Solar® Turbines

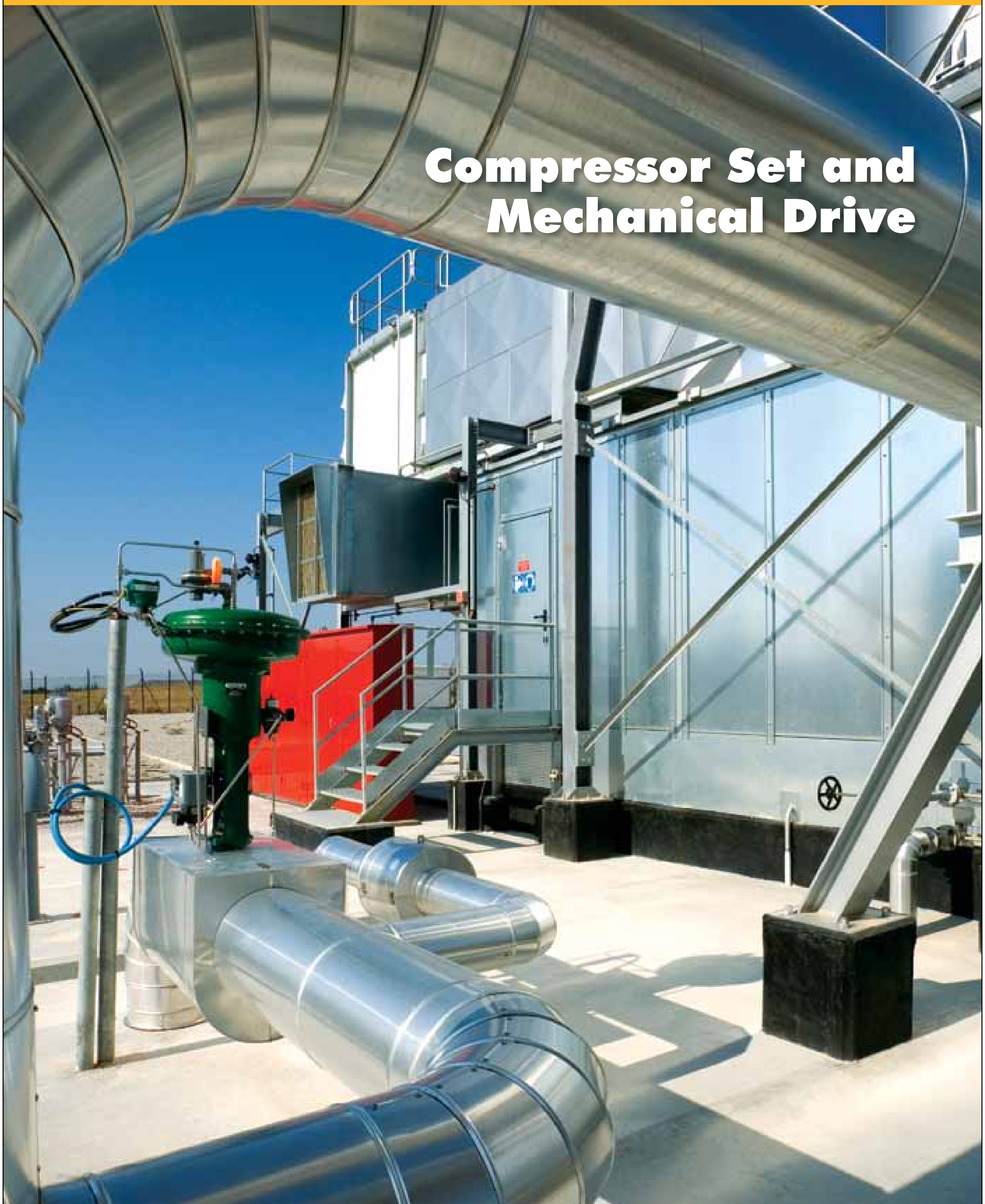
A Caterpillar Company

TAURUS 60

Turbomachinery Package Specification

Oil & Gas Applications

Compressor Set and Mechanical Drive



TURBOMACHINERY PACKAGE SPECIFICATION

Taurus™ 60 Compressor Set and Mechanical Drive

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TPS60CSMD/309

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1 Introduction

1.1 General Description

Solar Turbines Incorporated is a worldwide leader in the design, manufacture, and installation of industrial gas turbines. Solar's 40 years of experience integrating high technology with fluid compression, liquid pumping, power generation, and cogeneration applications has resulted in more than 12,500 gas turbine installations in 93 countries around the world. *Solar* gas turbine packages have logged more than 1.3 billion operating hours around the world in a wide range of applications. *Solar* gas turbine packages are complete packaged systems that require a minimum of site preparation prior to installation.

Taurus 60 compressor sets and mechanical drives represent years of intensive engineering and manufacturing design. Solar gas turbines are manufactured to rigid industrial standards and are thoroughly tested in modern facilities. Solar's operations are certified by Det Norske Veritas (DNV) to conform to International Standardization Organization (ISO) 9001:2000 Standard for Quality Management Systems.

1.2 Overview

This document describes product features and provides turbomachinery package specifications for *Taurus* 60 compressor sets and mechanical drives. Presented within this booklet are basic package configurations, ancillary descriptions, installation requirements, and a list of customer support services available at the time of publication. Please note that changes in equipment, service descriptions, and specifications may occur without prior notice.

1.3 Terminology

In describing different package configurations, Solar uses the term "Mechanical Drive" to cover the gas turbine packaged on a skid with all the required accessory equipment required for operation. The term "Compressor Set" is used when the mechanical drive package is combined with a *Solar* gas compressor packaged on its own skid. Compressor Sets are fully integrated packages, although the driver and driven packages may be shipped separately for logistical reasons. When the mechanical drive is provided for use with a third party's driven equipment, typically either a gas compressor or a pump, Solar will work with the driven equipment supplier to ensure that the two packages are properly interfaced. Control and monitoring of the driven equipment is usually in Solar's scope of supply and will be integrated into the *Turbotronic* control system.

2 *Taurus* 60 Gas Turbine Mechanical Drive

2.1 General Description

The *Taurus* 60 gas turbine mechanical drive package is completely integrated and fully operational, equipped with the accessories and auxiliary systems required for operation. In addition to the standard package features, a wide array of optional equipment is available to meet customers' installation and operation requirements. The driver package can be combined with one or more *Solar* centrifugal gas compressors to form a complete compressor set (see section 4) or it can be used to drive other manufacturers' gas compressors or pumps (see section 5). Designed specifically for industrial service, *Taurus* 60 packages are compact, lightweight units requiring minimal floor space for installation. Proven packaging designs greatly reduce installation costs, time, materials, and labor. Figure 1 shows a side view of a typical *Taurus* 60 Mechanical Drive package.

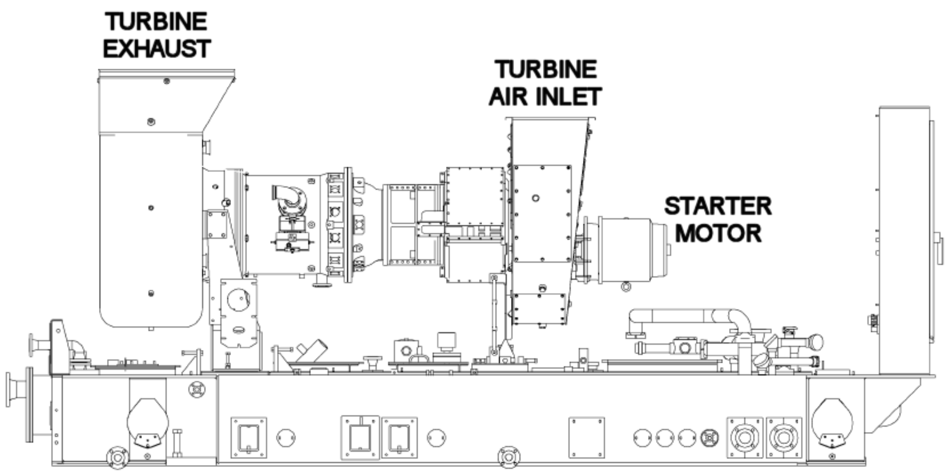


Figure 1. Typical Taurus 60 Gas Turbine Mechanical Drive

2.2 Package Description

The *Taurus* 60 gas turbine package is installed on a steel base frame referred to as the skid. The skid is a structural steel assembly with beam sections and cross members welded together to form a rigid foundation. Drip pans are included to collect any potential liquid leakage. Package connection points for fuel, lube oil, air, and water are located on the outer edge of the skid. Electrical connections are made in on-skid junction boxes. Machined mounting surfaces on the base frame facilitate component alignment. Major Components and Systems

Major components and systems of the *Taurus* 60 mechanical drive package typically include:

- Gas turbine
- Start system
- Fuel system
- Lubricating oil system
- *Turbotronic* 4 Control System
- Onskid electrical wiring
- Skid with drip pans
- Piping and manifolds

- Ancillary air inlet system
- Ancillary exhaust system
- Package enclosure (if specified) with:
  - Ventilation system
  - Fire detection and suppression system
  - Combustible gas detection

2.2.1 Package Electrical System

The onskid package electrical system can be furnished to meet the following certification requirements:

- National Electrical Code (NEC)
- Canadian Electrical Code (CEC)
- Conformité Européenne (CE) Mark (includes compliance to the ATEX directive)
- European Committee for Electrotechnical Standardization (CENELEC)

When supplied, the off-skid control console, variable frequency drives, and battery charger are not approved for hazardous duty areas and must be installed in a nonhazardous area.

Three-Phase Motor Voltage

All three-phase motors and three-phase electrical components have the same voltage rating. Motor starters and contactors are not provided.

2.2.2 Service Connections

The Taurus 60 Mechanical Drive is supplied with self-contained systems for starting, fuel, lube oil and control. All service connections (Figure 2) are conveniently located on the outer edge of the skid.

