

US EPA ARCHIVE DOCUMENT

# Pushing the limits of productivity

The all-electric liquefaction plant concept

Answers for energy.

**SIEMENS**





#### **Compression**

A portfolio of field-proven compressors, gas turbine and electric motor drives and their associated control systems including instrumentation for virtually all production, transport and process applications in the oil and gas industry.



#### **Power generation and distribution**

Comprehensive power solutions, including planning, finance, engineering and optimization of power grids; gas and steam turbine-based power plants; transformers; high, medium and low-voltage distribution switchgear; substation automation; energy management; network consulting.



#### **Automation**

A unique array of automation and electric-drive related products, systems and solutions for field, operation and management levels. Designed to achieve maximum productivity while realizing substantial cost savings.



#### **Life-cycle services**

A portfolio of life-cycle services, including feasibility studies, design and network studies as well as all levels of preventive and corrective maintenance, performance enhancement programs, service level agreements and training.



Statoil's Melkøya Island LNG plant near Hammerfest, Norway. The world's first all-electric LNG plant, its main refrigerant compressors are powered by two massive Siemens 65-megawatt variable-speed drive systems (VSDS). Siemens also delivered the compression solutions for methane mix and CO<sub>2</sub> re-injection.

## Dedicated solutions for electric LNG

Over past decades, liquefaction of natural gas has matured to become an economically viable as well as a technically and commercially proven scheme for shipping natural gas from remote production locations to distant consumers. Reducing the specific cost of LNG by upscaling liquefaction trains and increasing their productivity through innovative technologies is a recognized industrial trend. The reduction of greenhouse-gas emissions and construction times has become an additional issue, challenging traditional approaches.

Enter Siemens. With a complete range of rotating and electrical equipment, power generation, transmission and distribution systems, industrial controls & automation, and life-cycle services, Siemens provides a host of solutions designed to realize maximum LNG plant availability, and meet any of tomorrow's challenges, technical, economical or environmental.

Innovative design, excellence in engineering and project management, maximum lifetime value, and uncompromising compliance with health, safety, environmental and industry standards are common denominators for all components, products, systems and services in the Siemens LNG portfolio. Moreover, through its global manufacturing and service network, Siemens ensures maximum customer proximity and local content. Combining our competence and strengths with yours, we can together push the limits of LNG plant productivity even further, to meet the most rigorous contractual commitments of LNG production and delivery.





# The unique advantages of electric LNG

While today's vast majority of refrigeration compressors in LNG liquefaction plants are driven by gas turbines, E-LNG schemes stand out as an economically and ecologically superior approach — despite a higher initial investment for a larger thermal power plant. With variable-speed electric motors available for all relevant refrigerant compressors, the concept of electrical liquefaction of natural gas (E-LNG) can be applied equally well to all recognized and proprietary LNG liquefaction cycles, offering a host of benefits. The E-LNG concept has been made feasible by Siemens' distinctive technology position in large motors and drives, which are available to match the top end of the refrigerant-compression duties now demanded by the scale-up of LNG train capacities.

## **Dramatic boost of productivity**

The design concept of an E-LNG plant is to enable up to 365 days per year of uninterrupted refrigeration-gas circulation or for periods not limited by either the power plant or the compressor strings. This allows for a substantial increase of productivity by eliminating downtimes of the refrigeration compression trains. Initial additional investment costs for the power plant are expected to be compensated within a period of under five years, depending on the value of LNG at the time.

## **Significantly improved energy efficiency and reduced emissions**

Combined-cycle power plants for E-LNG service provide significant potential for improving overall thermal efficiencies. Even including distribution losses electric drive systems achieve 96 percent efficiency,

resulting in an overall refrigeration-system efficiency of up to 45 percent, compared to approx. 32 percent for traditional mechanical drive solutions. Combined-cycle power plants also reduce greenhouse-gas emissions by around 30 percent compared to traditional mechanical compressor drives. Including process-steam supply, overall thermal efficiency may reach 90 percent.

## **Increased operational safety, flexibility and asset utilization**

With E-LNG, process and compression-plant size is no longer restricted by available mechanical drives; there is no need for fired equipment and related scheduled maintenance inside the process plant. Associated risks are eliminated and can reduce insurance costs. Quick and controlled starting and re-starting of pressurized compressors minimizes downtimes and eliminates flaring of expensive refrigerant gas, while compressor speeds can be optimized, and target production can be reached with smaller train capacity and unaffected by ambient temperature.

## **Significantly accelerated schedules**

Typically, E-LNG schemes provide significant time benefits. Faster string test programs, modular motor-drive systems, and shorter installation times offer the potential for months of schedule reduction and a substantial decrease in related costs.

## **Particularly suited for floating LNG plants (F-LNG)**

The evolving concept of F-LNG plants prefers a physical separation of combustion equipment from the process area for personnel safety reasons. E-LNG installations can be optimally sized and located on board a barge or ship.

One of two massive Siemens 65-megawatt variable speed drive systems (VSDS) powering refrigerant compression at Statoil's Melkøya Island all-electric LNG plant.



# A single source from power to compression

Procuring a comprehensive power-to-compression solution from a single point of responsibility offers a host of benefits for end-customers and EPCs alike. A single point of contact means a significant reduction of interfaces, simplifying project management and communications. Moreover, engineering time as well as erection and commissioning costs are reduced through harmonized equipment and handling.

Siemens' core business comprises electrical engineering, rotating equipment, and a wide range of related services. As a partner in E-LNG projects, Siemens would take overall responsibility for a comprehensive range of compression and power generation equipment. Underlining our credibility as a single-source supplier, we are prepared to negotiate availability guarantees for specific projects and countries with contractually fixed bonus-penalty schemes, and long-term service and maintenance agreements for our scope of supply.

## **Comprehensive testing before shipping**

Major equipment packages are functionally and load-tested prior to shipment to reduce the risk of delays due to non-conforming or non-performing equipment. Testing comprises full-load full-speed tests of motor-compressor strings of up to 90 MW, as well as automation and control-system integration tests of all subsystems.

## **Speeding installation**

Wherever weight and size limitations for shipping allow, subsystems of an E-LNG compression plant are built in modular form with pre-installed and pre-commissioned equipment. Siemens' vast experience, a structured project-management process including a detailed transportation and construction execution plan, and advanced logistics concepts have allowed us project execution times of 24 months for standardized plants.

## **Easing commissioning**

Detailed planning of the entire commissioning process and a series of acceptance certificates form the basis for a smooth start-up process. Fine-tuning of control systems and performance testing of the power

plant necessitate at least a partial loading of the generators during commissioning. Siemens specialists employ dedicated measures and equipment to commission these systems without interfering with the LNG plant start-up process.

