or process changes which were not anticipated.

The interface management and associated schedule is a decisive factor that ultimately impacts the success of the retrofit project. As previously mentioned, to avoid production downtime, the conversion project takes place during regular maintenance cycles (i.e., major turnarounds), which for petrochemical plants can last up to six weeks. Executing the retrofit successfully in this time requires several months of detailed planning in advance and extensive knowledge gained from practical experience.

Another important aspect is the lead time for equipment availability (i.e., manufacturing time) of the electric motor. Conversion projects often involve non-standard drives. In such cases, motor designs need to account for site-specific variables, such as environmental conditions and operating requirements. Therefore, the delivery time can be significantly longer than for a standard motor. To minimize the risk of delays in this process, the detailed design has to be completed as early as possible in the project schedule. As previously stated, major changes may extend the project schedule and require changes to associated components and infrastructure, thereby also increasing costs.

The most important design characteristics are the size and operational frequency of the electric motor.

One of the critical factors to consider is the natural operating frequency of the motor (i.e., resonating frequency). This refers to an operating point when the input frequency of the drive for a specific speed matches the natural frequency of the motor, resulting in oscillation that is resonant. In addition to noise, this could ultimately overpower the motor magnetic field, resulting in lost synchronization. This speed point (input frequency) can be determined in advance to avoid this scenario.



Siemens Energy consults with customer's process engineers to determine which motor speed is required for the process. If the process requires a motor speed within the natural frequency of the motor, then necessary design changes can be made during the manufacturing of the motor to avoid resonance. Alternatively, the flexibility provided by electrical motor speed variability can be used to operate the string at speed points to avoid frequency resonance.
If a slow-speed motor is used, gears and clutches are required between the motor and the compressor. The resulting equipment configuration usually protrudes beyond the concrete table, which requires additional evaluation to determine if the foundation is safe and stable under the new conditions.

Another factor to consider, the electric motor itself will likely be 50 – 70% physically larger than the steam turbine. For example, high-speed motors can achieve up to 17,200 RPM. The concrete foundation typically several meters high on which the existing steam turbine is installed is likely not built for the torque and vibration associated with these speeds and will require some type of modification.

In most cases, the existing foundation can be used for the electrical motor. However, strict limitations on footprint and / or weight must often be adhered to. While adapter frames can be used to compensate for the interfaces between physical dimensions, other factors such as vibrations and thermal expansion must be considered. Additionally, torsional, and lateral analyses must be carried out to ensure that the foundation is suitable for the conversion.

Another challenge is the power distribution infrastructure. Being able to implement the new system in the existing electrical infrastructure - even if the equipment for it is already 50 to 60 years old - is an important cost saving factor consideration. With our extensive electrical equipment portfolio and many years of experience, Siemens Energy can design and implement power distribution cost-effectively. As an option to reduce installation time onsite, prefabricated electrical houses (i.e., e-houses) can be used for medium-voltage and low-voltage systems, control systems, and auxiliary equipment (if space permits). In certain cases, it may be possible to dismantle existing structures or modify parts of the site layout to create additional space for e-houses. It is important that this decision is made early on to effectively manage downtime. Regulations are also important to consider. Siemens Energy is represented in many countries around the world and works closely with regional and local partners. In this way, we can draw on extensive knowledge of the respective laws and regulations to support on necessary permissions and approvals.

Overall, the process for executing the drive conversion is planned very precisely in advance.

© 2024 Siemens Energy

8. Return on investment (ROI)

Converting a steam turbine to an electric drive is a cost-intensive undertaking. However, it can be an investment that can deliver a significant ROI - and within a relatively short timeframe. A steam turbine with a capacity of 5 MW produces around 25,000 tonnes of CO2 per year. If one assumes a tax of 100 euros per tonne of CO2, the cost would be 2.5 million euros if OPEX is included, which might assumingly be reduced by one third through electrification, with the ROI to be achieved in approximately 1.5 years.

Operational expenditure (OPEX) benefits are also captured in the form of production uptime. After an extended outage, an electric drive can be started up within seconds. With a steam turbine, the process can sometimes take over a week, as the temperature must be raised very slowly to avoid exposing the drive train to any danger and/or stress. This also becomes a significant advantage in being able to restart the process very quickly after an unexpected process disruption.

Additionally, OPEX reductions are realized by eliminating several components of the drivetrain. With electric drives, operators can drastically reduce their inventory of spare parts. Maintenance personnel and man-hours are reduced accordingly.

The higher efficiency of the electric motor (95 – 96%) compared to a steam turbine (30 – 40%)* has financial implications as well. This is particularly relevant in the world today, where the cost of gas and electricity is more expensive due to changes in the energy landscape. In a high-price environment, efficient use of energy becomes a critical factor in profitability. While the direct emissions reductions achieved through drive electrification are more difficult to incorporate into an ROI analysis (outside of carbon tax avoidance), the ability to decarbonize is a key advantage for operators.

For petrochemical and downstream plants, electrification is an important step for meeting near- (2030) and long-term (2050) climate targets. However, replacing a steam turbine with an electric drive is a complex endeavor. Selecting the right partner with extensive experience across the entire value chain is crucial to success.

As a solution provider with comprehensive expertise and decades of practical experience in brownfield electrification, Siemens Energy is a strong partner capable of implementing integrated electric drive solutions, from early phase studies, the supply of electrical distribution system and motor, to the compressor and gearboxes. Through detailed planning and know-how, we work with customers to identify and minimize possible challenges in advance of performing any activities onsite. By managing important interfaces from a single point of responsibility and by close collaboration with the customer the entire steam turbine replacement can usually be completed within the regular turnaround period, avoiding additional plant downtime.



*) efficiency of electrical motor only, efficiency of power generation depends on energy source and is not considered

© 2024 Siemens Energy

1 A working group from the Institute of Energy Economics and Rational Energy Use (IER) at the University of Stuttgart, together with researchers from the Leibniz Centre for European Economic Research (ZEW) and the Potsdam Institute for Climate Impact Research, has calculated several variants: What prices would be needed to actually advance national climate goals? The study was part of the Copernicus project Ariadne. Sources: www.ingenieur.de

Other sources:
Energy-intensive industries in Germany www.energieintensive.de
German Engineering Federation VDMA www.vdma.org
Federal Environment Agency www.umweltbundesamt.de
World Energy Council: www.weltenergierat.de
European Gas and Steam Turbine Industry www.euturbines.eu
International Energy Agency (IEA) www.iea.com

Published by

Siemens Energy Global GmbH & Co. KG
Transformation of Industry
Electrification – Automation – Digitalization
Freyeslebenstr. 1
91058 Erlangen
Germany

siemens-energy.com

Subject to changes and errors. The information given in this document only contains general descriptions and / or performance features which may not always specifically reflect those described, or which may undergo modification in the course of further development of the products. The requested performance features are binding only when they are expressly agreed upon in the concluded contract.

Siemens Energy is a trademark licensed by Siemens AG.