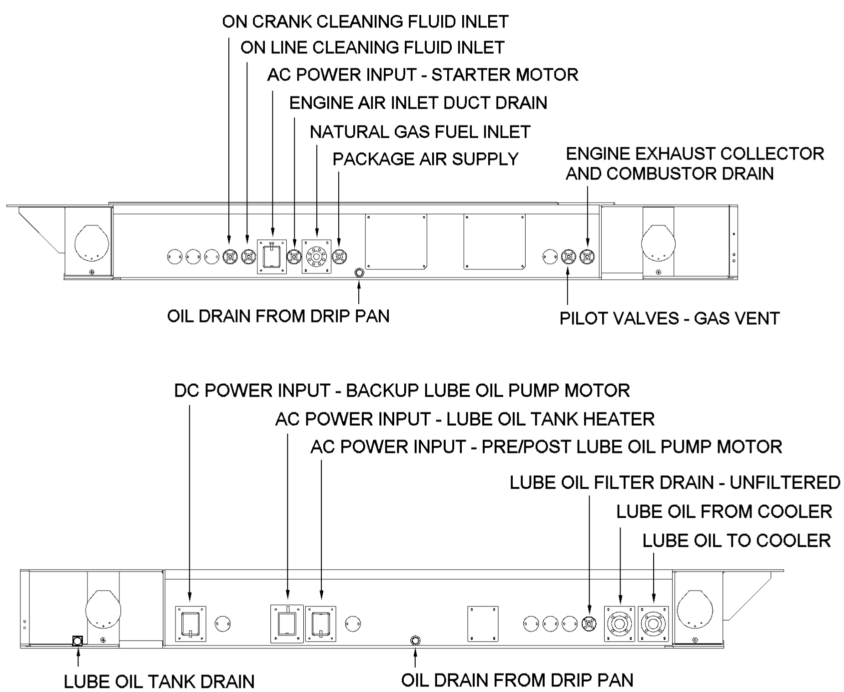


Figure 2. Typical Taurus 60 Mechanical Drive Service Connections

Table 1. Package Specifications

Dimensions		
Approximate Package Measurements		
Height, Unenclosed	2.72 m	(8 ft 11 in.)
Height, Enclosed	3.20 m	(10 ft 6 in.)
Width (to skid edges)	2.46 m	(8 ft 1 in.)
Width (including lifting bollards)	2.59 m	(8 ft 6 in.)
Length, Engine Skid	6.02 m	(19 ft 9 in.)
Approximate Package Weights		
AC Start Motor Assembly	370 kg	(820 lb)
Pneumatic Start Assembly	260 kg	(570 lb)
Gas Turbine Assembly (*SoLoNOx*)	3290 kg	(7250 lb)
Total Driver (unenclosed package, without oil)	15 422 kg	(34,000 lb)
Total Driver (enclosed package, with oil)	20 607 kg	(45,430 lb)
Piping and Tubing Thickness		
Piping $\geq$ 76.2 mm (3 in.) Nominal Pipe Size (NPS)	Schedule 40 (Unless Otherwise Specified)	
Piping $\leq$ 50.8 mm (2 in.) NPS	Schedule 80 (Unless Otherwise Specified)	
Tubing 3.175 mm (0.125 in.) Nominal Tubing Size (NTS)	0.889 mm (0.035 in.) Minimum Wall Thickness	
Tubing 6.35 mm (0.25 in.) NTS	1.245 mm (0.049 in.) Minimum Wall Thickness	
Tubing 12.7 mm (0.500 in.) NTS	1.651 mm (0.065 in.) Minimum Wall Thickness	
Tubing 19.05 mm (0.75 in.) NTS	1.651 mm (0.065 in.) Minimum Wall Thickness	
Tubing 25.40 mm (1.00 in.) NTS	2.108 mm (0.083 in.) Minimum Wall Thickness	
Tubing 31.75 mm (1.25 in.) NTS	2.768 mm (0.109 in.) Minimum Wall Thickness	
Construction Materials		
Piping, Manifolds, and Tubing < 10.2 cm (4 in.) Note (a)	316L Stainless Steel (Unless Otherwise Specified)	
Piping, Manifolds, and Tubing > 10.2 cm (4 in.) Note (a)	Carbon Steel (Unless Otherwise Specified)	
Piping Interface Connections	316L Stainless Steel (Unless Otherwise Specified)	
Flange Assembly Hardware	316L Stainless Steel	
Pipe Support Brackets	Carbon Steel (Standard) 316L Stainless Steel (Optional)	
Pipe Flexible Couplings	Carbon Steel (Standard) 316L Stainless Steel (Optional)	
Tubing Dual Ferrule Compression Fittings	316L Stainless Steel	
Sliding Lube Oil Drain Couplings and Plates	Carbon Steel (Standard) 316L Stainless Steel (Optional)	
Lube Oil Vent Flame Arrestor	Carbon Steel (Standard) 316L Stainless Steel (Optional)	
Electrical System Certifications		
NEC	Class 1, Group D, Division 1 or 2	
CENELEC	Zone 1 or 2, Group II	
CE, ATEX	Zone 2, Group II	
Three-Phase Package Motors		
Optional Motor Voltage Ratings	380, 400, or 415 VAC, 50 Hz 460 VAC 60 Hz	
Single-Phase Battery Charger		
Optional Battery Charger Voltage Ratings	220, 230, 240, 380, 400, 415, 440, 460, or 480 VAC, 50 Hz or 60 Hz	

Single-Phase Lighting and Space Heater Voltage	
Optional Package Lighting and Space Heater Voltage Ratings	120, 220, 230, or 240 VAC, 50 Hz or 60 Hz
Ingress Protection (IP) Ratings	
Onskid Junction Boxes	IP56 to IP66
Control Console	IP50
Battery Charger, NEC	IP22
Battery Charger, CE	IP31

Solar's Applicable Engineering Specifications	
ES 9-56	Fusion Welding
ES 9-58	Standard Paint Program – Turbo Machinery
ES 1593	Guidelines for NEC Compliance of Solar's Product Lines: Class I, Group D, Division 1 and Division 2
ES 1762	Standards and Practices for Electrical Systems for Gas Turbine Packages Installed In Hazardous Areas (CENELEC/IEC Standards – European ATEX Directive 94/9/EC)
ES 2201	Auxiliary Air
ES 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cables Installed In Class 1, Division 2 Hazardous Areas
Solar's Applicable Product Information Letters	
PIL 127	Product Certification
PIL 140	Dry Gas Face Seals for *Solar* Compressors

Notes:

(a) All package piping is fabricated from 316L stainless steel with the exception of lube oil vent lines and any piping welded directly to a carbon steel lube oil tank or tank cover.

3 *Taurus* 60 Gas Turbine

3.1 General Description

The two-shaft *Taurus* 60 gas turbine (Figure 3) is a completely integrated and self-contained prime mover. The gas turbine combines high performance operation with rugged industrial construction. This design philosophy allows for high efficiency, low maintenance, and a long service life. The *Taurus* 60 gas turbine is designed for a high degree of compliance with American Petroleum Institute (API) requirements.

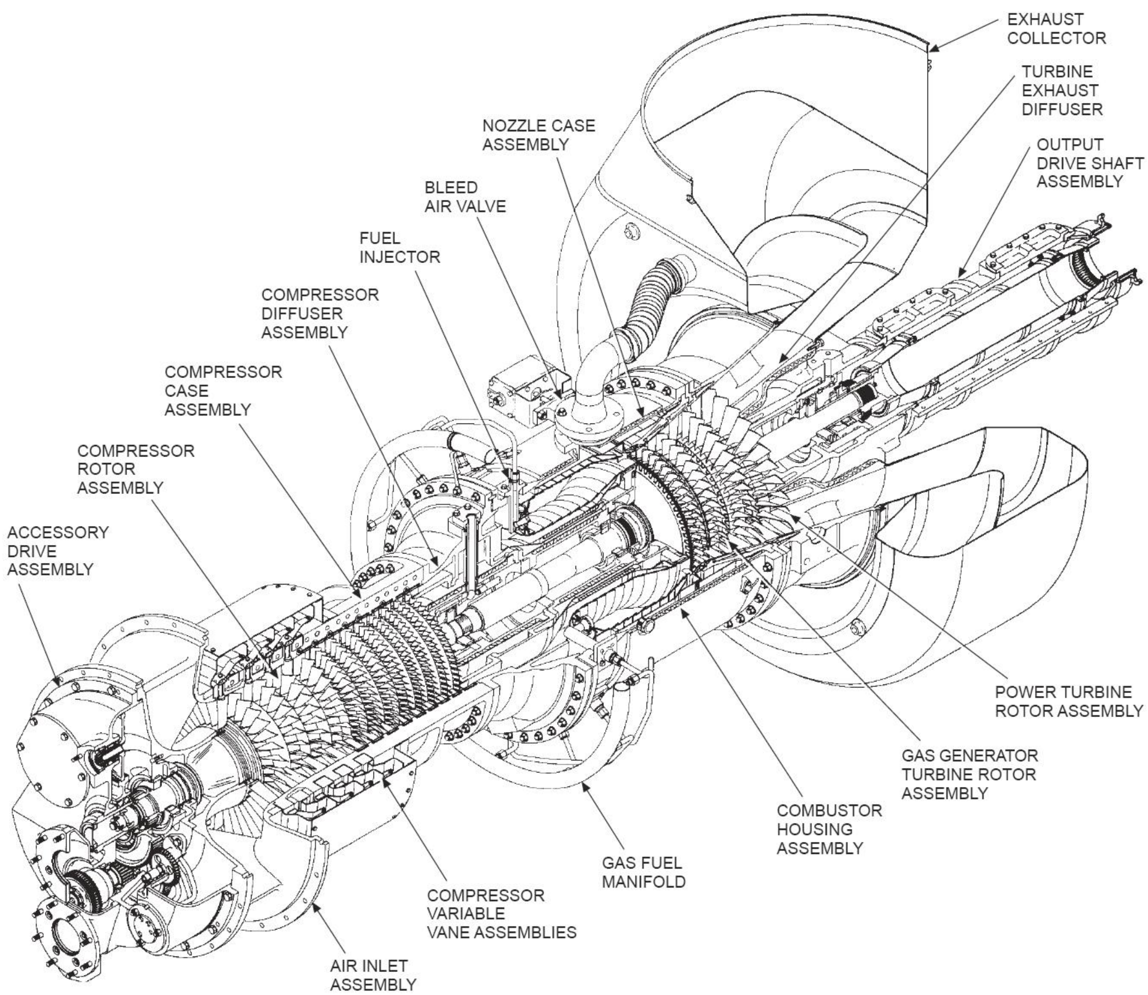


Figure 3. Typical Taurus 60 Two-Shaft Gas Turbine

3.1.1 Principles of Operation

During the typical combustion process (Figure 4), air is drawn into the gas turbine air inlet and is compressed by the multi-stage, axial-flow engine compressor. The compressed air is directed into the annular combustion chamber at a steady flow. Fuel is injected and mixed with the compressed air and ignited during the start cycle. Continuous combustion will be maintained as long as there is an adequate flow of pressurized air and fuel. Hot-pressurized gas from the combustor expands through and drives the turbine, dropping in pressure and temperature as it exits the turbine. This combustion cycle converts the energy in the fuel into kinetic rotating power at the turbine output shaft.