## **Scalable operation and maintenance services**

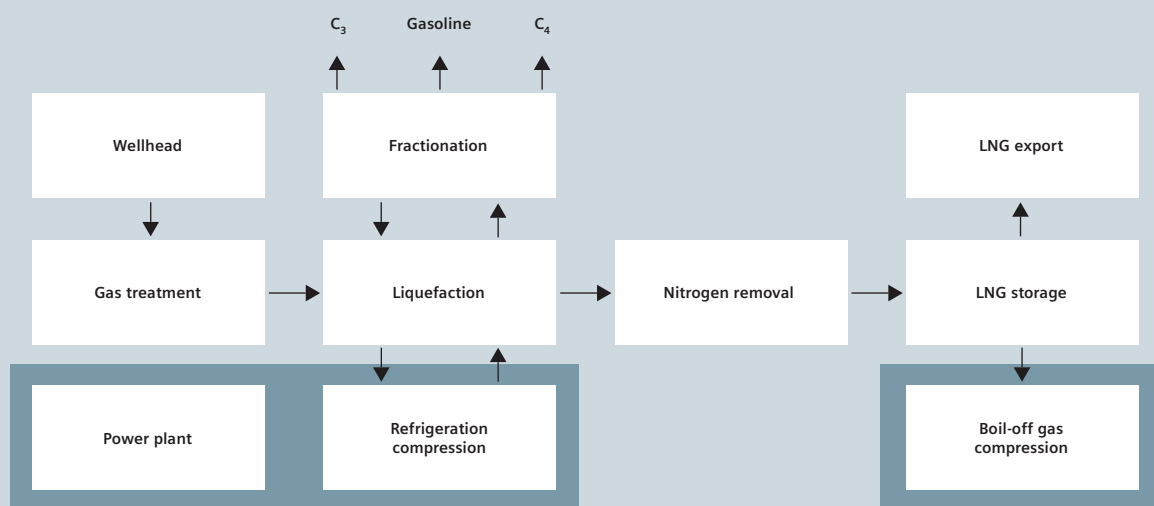
Siemens has a tradition of going way beyond the conventional meaning of service. Our services accompany you from the initial project-engineering phase, during project execution, and through the plant's entire life cycle. Supported by comprehensive diagnostic and logistic functions from service centers, factories and headquarters, our local and regional organizations deliver a full range of services for Siemens' scope of supply, from on-call services through all-inclusive operation and maintenance. Availability guarantees are offered as optional parts of long-term operation and maintenance contracts.

## **Optimizing asset service and availability**

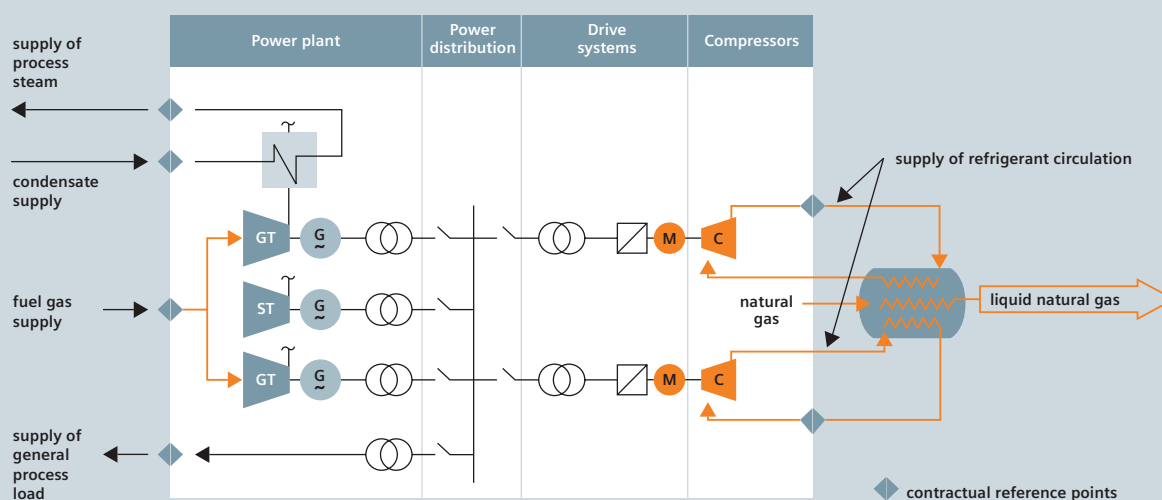
All of Siemens' thermal power plants, motor-compressor and power transmission and distribution subsystems can be connected to one of two Global Service and Diagnostic Centers for permanent online performance monitoring. The scheme allows the development of condition-monitoring based maintenance strategies, and comparative fault analyses of Siemens' entire fleet for the whole life cycle.

## **Tailored training measures**

Comprehensive training of customer personnel is part of every contract, the scope and depth of which depends on qualifications and duties to be performed. Programs include training on real-time power-plant simulators, duplicating essential parts of the information and control system, and allowing hands-on training without interfering with the actual operation, plus the proactive development of operating and emergency procedures.



Including rotating and electrical equipment, power generation, transmission and distribution as well as all related control and automation systems, Siemens provides a host of solutions for LNG plants from a single source.



Avoiding potential interface problems of traditional piece-meal contracting, Siemens can take responsibility for supplies and services from power to compression.

GT – gas turbine  
ST – steam turbine



# Electric drive solutions



Backed by decades of experience in the design and manufacture of high-power rotating electric machines, Siemens e-motors provide the ideal drive solution for even the largest-scale liquefaction trains.

Driving the main refrigerant compressors, variable-speed drive systems (VSDS) are at the heart of the E-LNG plant concept. The system includes simple, robust and low-stressed, brushless synchronous motors renowned for their superior reliability and availability in the most demanding applications in many industries. In fact, Siemens is the world's leading supplier of such large drives.

Siemens electric motors for E-LNG compressor drive utilize established, proven design concepts and materials that have been used in power generation for decades. Identical mechanical, thermal and electrical stress levels in both applications virtually eliminate the risk of "unproven" equipment application. Variable speed-drive electronic equipment is actually proven in much higher ratings, e.g. in high-voltage DC transmission applications. Allowing for a customized and optimized compressor string design, Siemens offers electric-drive solutions for E-LNG plants in power ratings of up to 90 MW and speeds exceeding 3600 rpm.

#### Space saving modular designs for every climate zone

Variable-speed drive systems are custom-engineered from proven modular designs. They are pre-installed and pre-commissioned for compressor-string performance tests and

rapid on-site installation. Adaptations to local conditions and project requirements, such as autonomous cooling systems, are trouble-free as well, reducing EPC costs for the refrigeration plant.