For combustion, the gas turbine requires approximately one-fourth of the total air it compresses. The excess air is mixed with the combustion products to reduce the gas temperature at the turbine first stage-inlet. The cooling air also keeps metal temperatures in the combustor and turbine assembly relatively low to ensure a long service life.

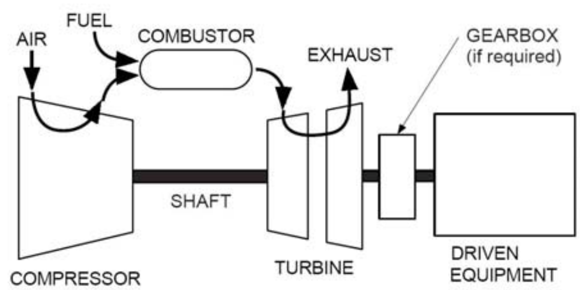


Figure 4. Typical Combustion Process

3.1.2 *SoLoNOx* Combustion System (Optional)

In addition to the conventional combustion system, Solar's proprietary *SoLoNOx* dry emissions system reduces pollution by limiting the formation of nitrous oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (UHC). This system uses lean premix combustion to lower the maximum flame temperature and reduce pollution formation. Solar's engineering staff works with customer's to meet local permitting emission requirements.

Table 2. Taurus 60 CSMD Gas Turbine Specifications

<table>
<tr><th colspan="2">Compressor</th></tr>
<tr><td>Type</td><td>Axial Flow</td></tr>
<tr><td>Number of Stages</td><td>12</td></tr>
<tr><td rowspan="2">Compression Ratio</td><td>12.2:1 (Compressor Set)</td></tr>
<tr><td>11.5:1 (Mechanical Drive)</td></tr>
<tr><td rowspan="2">Flow (Nominal)</td><td>21.3 kg/sec (47.0 lb/sec) (Compressor Set)</td></tr>
<tr><td>21.1 kg/sec (46.5 lb/sec) (Mechanical Drive)</td></tr>
<tr><th colspan="2">Combustion Chamber</th></tr>
<tr><td>Type</td><td>Annular</td></tr>
<tr><td>Ignition</td><td>Torch</td></tr>
<tr><td>Number of Fuel Injectors</td><td>12</td></tr>
<tr><th colspan="2">Gas Producer Turbine</th></tr>
<tr><td>Type</td><td>Reaction</td></tr>
<tr><td>Number of Stages</td><td>2</td></tr>
<tr><td>Maximum Speed</td><td>15,000 rpm</td></tr>
</table>

Power Turbine	
Type	Reaction
Number of Stages	2
Maximum Speed	14,300 rpm
Bearings	
Radial	3 Tilt Pad with Proximity Probes
Thrust	1 Tilt Pad with Resistance Temperature Device Probes
Construction Materials	
Compressor Case	
Forward Section	Nodular Iron
Aft Section	WC6 Alloy Steel
Combustor Case	410 Stainless Steel
Exhaust Diffuser	Nodular Iron
Accessory Gear Housing	Ductile Iron
Protective Coatings	
Compressor Rotor and Stator Blades	Inorganic Aluminum
Nozzles, First and Second Stage	Precious Metal Diffusion Aluminide
Blades, First and Second Stage	Precious Metal Diffusion Aluminide
Performance	
Output Power	5740 kW (7700 hp), **See Note (a)**
Heat Rate	11 265 kJ/ kW-hr (7960 Btu/ kW-hr)
Exhaust Flow	77 880 kg/hr (171,690 lb/hr)
Exhaust Temperature	510°C (950°F)
Vibration Monitoring	
Turbine Bearing #1	Displacement Probes, X and Y axis
Turbine Bearing #2	Displacement Probes, X and Y axis
Turbine Bearing #3	Displacement Probes, X and Y axis
Turbine Bearing #4	Displacement Probes, X and Y axis
Turbine Bearing #5	Displacement Probes, X and Y axis
Turbine Rotor Shaft	Displacement Probe, Axial Position
Turbine Rotor Shaft	Keyphasor

Notes:

(a) Performance on gas fuel is calculated under the following conditions:
Nominal Rating - ISO at 15°C (59°F), Sea Level
No Inlet/Exhaust Losses
Relative Humidity at 60%
LHV = 31.5 to 43.3 MJ/nm^3 (800 to 1,100 Btu/scf)

4 *Solar* Compressor Set Packages

4.1 Compressor Set Packages

Solar offers complete and fully integrated compressor set packages with the *Taurus* 60 gas turbines driving one or more *Solar* centrifugal gas compressors (Figure 5). The packages are fully operational and include all the necessary accessories, auxiliary and control systems. The compressor sets combine the gas turbine driver with matching integrated centrifugal compressor modules, available in single-body, two-body, or three-body tandem configurations for direct-drive or gear-driven applications. Compressor sets with a single *Solar* compressor can produce pressure ratios of over 3:1 while multiple, tandem-mounted compressors can produce pressure ratios approaching 30:1.

Solar compressor sets are complete with all unique system requirements built into the basic package. This inherent single-source responsibility eliminates any risk of drive train incompatibility or performance questions that may arise when the driver and the driven compressor are built by different manufacturers.

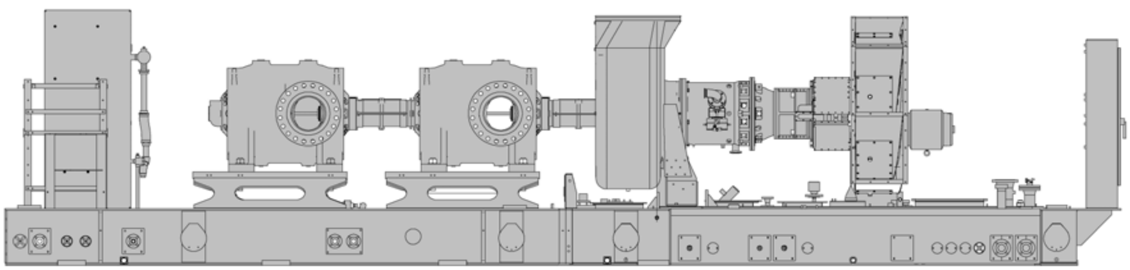


Figure 5. Compressor Set with Taurus 60 Driving Tandem Solar Compressors

4.2 Solar Gas Compressors

Solar offers a broad range of centrifugal gas compressors for both gas production and gas pipeline applications. Table 3 lists the *Solar* compressor products that are suitable for operation with the *Taurus* 60 gas turbine. Solar's approach to compressor design is to maximize simplicity and flexibility. Solar gas compressors are designed to achieve a minimum of three years of continuous full-load duty between inspections, and major components are designed for 20 years of continuous operation. Many features commonly used in *Solar* compressor designs conform to American Petroleum Institute (API) 617.

Standard features include:

- Vertically split barrel-type construction
- Tilt-pad journal bearings
- Self-aligning tilt-pad thrust bearings
- Rigid modular rotor construction
- Rotor trim balancing
- Overcompensating balance piston
- Radial vibration measurement
- Thrust bearing temperature sensors

For more details about *Solar* centrifugal compressors, please consult Solar's engineering for project specific gas compressors. Figures 6 and 7 show the internal construction of typical *Solar* compressors.