#### Wide selection of drives

Two families of electronic variable-speed drives are available, current-source (LCI) and voltage-source (PWM), with each type offering specific advantages. The optimum drive system will be selected in close cooperation with the client's experts based on circumstances and criteria.

#### Side effects mitigated

Electronic variable-speed drives show different degrees of side effects during operation, including power-system harmonics and oscillating torques in the compressor strings. These side effects are well known and understood, and are mitigated to the point where they do not pose a risk to operator or equipment.

One of two liquefaction compressor drivers rated 65 MW at 3600 rpm for the Statoil Snøhvit project in Hammerfest (Norway). These LCI-supplied 2-pole brushless synchronous motors are complemented by a 32 MW/3600 rpm and one 16 MW/6600 rpm motor, all of which have been full-load full-speed tested prior to shipment to the site. Additional Siemens scope of supply: VSDS-driven compressor string for the methane mix train; 32-MW VSDS for the liquefaction compressor; CO<sub>2</sub> re-injection compressor; harmonic study; containerized load-commutated inverter (LCI) frequency converter units, drive control and fault diagnosis systems; transformers; containerized harmonic filters; converter cooling systems and auxiliary equipment.



One of three motor-driven natural-gas compressors rated 38 MW/4200 rpm at NAM's UGS facility near Groningen, Netherlands. Operational since 1986, these machines were the largest VSDS at that speed until the Hammerfest drives were built in 2004. Additional Siemens scope of supply: entire electrical system from 150 kV power supply to medium and low-voltage distribution; harmonic filters, including installation and commissioning; LTSA for the drive systems.



One of NAM's compressor stations producing natural gas from the Groningen gas field in the Netherlands. A series of 16 (ultimately 21) motor-driven depletion compressor sets rated 23 MW at 6100 rpm have been supplied since 2001, the world's first electrical high-speed variable-speed drive systems in that class with active magnetic bearings. Additional Siemens scope of supply: harmonic filter plant and all auxiliaries; fan motors for cooling banks; system integration; conceptual and detail engineering; network analysis and vibration studies.



Two starter/helper motors rated 17 MW at 3600 rpm supply starting power and additional torque for the gas turbines at an LNG plant in North Africa. A total of eight such 2nd-generation variable-speed drive systems have been ordered for mechanically driven LNG refrigeration compression systems since 2003, using 2-pole solid-steel turbo-rotor motors with brushless excitation and LCI-type variable-frequency drives.

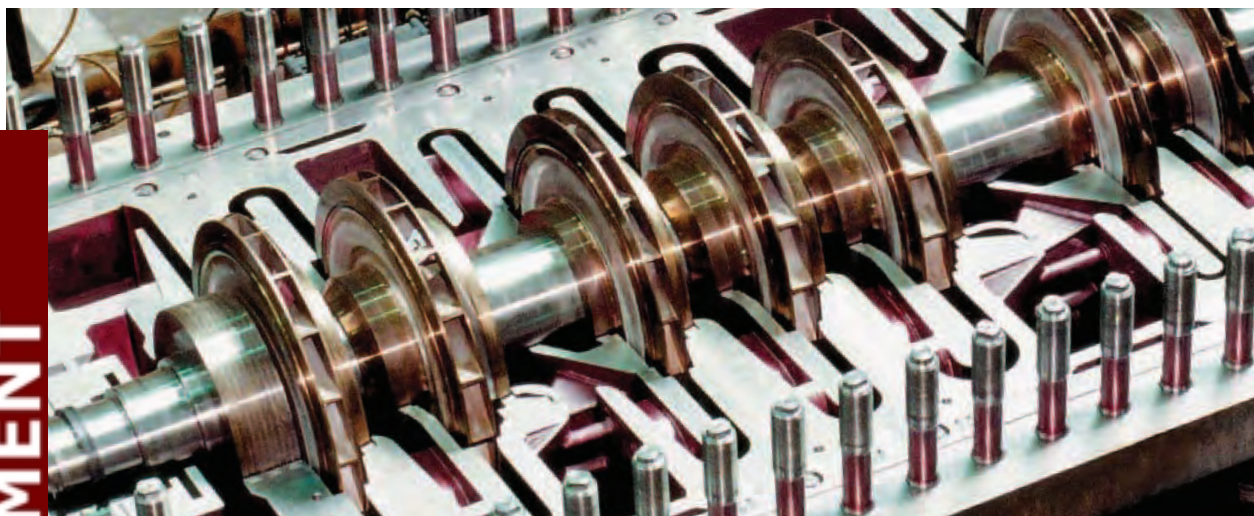


Two boiler feed-pump drivers rated 15.6 MW at 5100 rpm for the German utility company STEAG. These LCI-supplied motors operate successfully since 1981 in a thermal power plant 24 hours/365 days without being disassembled for service. The drives initiated the industrial use of high-speed LCI drives and have many similar installations.





# Compressors for LNG



Defining the art of compressor technology, Siemens compression solutions are available for all stages of the LNG supply chain, from gas treatment through liquefaction to boil-off gas compression.

Siemens compressors have a long tradition of excellence. In applications as wide as the process and oil and gas industries, they have earned a reputation of technological leadership and dependability. In many areas, Siemens enjoys a position of global market leader, including boil-off gas compression.

For main refrigerant-gas compression of LNG process plants, Siemens offers proven single-shaft refrigeration compressor trains in all appropriate ratings for E-LNG plants. These include horizontally or vertically split designs for all common flow rates and pressure ratios. The features include dry gas seals and hydrodynamic or active magnetic bearings from reputable vendors, and state-of-the-art rotor-dynamic design and verification tools to meet the industry's tough performance criteria. For new processes and larger plant sizes, existing aerodynamic, rotor-dynamic and casing designs are taken as a basis and tested with scaled models to accurately predict their performance, reducing planning risks to the minimum.

## **Mastering rotor dynamics**

Full rotor stability over the entire operating-speed range, including starting, is crucial to obtain optimum compressor performance and reliability. Siemens uses advanced analyti-

cal and modeling tools to predict rotor dynamics, taking into account the influence of gas forces from labyrinths. Advanced standardization of rotor designs allows for detailed design already in the planning phase of a project.