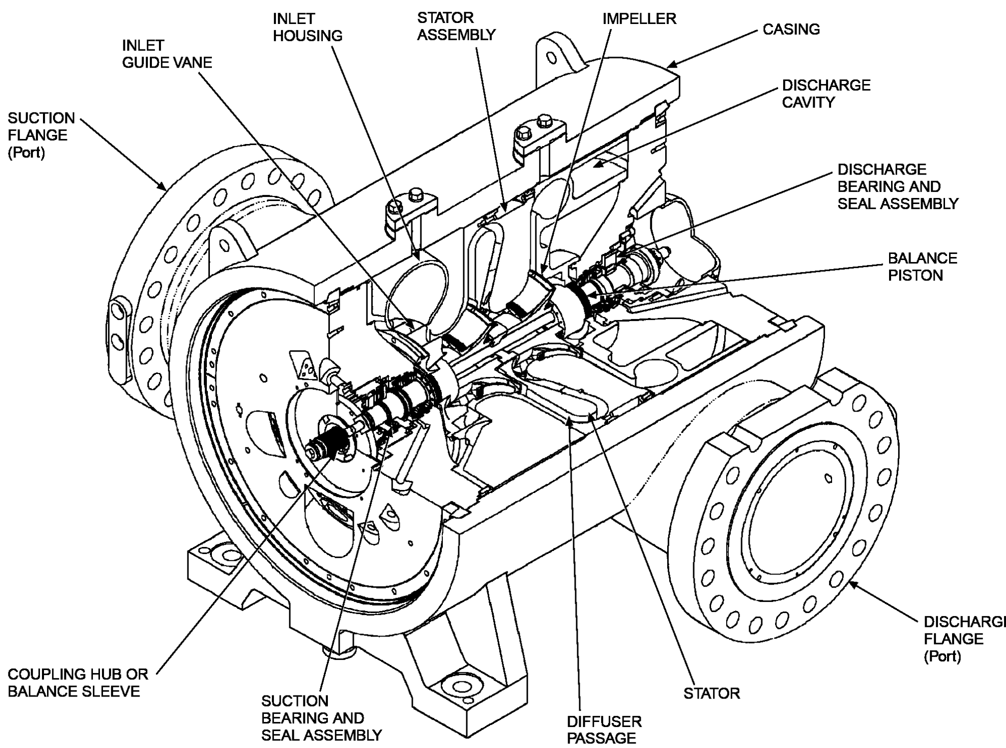


Figure 6. Cutaway Diagram of a Solar Gas Compressor

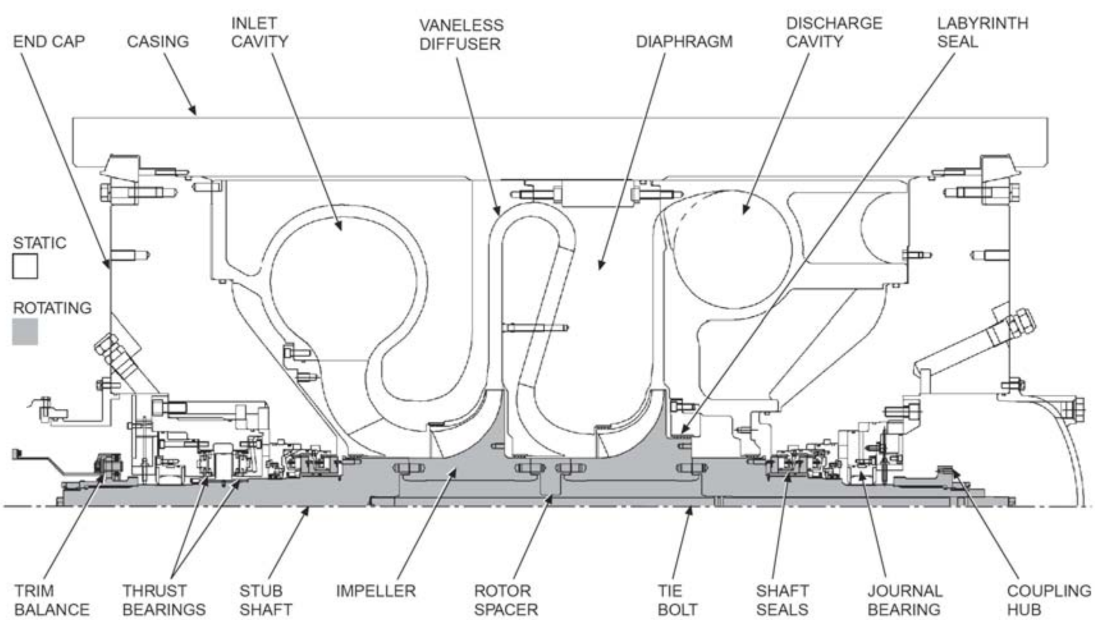


Figure 7. Cross Section of a Solar Gas Compressor

Table 3. Typical Solar Gas Compressors

Compressor Family	Number of Stages	Maximum Pressure Rating		Maximum Flow		Maximum Total Head	
		kPa	psig	m^3/min	ft^3/min	kJ/kg	ft-lb_f/lb_m
For Gas Production Applications							
C16	1-10	20 700	3000	50	1800	215	72,000
C33	1-12	15 510	2250	270	9500	325	108,000
C40	1-6	17 240	2500	255	9000	255	85,000
C50	1-5	10 350	1500	565	20,000	285	95,000
For Gas Pipeline Applications							
C40	1-2	11 040	1600	270	9500	95	32,000

4.2.1 Impellers

Compressor impellers are designed to conservative stress levels. All impellers are suitable for sour gas applications. Each impeller, after machining, is proof tested to 115% of its maximum mechanical speed.

4.2.2 Rotor Assembly

The rotor assembly consists of stub shafts, impellers, and, if required, rotor spacers (to maintain a constant bearing span) and a centerbolt. These components are individually balanced and are rabbet-fit to each other for concentric alignment. Torque is transmitted through dowel pins. The entire assembly is clamped together with the centerbolt. The rotor assembly is easy to disassemble. The benefits from this type of construction are two-fold. Impellers that can be used in a “restaged” rotor are easily salvaged and downtime is minimized. Reusing old impellers, instead of purchasing new ones to match new operating conditions, enhances the economic feasibility of restaging to maintain optimum compressor performance and the lowest possible operating costs.

4.2.3 Casings

The pressure-containing outer casing of a compressor is an assembly of three components: the suction and discharge end caps, which contain the bearing and seal assemblies, and the centerbody, which holds the rotor and stator assemblies. This is considered a vertically split “barrel” design. The end caps contain all the service ports for oil and gas supply and discharge.

4.2.4 Compressor Module

The compressor module includes the centrifugal compressor(s) mounted on a structural steel matching base that, when bolted to the driver skid, forms a continuous base plate on which all the required subsystems are installed.

4.2.5 Lube Oil System

The gas turbine, gearbox (if required), and compressor modules have a common lube oil system.

4.2.6 Compressor Dry Seal System

The dry seal system consists of the seal gas and separation gas systems. The seal system maintains a barrier between the process gas and the compressor bearings. The separation gas system maintains a barrier between the compressor bearing lube oil and the dry gas seals.

Seal Gas System

The seal gas system consists of a primary and secondary gas face seal to prevent the escape of process gas for each shaft end. The primary dry seal takes the full pressure drop. It is used to provide the main sealing function. The secondary or backup seal acts as an emergency barrier between the process gas and the atmosphere and operates at a zero pressure differential.

The system can use clean and dry process gas or an independent clean and dry gas source as seal gas. A customer-furnished separation gas source of air or nitrogen is required to isolate lube oil from the seal gas. The separation gas must be available at all times during lube oil pump operation. Typical seal gas supply flow is 1.34 to 3.35 nm^3/min (50 to 125 scfm) at 689 kPag (100 psig) above maximum suction pressure, depending on the compressor model and suction pressure. The seal gas flow rates are metered by maintaining a constant pressure drop across a flow-limiting orifice in each seal gas supply line to each compressor seal capsule. Differential pressure switches provide low flow alarm and shutdown functions.

The seal gas supply flow is higher than the primary seal leakage. The majority of the seal gas flow travels past the compressor shaft labyrinth seals and into the compressor case. This ensures the dry seal cavity is flushed with clean dry gas and that the dry seal operates in a clean environment. The seal gas may be supplied from the compressor discharge, preferably downstream of the gas cooler, provided the process gas is clean and dry.

The onskid duplex seal gas coalescing filters are designed for typical clean transmission pipeline conditions. If larger particle or liquid loads are expected, a larger off-skid filtration system with a high pressure external seal gas supply is recommended. When the seal gas is supplied from the compressor discharge but the compressor is not operating with a pressure ratio (start-up, shutdown, or pressurized hold), there is no flow of seal gas through the filters. During these times, the gas leakage across the dry seals is raw process gas from the compressor case.

This is normally not a problem on clean transmission pipeline applications; however, it may be an issue on new pipelines during initial operation, or on pipelines handling wet and/or dirty gas. Under these conditions, an external high-pressure seal gas supply is recommended. Leakage past the primary dry seals is measured by monitoring the pressure drop across an orifice run. High leakage flow alarms and shutdowns are provided by pressure switches. Primary and secondary seal vent lines must be vented by the customer to a safe location.

Separation Gas System

A circumferential buffer air or nitrogen circumferential-segmented split-ring type seal provides a barrier between the compressor bearing lube oil and the dry gas seals. It is the most outboard component of the complete seal assembly. Air flows between the seal rings and the compressor stub shaft. Separation gas flowing past the outboard seal mixes with lubricating oil and drains to the lube oil reservoir. Air flowing past the inboard seal is vented through the secondary seal gas/buffer air vent.

The separation gas source may be clean dry shop air, instrument air, or nitrogen. The system includes a hand valve for maintenance, a coalescing filter, a differential pressure regulator, and pressure switches and gauges to monitor the separation gas differential pressure. The system forms a positive separation between the lube oil and the dry seal. Flame arrestors are supplied for the primary and secondary vents. Leakage seal gas and separation gas must be piped away by the customer to selected safe areas.

4.2.7 Hydrostatic Testing

Hydrostatic pressure testing of all compressor casings and end caps is done per API 617 for 30 minutes at 1.5 times the maximum casing design pressure, regardless of application. Test water is treated with a wetting agent to allow better penetration of possible casing defects. After the hydro and final magnetic particle test, the casing is steam cleaned and bead blasted for surface preparation. Afterwards, it is painted per Solar's specification ES 9-58.

4.2.8 Shaft Coupling

Solar's standard shaft interconnect is a Kop-Flex dry coupling.

4.2.9 Preliminary Alignment

The drive train is aligned preliminarily at the factory to simplify final field alignment.

Table 4. Driven Equipment and Associated Equipment Specifications

Typical Driven Skid Weight	
One to Three Compressor Bodies	6800 to 34 000 kg (15,000 to 75,000 lb)
Typical Driven Skid Lengths	
One to Three Compressor Bodies	4.0 to 10 m (13 to 33 ft)
Compressor Inspection Interval	
Major Inspection Interval	Three Years of Continuous Full-Load Duty
Compressor Construction Materials	
Impeller	15-5PH, Type 100
Casing	ASTM A216 GR WCC
Diaphragm/Guide Vane	Alloy Steel
Rotor Spacer	Alloy Steel
Stub Shafts	AISI 4140
Labyrinth	Steel-Backed Babbitt
Compressor Bearings	
Journal Bearing	Tilting Pad
Thrust Bearing	Self Aligning, Tilting Pad
Compressor Vibration Monitoring	
Driver End Bearing	Displacement Probes, X and Y Axis
Driven End Bearing	Displacement Probes, X and Y Axis
Thrust Bearing	Displacement Probe, Axial
Compressor Rotor Shaft	Keyphasor
Seal Gas	
Fluid	Clean Process Gas or Nitrogen
Particle Size	Less Than 2 micron
Minimum Supply Pressure	689 kPag (100 psig) above highest compressor suction pressure but below pressure rating of seal system
Maximum Supply Pressure	13 790 kPag (2000 psig)
Flow	1.3 to 3.3 nm^3/min (50 to 125 SCFM)
Temperature	0 to 93°C (32 to 200°F)
Separation Gas	
Air Quality	Refer to Solar Engineering Specification ES 2201
Supply Pressure	517 to 1344 kPag (75 to 195 psig)
Flow	0.134 nm^3/min (5 SCFM)
Solar's Applicable Engineering Specifications	
ES 9-58	Standard Paint Program - Turbomachinery

5 Mechanical Drive Packages

5.1 Mechanical Drives

The *Taurus 60* gas turbine mechanical-drive package is designed for a variety of driven equipment, including centrifugal pumps and centrifugal, rotary, and reciprocating compressors. The *Taurus 60* gas turbine is well suited to drive pumps and compressors, where its variable-speed capability can be used to advantage in adjusting to changing specific gravity and flow.

Solar's mechanical-drive units are widely used for crude oil or liquid product pumping and water flooding applications. As an option, Solar can provide a gear to match the speed of the driven equipment to that of the gas turbine. The gear can be located either on the driven equipment skid or on a separate skid between the driver and driven equipment skids.

5.1.1 Unitized Packaging

While the gas turbine driver package can be supplied separately for integration by others into a complete system, Solar also offers unitized packages. When a unitized package is supplied, Solar's scope of supply may include the following options:

Driven Equipment

Supplied by original equipment manufacturers in compliance with customer requirements and Solar's procurement specifications.