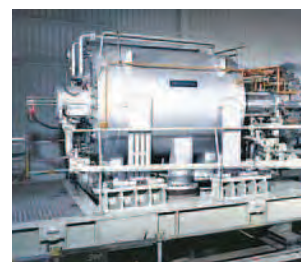
## **Eliminating start-up risks**

Full-load, full-speed performance tests of complete VSDS can be performed at the factory to augment the routine component tests and dramatically reduce start-up risks at the job site. Multiple installations are cost-effective and represent no additional risk due to prefabricated and modular VSDS designs. Complementing these back-to-back tests, Siemens' new Mega Test Center in Duisburg (Germany) allows set-up and testing of up to three fully assembled compressor strings in ratings up to 90 MW for API class-2 tests under full load at full speed with all major auxiliary systems. This enables the design and performance of the complete compression solution to be verified prior to shipment. Direct access to the Rhine waterway allows for unobstructed shipment to all continents of even the largest machines.

Propylene refrigeration compressor STC-SH 20-5-A with three side streams for an ethylene plant in Texas, USA. Inlet volume flow of 188,400 m<sup>3</sup>/h, discharge pressure of 17.9 bar. Driver power is 54 MW at 3,600 rpm. Impeller diameter is 1,495 mm. Siemens has built a significant number of large-size propylene and propane refrigeration compressors for ethylene plants with services nearly identical to those for LNG.



Two-casing end-flash gas compressor for an LNG plant in Indonesia. Frame sizes STC-SH 14-6-A (horizontally split) and STC-SV 14-8-B (vertically split) with an impeller diameter of 900 mm. Designed for a suction temperature of approx. -160 °C. Driver is a fixed-speed electric motor of approx. 16 MW. The end-flash gas is utilized as fuel gas for the mechanical-drive and gen-set gas turbines of the plant at compressor discharge pressures of approx. 30 bar.



Two-casing boil-off gas compressor for an LNG plant in Indonesia. Frame sizes STC-SH 10-6-A (horizontally split) and STC-SV 10-6-A (vertically split). Impeller diameter is 600 mm. Boil-off gas compressors normally operate at suction temperatures of -160 °C. They also provide fuel gas for the gas turbines at discharge pressures of approx. 30 bars. The driver is a fixed-speed electric motor of approx. 8 MW.



8-impeller barrel-type propane compressor STC-SV 14-8-A with one sidestream and nozzles upwards for a gas plant in Saudi Arabia. Impeller diameter is 950 mm. Discharge pressure is 24 bar at a driver power of 19 MW. Siemens has built barrel-type compressors of this size for discharge pressures of up to 90 bar. Such barrel-type compressors are used as high-pressure casings for mixed-components refrigerant compressors in LNG plants.





# Power generation



Air cooled standardized combined-cycle power plants in modular construction are cost effective, environmentally friendly and highly reliable generating facilities for E-LNG plants.

For any E-LNG scheme, power-plant availability is key. Operated under island-type conditions without the possibility to export or import electricity, Siemens' expertise and experience as the leading OEM supplier of turnkey power plants worldwide makes all the difference in ensuring ultimate reliability.

LNG plants are typically located remotely from populated areas, frequently without access to stable and robust power-transmission networks. As a result, power stations for E-LNG plants operating in island mode have to meet special requirements, including self-controlled system frequency with fast response capability, steep load gradients, and tolerance for harmonics. Specifically, measures have to be implemented to ensure a fast transfer of electric loads within such island power systems to keep the liquefaction process running within specifications. Only then, the core benefit of five years or more of uninterrupted service offered by the E-LNG design concept can be fully leveraged.

## Combined-cycle schemes for optimum efficiency

An initial decision for operators and investors to make is choosing the type of power plant and the method of financing and building it. Self-cooled combined-cycle power plants are the proven state-of-the-art solution, outperforming simple-cycle power plants with about 40 percent higher thermal efficiency and a 30 percent reduction in greenhouse-gas emissions. They consist of gas turbines, waste-heat recovery boilers, and steam turbines to make maximum use of the feed gas, and reduce emissions. Building such power stations in accordance to the manufacturer's standardized modular design results in cost effective projects and yields maximum value for owners and investors. While Siemens delivers simple-cycle power plants as well, combined-cycle schemes are recommended for their superior performance.

## Ensuring continuous productivity

In order to guarantee uninterrupted supply of electricity even during unscheduled outages of turbogenerators, surplus generation capacity has to be installed in the power plant and operated at all times. Following the so-called n+1 principle, an additional turbogenerator provides the positive spinning reserve that prevents temporary overloading of generators in the event of one unit failing. In the E-LNG concept, all turbines and generators operate continuously in part-load, capable of assuming full load in a very short time, without affecting the power output or the refrigeration process. The cost of the additional generator is easily compensated through additional 15+ productive days per year an E-LNG plant achieves compared to traditional gas-turbine driven plants. However, if an adequate power-grid connection is available at or near the project site, the n+1 generator may be omitted.

## Adapted to specific E-LNG power plant needs

Gas turbines are typically designed for maximum efficiency, meaning maximum firing temperatures. In order to optimize the whole economic model of an LNG plant taking into account the importance of availability, the gas turbines are adapted and operated at lower firing temperatures. This allows the operator to achieve exceptionally long maintenance intervals up to six years for a major overhaul while having fast load reserve available during operation.

## Financing tailored to customer needs

Siemens' standardized power-plant designs are modular and expandable, pre-engineered to a large extent, and make use of local content wherever appropriate. These designs are easily and cost-effectively integrated into E-LNG plant projects. Independent power-producer (IPP) concepts are available for alternative financing schemes of such power plants, removing CAPEX from the project balance sheet and paying power-consumption charges from the OPEX budget instead.

## Water-steam cycles

Heat from gas-turbine exhausts is very effectively used to generate high-pressure steam for combined-cycle use and low-pressure steam for process use. Based on well-proven standards and modular concepts, Siemens designs the entire water-steam cycle to provide safe, reliable, and efficient operation, and an optimum match of capital cost and plant performance.