Mating Baseplate

The separate structural steel driver skid and driven equipment skid (optional) have mating flanges so they can be rigidly bolted together at the installation site. The skids may also be bolted and dowelled together at the factory and then separated for shipment.

Shaft Coupling

Several supplier-furnished shaft coupling styles are available. Coupling hubs may be mounted on both shafts at the factory. A coupling guard is included.

Preliminary Alignment

A preliminary alignment of the gas turbine driver and the driven equipment shafts can be performed at the factory to simplify final field alignment.

Unitized Lubrication and Cooling

On packages using compressors or pumps with sleeve or tilt-pad bearings, the bearings may be force fed with cooled oil from the gas turbine lubrication system. Pumps with anti-friction bearings are usually furnished with self-contained ring oiling and the oil is cooled by the product being pumped.

Unitized Controls

Driven equipment protective devices may be integrated into the package control system to provide alarms and shutdowns for a variety of abnormal operating conditions, including low suction and high discharge pressure, seal leakage, high bearing or case temperature, excessive vibration, or any other measurable quantity. Additionally, driven equipment valving (suction, discharge, bypass, vent) may be integrated into the start-up and shutdown sequence controls, so those valves are automatically actuated and monitored. Additional digital and analog values can also be monitored by the control system.

Single-Source Responsibility

Solar is able to provide overall coordination to ensure that the unitized package will perform to its full potential with a minimum of installation time and cost. Performance characteristics of the driver and driven equipment are analyzed to provide an optimum match at design and off-design conditions. Installation drawings and technical manuals are prepared for customer use, detailing mechanical/electrical interface and alignment instructions. Consistency in surface preparation and painting, preservation, shipment and warranty is ensured by Solar's Quality Assurance.

Unitizing at Installation Site

Solar's Customer Services personnel can interface and unitize the equipment at the installation site as required.

5.1.2 Non-Unitized Packaging

When the gas turbine package is furnished without driven equipment, Solar cannot ensure proper interface between the gas turbine and the driven equipment. Solar is able to offer optional equipment and services, including the following, to facilitate the task of interfacing the gas turbine package with the driven equipment.

Shaft Coupling

The driver coupling hub may be furnished machined and ready for fitting to the shaft by others. The driven equipment coupling hub is pilot bored for machining by others, unless a driven equipment shaft end detail drawing is furnished at the time of order definition. A coupling guard can also be included.

Torsional Vibration Analysis

Solar is able to define operating speeds at which excessive vibration stress in the drive train might occur. Solar should be furnished, at the time of order definition, with mass elastic data for the shaft coupling and the rotating equipment elements, including polar moments of inertia and torsional stiffness. In lieu of mass elastic data, a drawing of rotating elements together with definition of materials may be used.

Lateral Vibration Analysis

Using the same data furnished for the torsional vibration analysis, Solar can define operating speeds at which stress in each piece of rotating equipment, including the turbine gearbox if required, and driven equipment, might occur due to excessive vibration. The data should be provided to Solar at the time of order definition. Once the analysis is completed, a written report is provided.

6 Gearbox

6.1 General Description

If required, a gearbox (Figure 8) can be provided selected specifically for compressor set and mechanical drive applications. The gearbox uses few moving parts, providing high reliability and ease of assembly and disassembly. The gearbox is designed for continuous-duty operation and matches the output speed of the turbine or tandem compressor to the required operating speed of the driven compressor. Gear lubrication is provided by the package lube oil system. The gears can be serviced without removing the main case.

Depending on the application, the gearbox may be primary speed increasing or speed decreasing (between the gas turbine and the first or only driven compressor) or it may be inter-body speed increasing (between tandem compressors).

The gear unit is designed in accordance with American National Standards Institute/American Gear Manufacturers' Association (ANSI/AGMA) standards as described in Solar's specification ES 2238. The gear unit design includes a fabricated steel or cast iron housing, double helical precision hobbed and finished ground gear elements, and split steel-backed babbitt lined journal bearings on all shafts.

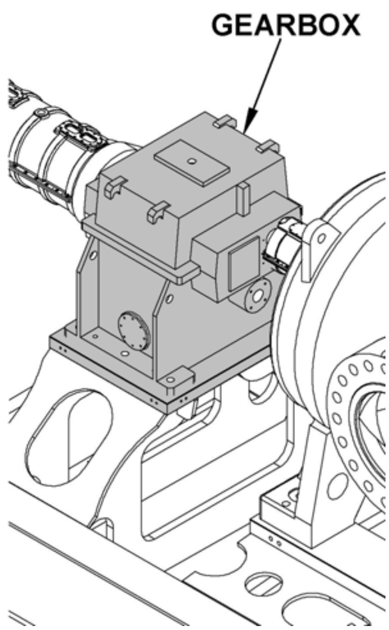


Figure 8. Typical Gearbox

6.1.1 Primary Speed-Increasing Gearbox

The primary speed-increasing gearbox will have a specific gear ratio and speed range. The gearbox increases the output speed of the turbine to the required operating speed of the driven compressor, optimizing the power turbine speed for each application. The gearbox output shaft direction of rotation is counterclockwise, when viewed from the aft (exhaust) end of the package looking forward.

The gearbox is mounted on the driven skid and, together with the input shaft coupling, is lubricated and cooled by forced-fed lubricating oil from the turbine. Gearbox journal and thrust bearing temperatures are monitored by two simplex resistance temperature devices (RTDs) at each radial bearing and two per thrust face on the thrust bearing. The monitoring system is connected to one each of the radial bearing RTDs and one each RTD from each side of the thrust bearing, with the remaining circuits available as spares.

6.1.2 Inter-body Speed-Increasing Gearbox

The inter-body speed-increasing gearbox will have a specific gear ratio and speed range for the tandem compressor set application. The gearbox increases the output speed of the driving compressor to the required operating speed of the driven compressor. The gearbox output shaft direction of rotation is counterclockwise, when viewed from the aft (exhaust) end of the package looking forward towards the air inlet end of the package.

The gearbox is mounted on the driven compressor skid and together with the input shaft coupling, is lubricated and cooled by forced-fed lubricating oil from the turbine. Gearbox journal and thrust bearing temperatures are monitored by two simplex RTDs at each radial bearing and two per thrust face on the thrust bearing. The monitoring system is connected to one each of the radial bearing RTDs and one each RTD from each side of the thrust bearing, with the remaining circuits available as spares.

6.1.3 Primary Speed-Reducing Gearbox

The primary speed reducing gear will have a specific gear ratio and speed range. The speed-reducing gearbox reduces the output speed of the turbine to the required operating speed of the driven equipment, optimizing the power turbine speed for each application. The gearbox output shaft direction of rotation is counterclockwise, when viewed from the aft (exhaust) end of the package looking forward.

The gearbox is mounted on the driven equipment skid and, together with the input shaft coupling, is lubricated and cooled by forced-fed lubricating oil from the turbine. Gearbox journal and thrust bearing temperatures are monitored by two simplex RTDs at each radial bearing and two per thrust face on the thrust bearing. The monitoring system is connected to one each of the radial bearing RTDs and one each RTD from each side of the thrust bearing, with the remaining circuits available as spares.

Table 5. Gearbox Specifications

Approximate Weight	
Gearbox	1100 kg (2400 lb)
Inspection and Overhaul Intervals	
Major Inspection Interval	30,000 hours
Overhaul Interval	100,000 hours
Compliance	
American Petroleum Institute (API)	613 Compliant With Exceptions, Refer to Solar's Standard List of Exceptions
Ratings	
American National Standards Institute/American Gear Manufacturers' Association (ANSI/AGMA)	2001-C95, 6025-D98, 6011-H98 and 6001-D97
Vibration Monitoring	
Gearbox	Acceleration Probe (Optional) Displacement Probes, X and Y axis (Optional) Displacement Probe, Axial (Optional)
Applicable Engineering Specifications	
Solar's Engineering Specification ES 2021	*Solar* Turbine Package Head Loads and Oil Flows
Solar's Engineering Specification ES 2238	Parallel Shaft Gear Units

7 Start System

7.1 General Description

The start system provides torque to initiate engine rotation and to assist the engine to reach a self-sustaining speed. The start system consists of either a direct-drive AC starter motor driven by a solid-state variable frequency drive (VFD) or an optional pneumatic start system.

7.2 Direct-Drive AC Start System

The direct-drive AC (DAC) start system consists of a squirrel cage, three-phase, ac-induction motor with a solid-state variable frequency drive (VFD). The starter motor is mounted directly on the gas turbine accessory drive gearbox. The VFD regulates voltage and frequency to the starter motor for engine rotation as commanded by the *Turbotronic* 4 control system.

7.2.1 Functional Description

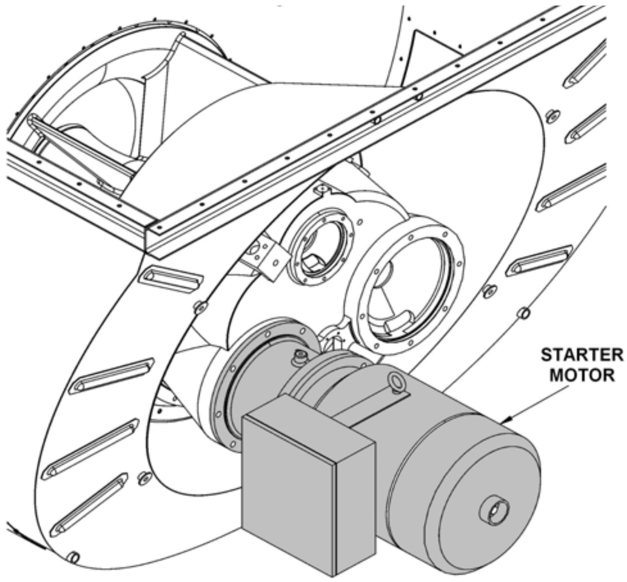
To begin gas turbine rotation, the VFD initially provides low-frequency AC power to the starter motor. The VFD gradually increases the speed of the starter motor until the gas turbine reaches purging speed. When purging is completed, the control system activates the fuel system. The speed of the starter motor is gradually increased until the gas turbine reaches starter dropout speed. The VFD then deenergizes the starter motor and the motor clutch assembly is disengaged.

7.2.2 Starter Motor

The starter motor (Figure 9) provides high breakaway starting torque and acceleration from standstill to starter dropout speed. The motor is standard frame size and is constructed to be explosion proof and flameproof. The motor includes an integral over-temperature protection thermostat connected to the *Turbotronic* 4 control system for hazardous area motor certification and protection. Separate cable/conduit entry points are provided for power connections, thermal protection wiring, and the space heater wiring. Starting power is transferred to the gas turbine via the reduction-drive gearbox and over-running clutch and shaft assembly.