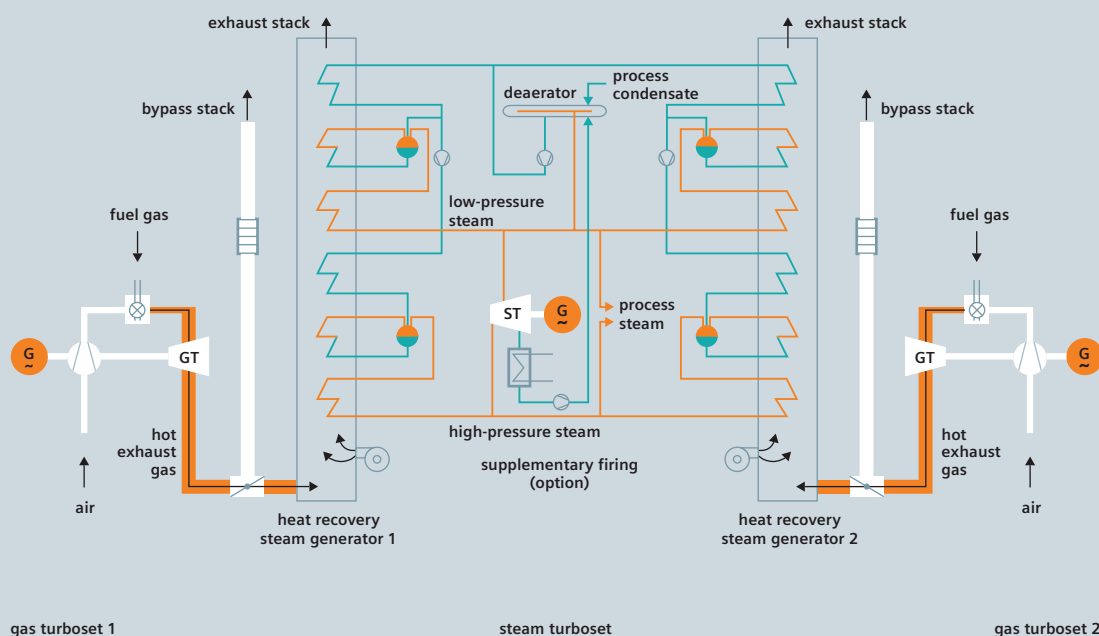
### Focused on flexibility

E-LNG power plants operating in island mode have to meet varying steam and load requirements. To boost steam production in the event of low electrical power demand, the heat-recovery steam generator (HRSG) can be supported by supplementary firing. The electrical load is then largely decoupled from steam production. Depending on the chosen plant concept, the HRSG generates steam of different pressure levels and condensate preheating. With space available, Siemens uses horizontal drum-type boilers with natural circulation. The HRSGs can be equipped with exhaust-gas bypass stacks and diverter dampers to allow switching from combined-cycle to single-cycle operation to increase operational flexibility. Meeting zero-discharge requirements, steam produced by the HRSGs is routed to

common headers and distributed to either the steam turbines and/or the process heating system. A steam regulating station meets varying steam demand. Exhaust steam from the steam turbines is typically liquefied in air-cooled condensers, and the condensate is fed to de-aerators to provide condensate qualities for long lifetime operation. Liquid losses can be reduced to keep the size of make-up water plants small.

### Redundancy for maximum availability

Deaerated condensate is pumped to common headers to allow for individual adjustment of multiple units but still using standardized HRSG designs. Redundant feed-water pumping systems ensure maximum availability. The information and control system also follows the redundancy concept of the entire power scheme. HRSGs are available for outdoor installation with combined heat and noise insulation, or for installation in a boiler house. Closed cooling loops with redundant circulation pumps and forced-draft fin-fan cooler banks transfer heat losses of generator and motor cooling water to the ambient air by virtually maintenance-free and highly reliable autonomous sub-systems.

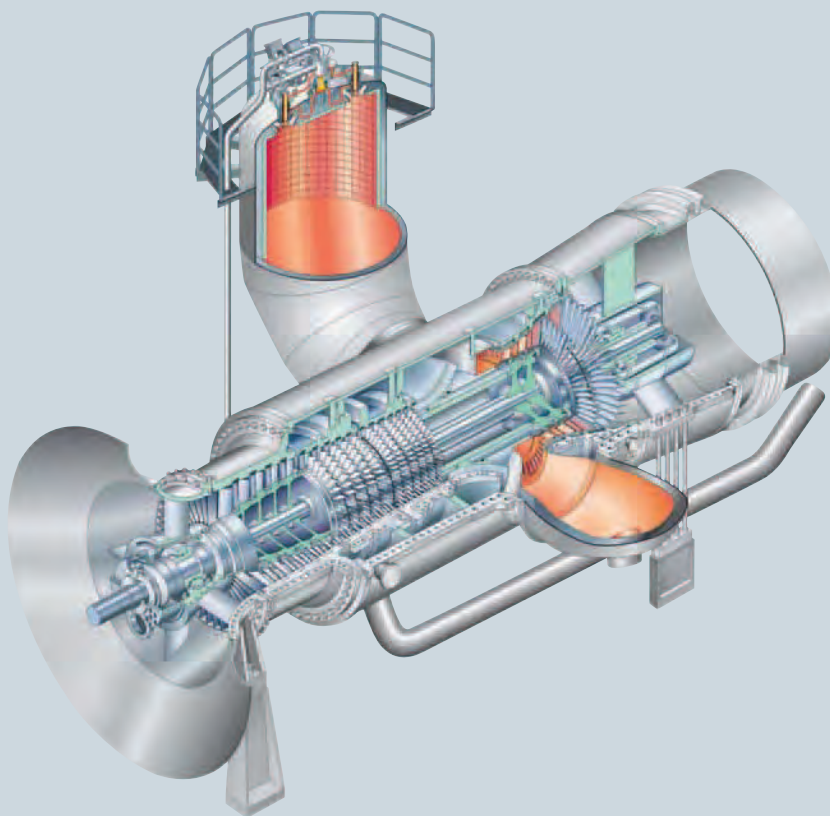


Making the most out of the feedstock, water-steam cycles enable power plants to achieve efficiencies of up to 52 percent.

GT – gas turbine  
ST – steam turbine



SGT5-2000E and SGT6-2000E: Boasting a spectacular reliability of 99.5 percent, they are the workhorses in large-scale industrial power generation around the world.



## Gas turbines

In the development of gas turbines for utility-type power generation, thermal efficiency remains the primary goal. For power-generation applications in the process industry, however, the focus is on maximum reliability and minimum downtime. Siemens gas turbines deliver just that, ensuring maximum plant availability and ultimate leverage from the E-LNG concept.

Siemens' tested and proven gas turbine SGT5-2000E for 50-Hz systems (163 megawatt (MW) ISO), and SGT6-2000E for 60-Hz systems are the ideal workhorses for E-LNG power plants. They complement extended periods between scheduled maintenance activities requiring a shutdown with shortest possible service times.

### Spectacular fleet reliability

With an installed base of more than 220 units boasting more than 10 million hours of operation, a spectacular fleet reliability in excess of 99.5 percent, and up to 48,000 equivalent operating hours (EOH) between major overhauls, these engines are uniquely qualified for E-LNG power-plant service. Built-up disk-type rotors with radial Hirth serrations and a central tie-bolt, cast vanes and blades in the

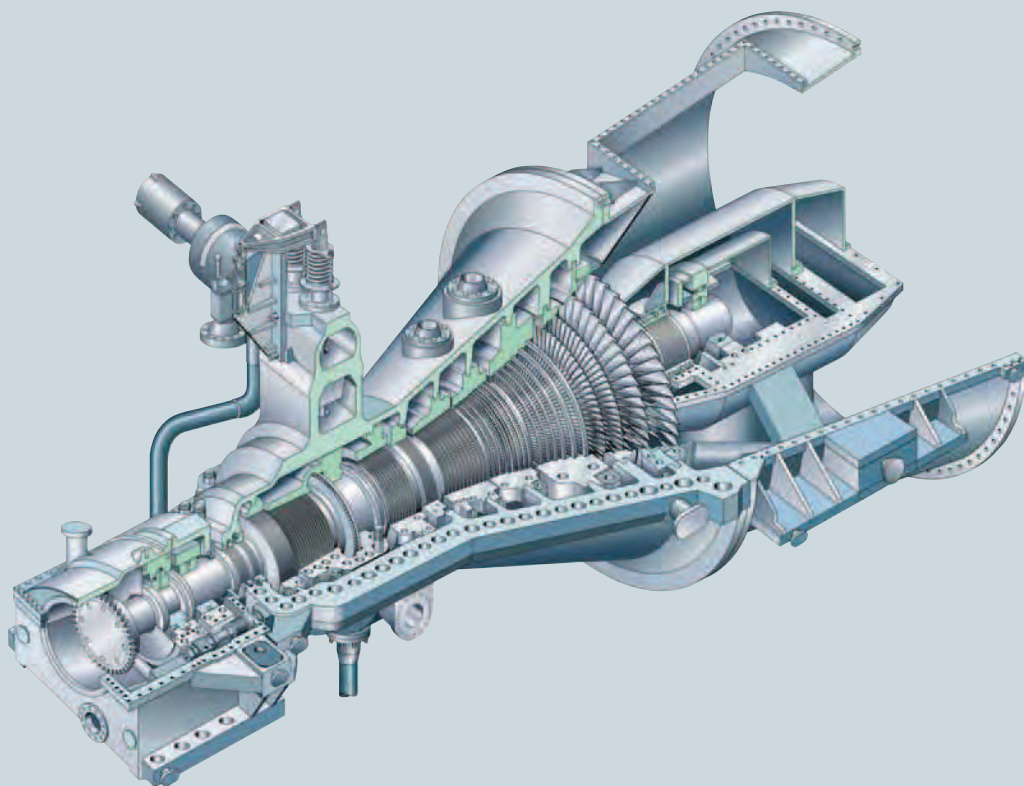
hot path, and specially selected auxiliary support systems account for leading-edge reliability. Lowered combustion temperatures and enhanced hot-gas path components enable long service intervals, while dedicated service concepts allow for short service times.

### High load gradients

Integrated control systems, a unique rotor design, a fast inlet guide vane (IGV) control at the gas-turbine compressor inlet, a steep thermal load gradient and thermal reserves in the firing temperature result in load gradients of more than 10 MW per second.

### High tolerance to inert and low-BTU gas

Fuel gas of an LNG process plant often has a very high inert-gas content. The selected engines with modified burners have a high tolerance to inert gases — up to 40 percent nitrogen ( $N_2$ ) — and show stable operation over the entire range of specified fuels without changing the burner mode.



SST-800: A single-casing direct-drive steam turbine ideally suited for combined-cycle E-LNG power plants.

## Steam turbines

Outperforming conventional simple-cycle schemes with a 40 percent improvement in thermal efficiency and reducing greenhouse-gas emissions by about 30 percent, Siemens combined-cycle power plants allow taking full advantage of the economic benefits offered by the E-LNG concept. Steam turbines distinguished by superior overall efficiency and proven suitability for industrial applications are employed.

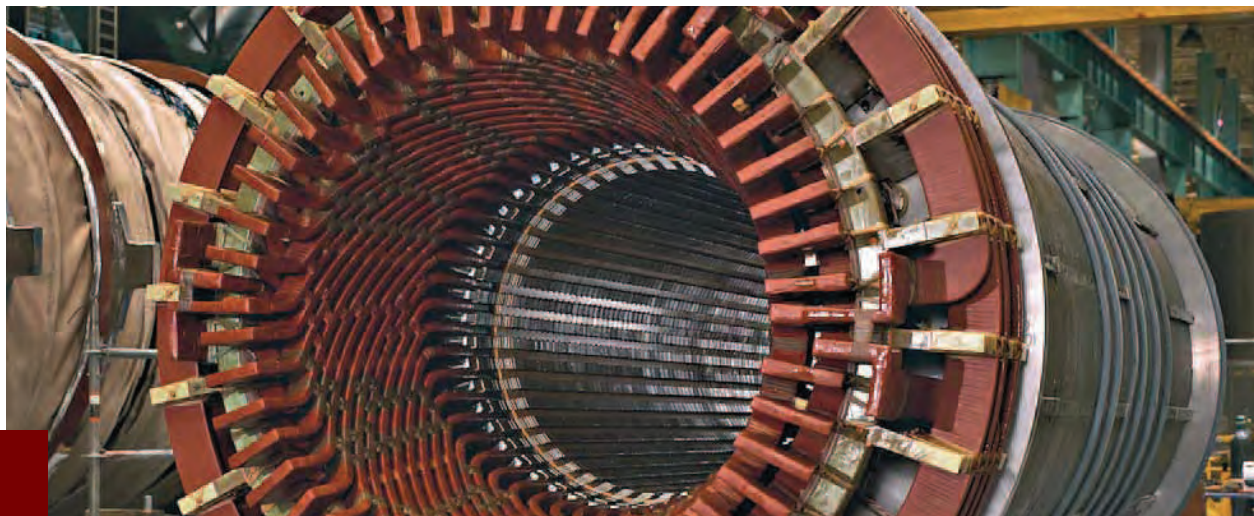
High-pressure steam produced in the heat recovery steam generator (HRSG) attached to each gas turbine is fed to a skid-mounted Siemens condensing steam turbine SST-800 directly driving a two-pole synchronous generator. Extraction turbines are used if process steam is also required, e.g. for boiling the amine fluid of the gas-processing plant. Exhaust steam flows axially or radially into shell-tube type condensers with either water or air-cooling, typically installed indoors behind the turbine, or outdoors close to the turbine hall.

### Excellence in industrial service

The SST-800 single-casing center-admission steam turbine has an impulse control stage, and reaction blades inside

removable blade carriers in the power section. Even though it is maintenance free for the 5+ years operating regimes in LNG liquefaction plants, the SST-800's horizontally-split casing allows for easy access to the rotor and the blade carriers. Simplifying installation and minimizing commissioning time, the turbine is of a standardized, modular design. It can be optimally matched to the thermo-dynamic data of the HRSG with live steam pressures of up to 140 bar and temperatures of up to 540 °C. Based on a century of experience within Siemens, more than 50 steam turbines of this design are successfully operating worldwide.