7.2.3 Variable Frequency Drive

The VFD (Figure 9) is a motor speed controller that provides pulse-width modulated power with variable frequency and voltage to the starter motor. Controlled by the *Turbotronic* 4 control system, the VFD regulates voltage and frequency to the starter motor to control engine speed from standstill to starter dropout speed. The system is capable of performing up to six start attempts per hour, as well as extended purge cycles for heat recovery unit applications and engine wash cycles. The VFD cabinet is designed for installation in a non-hazardous location. Electrical disconnects and overcurrent protection devices are not provided.



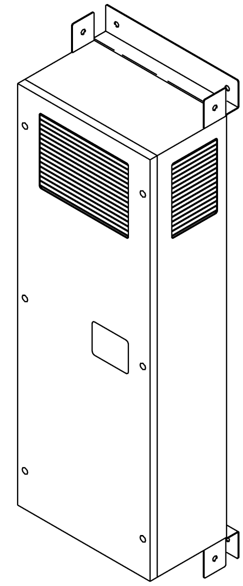


Figure 9. Typical Direct-Drive AC Starter Motor and Variable Frequency Drive

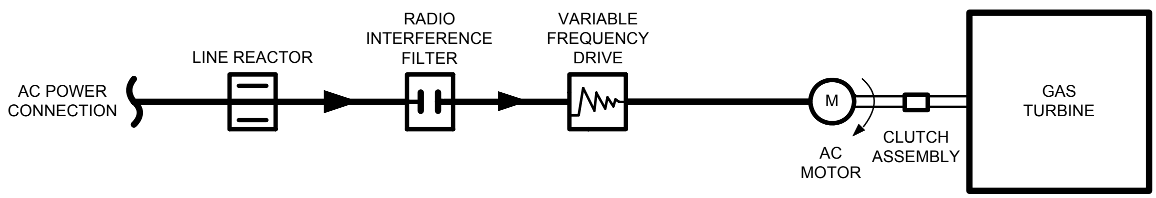


Figure 10. Typical Direct-Drive AC Start System

7.2.4 Power Wiring

The start system, (Figure 10) requires customer-furnished, three-phase AC input. Additional three-phase AC power wiring is required to connect the VFD to the starter motor. A start contactor is not required for VFD operation. A customer-furnished fused disconnect at the VFD input is recommended. Optional motor space heater wiring is available.

Table 6. Direct Drive AC Start System Specifications

Variable Frequency Drive	
Optional Voltage Input Ranges	380 to 460 VAC, (48 to 62 Hz)
Minimum Input Current	
- 380 to 460 VAC Input	525 amps
Voltage Output Range	0 to 460 VAC, (0 to 240 Hz)
Maximum Line Distribution Capacity	1000 kVa
Maximum Fault Current Capacity	30 000 amps, **See Note (a)**
Maximum Breakaway Amperage	383 amps
Maximum Breakaway Torque	918 N-m (677 ft-lb)

Variable Frequency Drive (cont.)	
Power Factor	0.96
Efficiency	98%
Minimum/Maximum Operating Temperature	-10 to 40°C (14 to 104°F)
Heat Rejection	
- 380 to 460 VAC Input	1780 watts
Input Fuse Rating	225 amp
Approximate Measurements	
- Height	85 cm (33.5 in.)
- Width	42 cm (16.6 in.)
- Depth	32 cm (12.7 in.)
Approximate Weight	70 kg (155 lb)
Starter Motor	
Motor Type	Squirrel-cage Induction
Motor Voltage Rating	380 AC, (0 to 133 Hz)
Power	56 kW (75 hp)
Operating Speed	0 to 4000 rpm
Maximum Breakaway Amperage	205 amps
Maximum Breakaway Torque	472 N-m (348 ft-lb)
Minimum/Maximum Operating Temperature	-25 to 60°C (-13 to 140°F)
Space Heater Voltage	120 VAC, 60 Hz 240 VAC, 50 Hz
Approximate Measurements	
- Length	75 cm (29.4 in.)
- Diameter	45.7 cm (18 in.)
Approximate Weight	
- AC Starter Motor Assembly	370 kg (820 lb)
Power Wiring	
VFD to Starter Motors Power Cable Length	38 m (123 ft), **See Note (b)**

Solar's Applicable Engineering Specifications	
ES 1593	Guidelines for NEC Compliance of *Solar* Product Lines: Class I, Group D, Division 1 and Division 2
ES 1762	Standards and Practices for Electrical Systems For Gas Turbine Packages Installed in Hazardous Areas (CENELEC Standards)

Solar's Applicable Product Information Letters	
PIL 149	Direct-drive AC Start Systems

Notes:

(a) Feeder circuits exceeding this limit require the use of an isolation transformer, line reactor, or other means of adding similar impedance to limit fault current.

(b) Longer cable runs may require an onskid marshalling box and/or output line reactor.

7.3 Pneumatic Start System (Optional)

The pneumatic start system, (Figure 11) can use either process gas or compressed air as a power source. The standard system consists of a strainer, shutoff valve, pneumatic starter motor, and associated stainless steel piping and manifolds. The pneumatic starter motor is mounted directly on the gas turbine accessory drive gearbox and transmits starting power to the gas turbine via an overrunning clutch and shaft. When the gas turbine reaches starter dropout speed, the start system is de-energized and the clutch overruns.

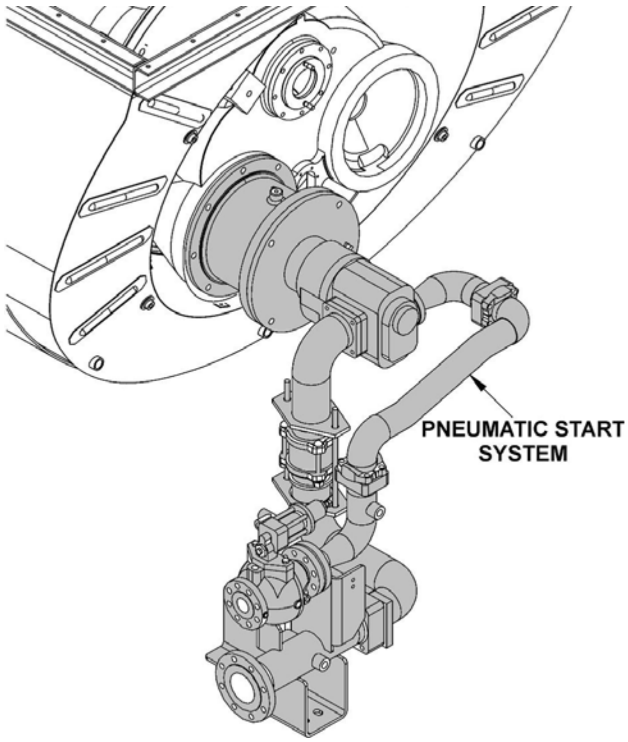


Figure 11. Typical Pneumatic Start System

Table 7. Pneumatic Start System Specifications

Pneumatic Start Motor	
Fluid	Air or Natural Gas See Note (a)
Pressure	1379 to 2758 kPag (200 to 400 psig)
Flow	113 nm3/min (4000 SCFM)
1 Minute Exhaust Purge Consumption	119 nm^3 (4200 SCF)
Solar's Applicable Engineering Specifications	
ES 2201	Auxiliary Service Air

Notes:

(a) The particle size in the air stream should not exceed 10µ. Since it is impractical to remove 100% of all particles larger than 10µ, this is defined as ß10 > 100, or 99% efficient. Oil or hydrocarbon content should not exceed 1 ppm. The dew point at line pressure shall be at least 6°C (10°F) below the minimum temperature to which any part of the air system is exposed or between -29°C and 93°C (-20°F and 200°F). Air should be free of all corrosive contaminants, hazardous gases, flammables, and toxics.

8 Fuel System

8.1 General Description

The fuel system (Figure 12), in conjunction with the control system, includes all necessary components to control ignition and fuel flow during all modes of operation. There are two available configurations:

- Gas fuel – conventional combustion
- Gas fuel – *SoLoNOx* combustion

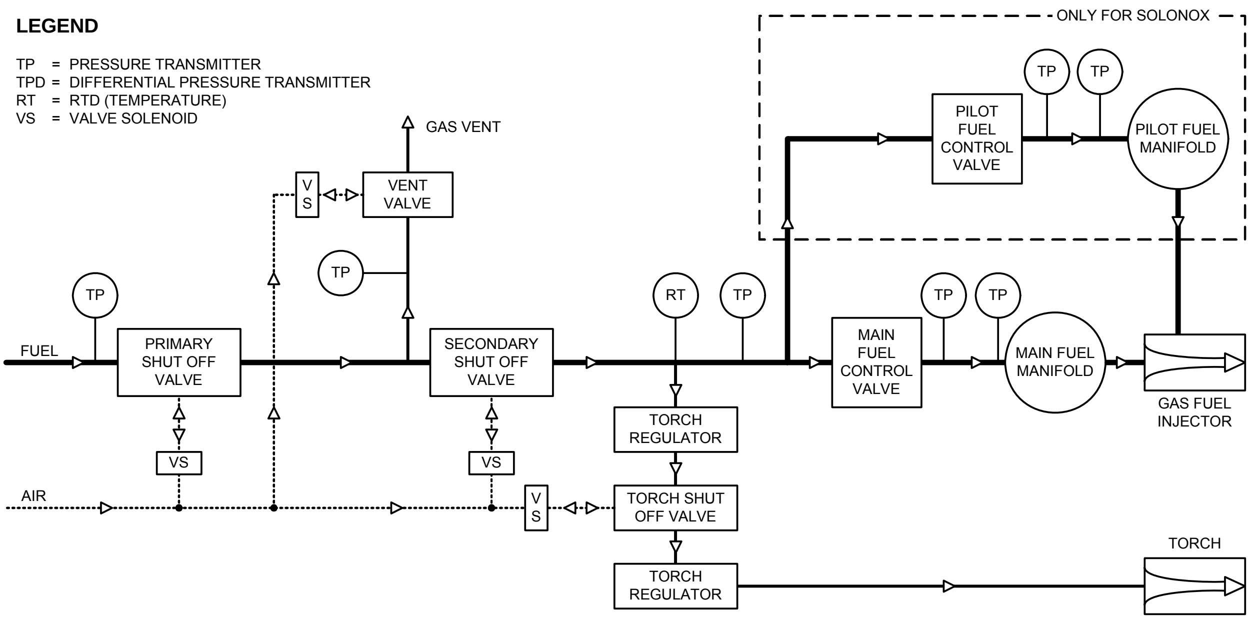


Figure 12. Typical Fuel System Schematic

8.1.1 Conventional Combustion System

Solar's conventional combustion system uses fuel injectors equally spaced around the combustor to inject fuel into the combustion chamber. The fuel injected into the combustion chamber is controlled during starting and steady-state operation to maintain stable combustion.

8.1.2 SoLoNOx Combustion System

The *SoLoNOx* combustion system uses special fuel injectors with main and pilot fuel ports. The fuel injected through these ports is controlled during starting and steady-state operation to maintain stable combustion and minimize the formation of nitrous oxides (NOx), carbon monoxide (CO), and unburned hydrocarbon (UHC) emissions. To further regulate emission levels, combustion airflow is regulated using a bleed valve mounted on the combustor case. The *SoLoNOx* combustion system also includes an additional inlet gas filter/coalescer for mounting offskid.

8.1.3 Fuel System

For conventional combustion, the fuel system includes:

- Supply pressure transmitter
- Pilot air operated primary gas fuel shutoff valve

- Pilot air operated secondary gas fuel shutoff valve
- Pilot air operated gas vent valve
- Electrically operated fuel control valve
- Torch with shutoff valve and pressure regulators
- Main fuel manifold
- Fuel injectors

For *SoLoNOx* combustion, the fuel system also includes:

- Fuel pilot control valve
- Fuel pilot manifold
- Inlet gas filter/coalescer loose shipped for field installation

Component Operation

The gas fuel pressure supplied to the turbine skid must meet minimum and maximum pressure and flow requirements. If the gas fuel pressure is too high or too low, the control system will prevent turbine operation. Pneumatically actuated primary and secondary gas fuel shutoff valves are controlled using pilot air pressure. For each valve, pilot air pressure is admitted to and exhausted from a pneumatic actuator through a solenoid valve. Fail-safe operation ensures both valves will close in case pilot air pressure is lost.

The gas fuel control valve and, when applicable, the *SoLoNOx* fuel pilot control valve, are powered by integrated DC motor-driven actuators. Integrated actuator electronics provide precise closed-loop valve control based on position command inputs versus position feedback outputs. Both valves are fast acting and provide fuel metering for light-off, acceleration, full load, and load transient conditions. Fail-safe operation ensures both valves will close in case the command signal or control power is lost. During the start sequence prior to ignition, the control system will verify gas pressure and perform a gas valve check to verify proper operation of all gas fuel valves.

Table 8. Fuel System Specifications

Gas Fuel System	
Acceptable Gas Fuels **See Note (a)**	Natural Gas Propane
Fuel Quality	Refer to Solar's Engineering Specification ES 9-98
Optional Fuel System Types	Conventional Combustion or *SoLoNOx* Combustion
Compliance	National Association of Corrosion Engineers (NACE) Compliant
Minimum/Maximum Gas Fuel Supply Pressure	1170 to 2068 kPag (170 to 300 psig), **See Note (b)**
Minimum Flow Rate	1475 kg/hr (3250 lb_m/hr), **See Note (b)**
Minimum/Maximum Fuel Supply Temperature	-40° to 93°C (-40° to 200°F), **See Note (c)**
Primary Gas Fuel Shutoff Valve	Pneumatically Actuated Spring-Closed Ball Valve
Secondary Gas Fuel Shutoff Valve	Pneumatically Actuated Vane Type Valve
Gas Fuel Control Valve and *SoLoNOx* Fuel Pilot Control Valve (If Applicable)	Actuator Valve
Actuator Voltage	120 VDC
Valve Discrete Signals	24 VDC
Valve Analog Signals	4 to 20 mA
Maximum Operating Pressure	1380 kPag (200 psig)
Maximum Operating Temperature	93°C (200°F)

Gas Fuel System (cont.)	
Response Time	Less Than 100 msec From 10-to-90% Stroke
Valve Body	Aluminum (Standard) Stainless Steel (Optional)
Gas Fuel Filter (Conventional Units Only)	10 Micron
Customer-Furnished Pilot Air System	
Fluid	Clean-Dry Air
Air Quality	**See Note (d)**
Minimum/Maximum Regulated Pressure Range	689 to 1379 kPag (100 to 200 psig)
Pilot Air Filter	10 micron
Construction Materials	
Piping, Manifolds, and Tubing	316L Stainless Steel

Solar's Applicable Engineering Specifications	
ES 9-98	Fuel, Air, and Water (or Steam) for *Solar* Gas Turbine Engines
ES 1593	Guidelines for NEC Compliance of *Solar* Product Lines: Class I, Group D, Division 1 and Division 2
ES 1762	Standards and Practices for Electrical Systems for Gas Turbine Packages Installed In Hazardous Areas (CENELEC/IEC Standards – European ATEX Directive 94/9/EC)
ES 2201	Auxiliary Service Air
Solar's Applicable Product Information Letters	
PIL 148	LPG and NGL Fuels
PIL 162	Recommendations and Requirements for the Sourcing, Handling, Storage and Treatment of Fuels for *Solar* Gas Turbines
PIL 176	Siloxanes in Gas Fuel

Notes:

(a) The gas fuel system is designed to operate with fuels that comply with Solar's Engineering Specification ES 9-98. Most commercially available natural gas fuels comply with ES 9-98. The gas fuel system can be modified to operate with fuels that do not comply with ES 9-98. *Solar* gas turbines can operate on low Btu fuels. Please contact Solar Turbines for assistance in evaluating fuel characteristics and gas turbine requirements.

(b) Fuel pressure and flow requirements can be affected by several factors such as: fuel temperature, fuel lower heating value, air inlet temperature, fuel composition, fuel specific gravity, engine injector type, inlet duct loss, relative humidity, site elevation, and piping length and diameter. Based on site conditions, minimum fuel pressure and flow requirements may be less than stated values. Please contact Solar Turbines for site-specific fuel pressure and flow requirements.

(c) Fuel must have a differential temperature (ΔT) of at least 27°C (50°F) above fuel dew point temperature.

(d) The particle size in the air stream should not exceed 10µ. Since it is impractical to remove 100% of all particles larger than 10µ, this is defined as ß10 > 100, or 99% efficient. Oil or hydrocarbon content should not exceed 1 ppm. The dew point at line pressure shall be at least 6°C (10°F) below the minimum temperature to which any part of the air system is exposed or between -29°C and 93°C (-20°F and 200°F). Air should be free of all corrosive contaminants, hazardous gases, flammables, and toxics.

9 Lubrication System

9.1 General Description

The lubrication system, (Figure 13) circulates oil under pressure to the gas turbine and driven equipment. Lube oil is supplied from the lube oil tank located in the driver frame. Oil temperature is maintained at optimal levels by a thermostatic control valve, oil tank heater, and optional oil cooler.

The lubrication system incorporates the following components:

- Oil tank
- Lube oil (customer furnished)
- Gas turbine driven main lube oil pump
- AC Motor-driven pre/post lube oil pump
- DC Motor-driven backup lube oil pump
- Duplex lube oil filter system with replaceable elements
- Oil level, pressure, and temperature indications
- Pressure and temperature regulators
- Strainers
- Oil tank vent separator
- Oil tank vent flame trap

Optional features include:

- Offskid oil cooler
- Oil tank heater
- Stainless steel oil tank and tank covers
- Stainless steel filter system

9.1.1 Lube Oil

Lube oil is customer furnished. Petroleum base or synthetic oil with a viscosity grade of C32 or C46 may be used. Synthesized hydrocarbon oils are recommended due to lower pour point, higher viscosity index, better heat transfer, and lower oxidation rate. Lube oil must conform to Solar's Engineering Specification ES 9-224.

9.1.2 Gas Turbine-Driven Main Lube Oil Pump

The main lube oil pump is mounted on an integral accessory drive gearbox. This positive-displacement pump provides lube oil pressure for normal operation.

9.1.3 AC Motor-Driven Pre/Post Lube Oil Pump

The pre/post lube oil pump provides lube oil pressure during package starting and for post-lube cooling of the gas turbine and driven equipment bearings. The pre/post lube oil pump provides lube oil pressure during a gas turbine roll down in the event the main lube oil pump has failed.

9.1.4 DC Motor-Driven Backup Lube Oil Pump

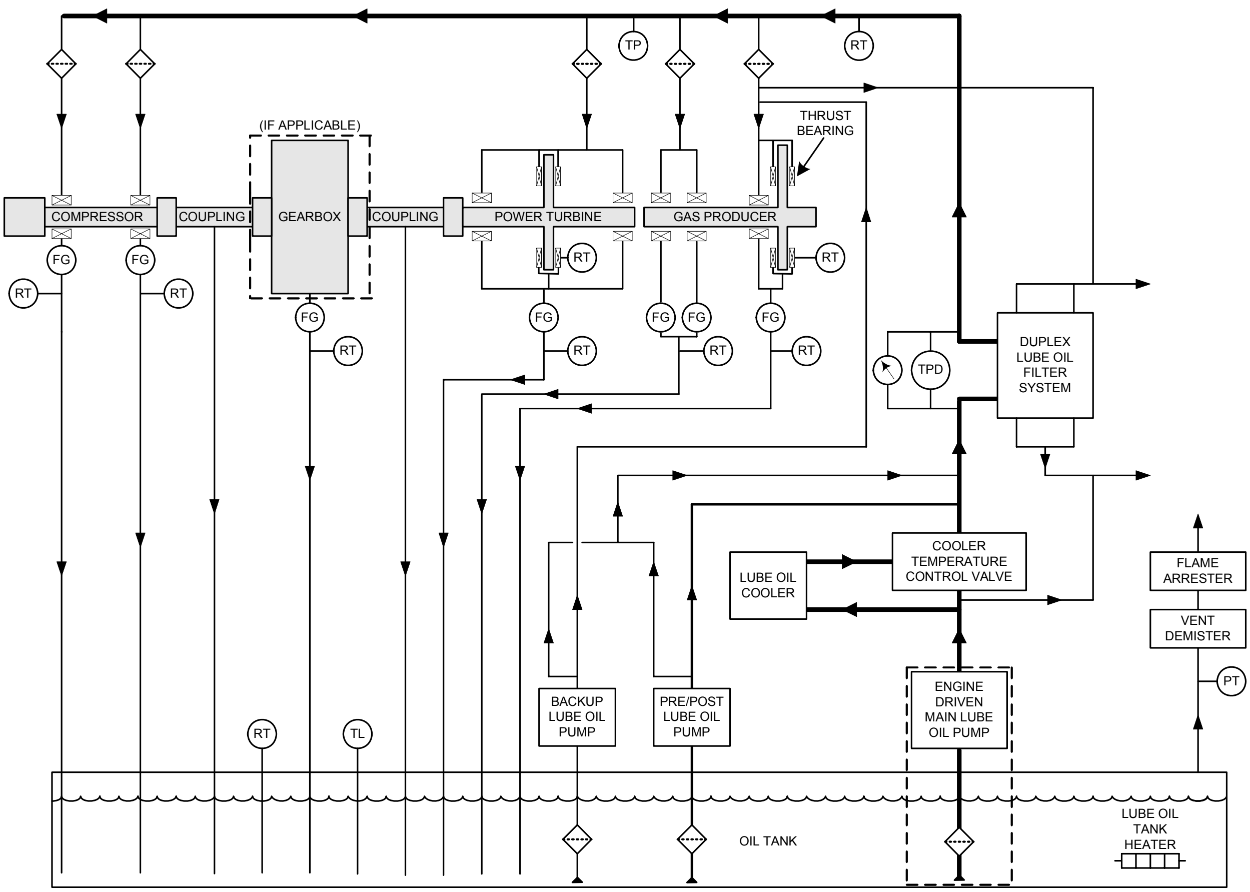
The backup lube oil pump provides lube oil pressure for post lube cooling of the gas turbine and driven equipment bearings in the event the pre/post lube oil pump fails. The backup lube oil pump provides lube oil pressure during a gas turbine roll down in the event the main lube oil pump and pre/post lube oil pump have both failed. The backup lube oil pump also provides lube oil pressure during an emergency condition such as a fire, control system failure, emergency stop, or if a turbine over speed is detected by the backup system.