Proving their credentials every day in more than 500 industrial and utility power-generation facilities around the world, Siemens synchronous generators are the quintessential choice for E-LNG power plants.

## Synchronous generators

The E-LNG concept promises superior overall efficiency. Employing proven technology, Siemens generators effectively live up to that promise. Turbine torque is converted to electric power in directly coupled standard air/water-cooled SGen 100A-2P two-pole synchronous generators with static excitation. More than 500 of these type-tested machines have been built in the past decades. They produce up to 165 MW at either 50 or 60 Hz, at a voltage level of typically 11 or 13.8 kV.

### Efficiency up to 98.7 percent

The vacuum-pressure impregnated (VPI) stator winding is indirectly cooled using the stator core as a heat sink, resulting in an efficiency of 98.7 percent, low noise, and totally maintenance-free operation for the 5+ year operating regime in LNG liquefaction plants. Class F insulating materials are used but utilized to Class B according to IEC 34-1 only. The rotor-bearing-stator assembly is supported by a solid welded steel-base frame of the box-type that — in combination with the fully assembled shipment — eases transportation, installation, and alignment to the turbine. A symmetric two-sided internal cooling-air stream is driven by two shaft-mounted axial fans and provides for efficient transfer of losses from the windings to built-in air-water heat exchangers, and for even thermal expansion of the rotor. In air-cooled liquefaction plants, generator cooling water is re-cooled to ambient air temperature using standard non-API fin-fan cooler banks. Electrical connections to the generator circuit breaker and unit transformers are via segregated-phase insulated bus bars.



The short power connections from generator terminals to unit transformers utilize insulated phase-segregated busbars for maximum safety and reliability.

## Power transmission and distribution

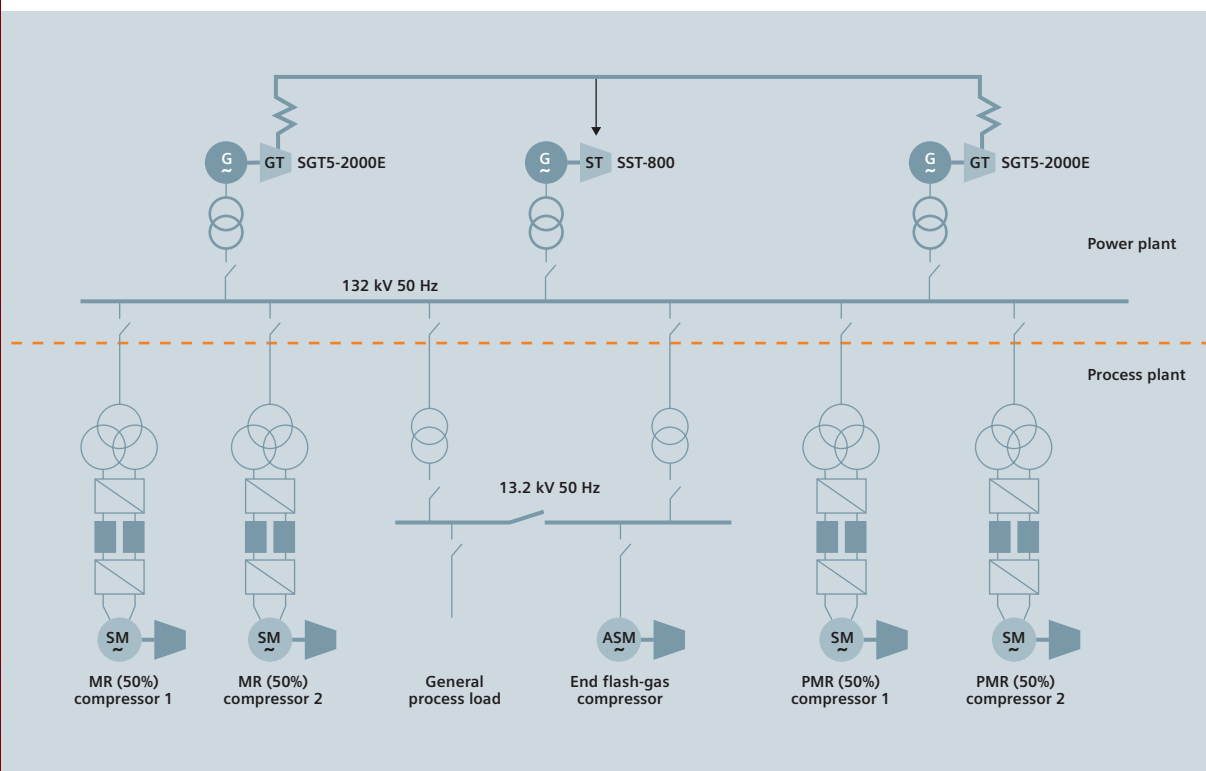
To cope with the large amounts of electric power required by the refrigeration-compressor drivers and short-circuit currents in the electrical system, E-LNG plants call for state-of-the-art high-voltage transmission systems with an excellent 30+ years service history. For maximum reliability and complete freedom of maintenance, Siemens uses fully encapsulated gas-insulated switchgears (GIS) in voltage ratings of typically 132 or 230 kV.

The high-voltage power transmission and distribution system forms an integral part of Siemens' E-LNG concept and its electrical distribution system. It is fully protected with microprocessor-based relays, and centrally controlled and monitored by the superimposed electrical network monitoring and control (ENMC) system. The equipment is maintenance free for 10+ years. As it is not normally possible to initiate and propagate arcing faults inside the gastight and grounded compartments, single busbar systems are preferred. Installed in lightweight site-erected buildings with a minimal footprint, the GIS is fully weather-protected. The SF6 puffer-type circuit breakers with spring or electro-

hydraulic operating mechanism are extremely reliable and maintenance-free. Harmful gas leakages from the GIS are virtually impossible.

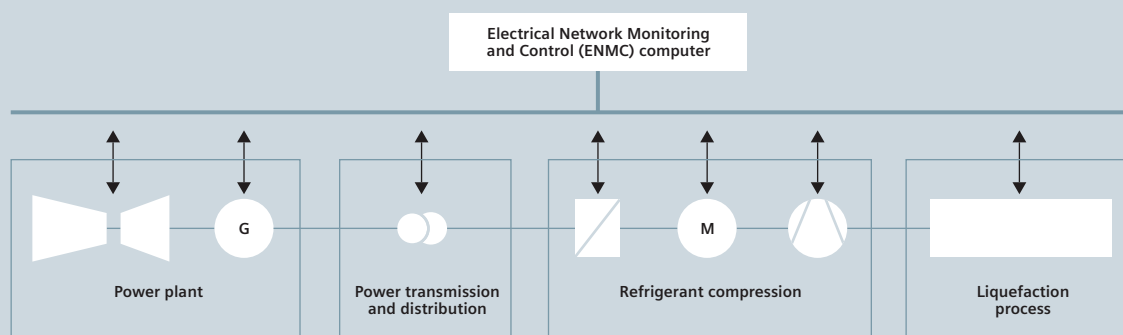
### Designed to last

Climate control is required for the electronic control and protection equipment only, which is installed in the same pre-fabricated modules as the motor-compressor and the power-plant supervisory control equipment. The high-voltage sides of the unit transformers at the generators and the converter transformers at the compressor-driver side are connected to the GIS by single-phase shielded cross-linked polyethylene (XLPE) insulated power cables which are directly buried in the ground, or laid in covered concrete trenches. These high voltage cables are generally protected by optical pilot-wire differential relays; their conductor size is determined using sophisticated finite element analysis (FEA) thermal analysis tools. In general, the oil-filled unit and converter transformers are naturally cooled (ONAN) for added reliability, with sealed oil systems and additional protection equipment.



High-voltage power distribution systems with gas-insulated switchgear (GIS) provide an absolutely safe and maintenance-free subsystem.

GT – gas turbine  
ST – steam turbine



Siemens' superimposed electrical network monitoring and control computer (ENMC) monitors all major electrical loads in order to keep the power-system frequency stable.

## Stability

Power systems for E-LNG plants exhibit an unusually low ratio of generating capacity to single electrical loads. Typically, the power consumption of some very large motors is distributed over a few generators, resulting in a low CAPEX and a highly reliable system. The main challenge is to maintain a stable power-system frequency under all circumstances. Stability in this context is essentially defined as keeping the power-system frequency within the limits set by the gas-turbine speeds.

The Siemens E-LNG concept is based on an  $n+1$  power-plant design: All gas and steam turbines in service operate permanently at part load, and the  $n$ -units assume full load within a very short time in the event of an unexpected shutdown of the surplus turbogenerator. Redistributing the load onto the operational turbogenerators is a key to liquefaction-compressor stability.

### Understanding the stability challenge

In-house simulation tools allow Siemens to accurately predict and document the stability of the E-LNG power system under single-fault conditions, within specified environmental and operating conditions, and fuel supplied to the power plant according to agreed parameters. Electronic variable speed drive systems (VSDS) employed to drive the main refrigerant compressors can function as negative spinning reserve in the power rebalancing process; they can reduce their speed (and thus their power consumption) instantaneously upon the unexpected loss of a turbogenerator in the power plant. The amount of negative reserve is determined by the momentary compressor stability line.

Siemens' stability solution is based on the following principal functions: fast signal and data exchange between all control and protection systems of the power-to-compression system; intelligent use of positive and negative spinning

load reserves; modified gas-turbine IGV controls, pre-control systems; and a dedicated superimposed electrical network monitoring and control system (ENMC, patent pending).

### Mitigating side effects

Electronic VSDS are non-linear electrical loads on the electrical system. As such they can exhibit side effects in the form of power-line harmonics, inter-harmonics, oscillating torques in the drive motors, and possible electromagnetic interferences (EMC) throughout the electrical system. Siemens has developed effective mitigation measures for all these unwanted effects. Passive harmonic filters are custom-engineered for each project. The effects of inter-harmonics are simulated, and corrections in control strategies are implemented if necessary. Oscillating torques in motor-compressor strings are damped sufficiently by design measures and rotor inertia. Effects of active and passive electromagnetic interferences on the entire electrical distribution system are investigated and solutions developed at the Siemens EMC research center, the largest of its kind in Europe.

### Ensuring quality from component to system level

Full lateral and torsional analyses according to international standards are performed in-house and documented for each rotating string prior to detail design. API vibration criteria and tests are generally applied to motor-compressor strings. Electrical stability of the power system, load-flow and short-circuit calculations, protection coordination, and load-shedding scenarios based on specified emergency shut-down (ESD) actions are routinely determined by our system engineers and made available to our clients and their consultants.



The Siemens Geregu project, an open-cycle power plant owned by NEPA in Nigeria. A full turnkey greenfield project based on three SGT5-2000E gas turbines delivering 420 MW at site conditions in base-load operation. The project was commissioned ahead of schedule and is one of the most reliable power producers in Nigeria.



The ESBI 500 MW combined-cycle power plant at Poolbeg, Ireland. The plant employs two SGT5-2000E gas turbines and one steam turbine. Specific features include fast inlet guide vanes for grid-frequency control. With this technical capability, Siemens is in a position to offer extremely steep load gradients, enhancing grid stability. Seawater cooling is used to condense the exhaust steam.



The Al Ezzel combined-cycle power plant of AEPC company in Bahrain with four SGT5-2000E gas turbines and two steam turbines was completed in 2007. Total electrical output is close to 1000 MW and accounts for one-third of the total capacity available to the Bahrain grid. The EPC contract executed by Siemens on a turnkey basis was accomplished on time within 29 months.



The Jebel Ali "G" facility of DEWA in Dubai, UAE, is a combined-cycle power plant based on four SGT5-2000E gas turbines with 500 MW rated power. In order to increase the overall efficiency, the plant is designed as an integrated power and desalination installation. Steam is extracted from the combined-cycle process to feed the multi-stage flash evaporators of the desalination process. Supplementary firing provides for balance between power and steam. The turnkey project was executed on a consortium basis with the desalination supplier, with Siemens acting as consortium leader.



The 1000-MW AzZour power plant in Kuwait uses eight SGT5-2000E gas turbines in simple-cycle mode. The design features of the plant have been carefully considered in order to reach an optimum balance between capital cost, plant performance, and operation and maintenance requirements. Equipped with hybrid burners for using both gas oil and fuel gas with dry low-NO<sub>x</sub> operation, the eight gas turbines are located in one single 275 meter long turbine hall, with provisions for later conversion to combined cycle. The schedule required a significant undertaking in logistics. In January 2004, more than 30,000 tons of freight had to be shipped to site within just two weeks.



Further information can be obtained  
from our offices and representatives  
or from  
Siemens AG  
Energy Sector  
E-mail: [oil-gas@siemens.com](mailto:oil-gas@siemens.com)  
[www.siemens.com/oil-gas](http://www.siemens.com/oil-gas)

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