9.1.5 Duplex Lube Oil Filter System

The duplex lube oil filter system is supplied with a filter transfer valve and filter differential pressure indication with alarm. The transfer valve allows a filter transfer to be performed while the gas turbine is running. The lube oil filter system is contained completely within the skid. The interconnect piping between the skid edge and the offskid oil cooler, if applicable, is not provided.

9.1.6 Lube Oil Vent Coalescer

An offskid lube oil vent coalescer is provided to remove oil vapor from the lube oil tank vent airflow. The coalescer drains trapped oil vapor back to the lube oil tank and allows the remaining vent airflow to exhaust to the atmosphere. A tank overpressure alarm and shutdown are also included. The lube oil vent coalescer is loose shipped for offskid installation by others.



LEGEND

TPD	TRANSMITTER, DIFFERENTIAL PRESSURE
FG	FLOW GAUGE (SIGHT GLASS)
TL	TRANSMITTER, LEVEL
RT	RESISTANCE TEMPERATURE DEVICE (RTD)
TP	TRANSMITTER, PRESSURE
◇	FILTER

Figure 13. Typical Lube Oil System

9.1.7 Lube Oil Vent Flame Arrestor

The lube oil vent flame arrestor prevents an ignition source from entering the lube oil tank. The flame arrestor is loose shipped for offskid installation by others.

9.1.8 Lube Oil System Options

Lube Oil Cooler

An air-to-oil type cooler is available to provide oil cooling for the gas turbine and the driven equipment. The cooler is sized for specified heat loads and ambient temperatures and is designed for a 22.2°C (40°F) approach temperature. The cooler is loose shipped for offskid installation by others.

Lube Oil Immersion Tank Heater

The lube oil tank immersion heater ensures the lube oil tank temperature is adequate for starting in cold conditions. The tank heater also facilitates a short lube oil temperature warm up period after a cold start. Electrical supply contactors are not included.

Table 9. Lubrication System Specifications

Main Lube Oil Pump	
Pump Type	Engine-Driven Rotary Screw
Flow	1060 lpm (280 gpm)
Discharge Pressure	607 kPag (88 psig), **See Note (a)**
Pre/Post Lube Oil Pump	
Pump Type	AC Motor-Driven Centrifugal
Optional Motor Voltage Ratings	380 VAC, 400 VAC, and 415 VAC (50 Hz) 460 VAC and 575 VAC (60 Hz)
Motor, Power	7.5 kW (10 hp)
Backup Lube Oil Pump	
Pump Type	DC Motor-Driven Centrifugal
Motor Voltage Rating	110 VDC
Motor, Power	0.9 kW (1.2 hp)
Lube Oil Cooler	
Lube Cooler Oil Volume (Per Cooler)	Project Specific
Design Heat Load (Per Cooler)	Project Specific
Design Oil Flow Rate (Per Cooler)	Project Specific
Air Flow Rate	Project Specific, **See Note (b)**
Maximum Ambient Temperature	43°C (110°F)
Maximum Design Lube Oil Cooler Outlet Temperature	66°C (150°F)
Maximum Lube Oil Cooler Design Pressure Drop	173 kPag (25 psig), **See Note (c)**
Minimum Lube Oil Cooler Design Pressure	1 035 kPag (150 psig)
Optional Motor Voltage Ratings	380 VAC, 400 VAC, and 415 VAC (50 Hz) 460 VAC and 575 AC (60 Hz)
Optional Motor, Power	7.5 kW (10 hp), 15 kW (20 hp), or 2 x 15 kW (20 hp)
Lube Oil Tank Immersion Heater, See Note (d) and (e)	
Optional Voltage Ratings	380 VAC, 400 VAC, and 415 VAC (50 Hz) 460 VAC (60 Hz)
Power	3-Phase VAC, 10 kW
Minimum/Maximum Regulated Supply Pressure	100 to 225 psig (689 to 1551 kPag)
Maximum Flow Demand Rate	4.67 nm^3/min. (165 scfm)

Main Lube Oil Duplex Filters	
Type	Self-Supporting Pedestal
Duplex Filters	10 Micron
Certification	ASME, Section VIII, Division 1
Backup Lube Oil Pump Filter	
Type	Bowl Filter
Minimum/Maximum Operating Temperatures	-54° to 135°C (-65° to 275°F)
Simplex Filter	β X $\geq$ 75 Micron
Lube Oil Vent Coalescer	
Type	Air/Oil Mist Eliminator
Maximum Working Temperature	93°C (200°F)
Orientation	Vertical
Performance	100% removal of all droplets greater than 3 microns and 99.5% removal of all droplets less than 3 microns.
Certification	ASME, Division 1
Approximate Dimensions (Height x Diameter)	262 cm x 35.6 cm (103 in. x 14 in.)
Approximate Weight	195 kg (430 lb)
Lube Oil Vent Flame Arrestor	
Orientation	Vertical, **See Note (f)**
Approximate Dimensions (Height x Diameter)	26 cm x 55 cm (10.3 in. x 21.6 in.)
Approximate Weight	26 kg (58 lb)
Strainers	
Tank Fill	20 mesh
Gearbox Breather Vent (If Applicable)	40 mesh
Gas Producer Start-Up Strainer	70 Micron, **See Note (g)**
Gearbox Start-Up Strainer (If Applicable)	70 Micron, **See Note (g)**
Compressor Driven End Start-Up Strainer	70 Micron, **See Note (g)**
Compressor Exciter End Start-Up Strainer	70 Micron, **See Note (g)**
Lube Oil	
Viscosity Grade ISO VG 32 (C32)	Use When Ambient Temperature is <43°C (110°F)
Viscosity Grade ISO VG 46 (C46)	Use When Ambient Temperature is >43°C (110°F)
Pour Point	Must Be At Least 6°C (11°F) Below The Lowest Ambient Temperature)
Lube Oil Tank Capacity	2250 L (594 gal.), **See Note (h)**
Weight	2080 kg (4590 lb)
Construction Materials	
Piping, Manifolds, and Tubing	316L Stainless Steel
Lube Oil Tank and Tank Covers	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Main Lube Oil Duplex Filter Housing and Transfer Valve	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Backup Lube Oil Pump Filter Housing	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Lube Oil Vent Coalescer	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Lube Oil Vent Flame Arrestor	Carbon Steel (Standard) 316L Stainless Steel (Optional)

Solar's Applicable Engineering Specifications	
ES 9-224	Fuel, Air, and Water (or Steam) for *Solar* Gas Turbine Engines
ES 1593	Guidelines for NEC Compliance of *Solar* Product Lines: Class I, Group D, Division 1 and Division 2
ES 1762	Standards and Practices for Electrical Systems for Gas Turbine Packages Installed In Hazardous Areas (CENELEC/IEC Standards – European ATEX Directive 94/9/EC)
Solar's Applicable Product Information Letters	
PIL 058	Package Sound Levels
PIL 161	Lube Oil System Cleanliness

Notes:

(a) A pressure control valve regulates main lube oil supply pressure to 345-414 kPag (50-60 psig) when unit is at normal operating temperature.

(b) Prevailing winds must be considered to prevent the lube oil cooler from exhausting into the engine air inlet system or to take air in from the engine exhaust system. No airflow backpressure is allowed at the lube oil cooler face.

(c) The maximum total design pressure drop of the off skid oil cooler loop including supply and return lines shall not exceed 276 Kpad (40 psid) at the design flow rate and an oil viscosity of 60 ssu (10.5 centistokes). No check valves are allowed in the oil cooler loop. This is recommended for all applications (but mandatory for units in cold climates), oil cooler supply, return and optional vent lines must slope from the oil cooler to the turbine package to facilitate draining when the unit is not operating.

(d) The heater is mandatory if unit ambient temperature is less than 10°C (50°F).

(e) The lube oil tank immersion heater ensures the lube oil tank temperature remains above 10°C (50°F) for starting in cold temperatures.

(f) The flame arrestor must be installed vertically at the end of the lube tank vent piping.

(g) Start-up strainers must be inspected after 100 hours of operation.

(h) An additional 246 L (65 gal) is required for package filters and piping. Additional oil will also be required to fill any offskid oil piping and vessels (if applicable).

10 Turbotronic 4 Control System

10.1 General Description

The *Turbotronic* 4 control system controls and monitors the turbomachinery package including the gas turbine and driven equipment. The system scope can be expanded to include monitoring and/or control of balance of plant equipment that is directly package related. The system architecture is based on a Rockwell Automation/Allen-Bradley hardware and software platform and includes fully integrated driven equipment, vibration and, when required, fire and gas monitoring and control subsystems. The primary control system components may be mounted either "onskid" on the package skid (Figure 14) or "offskid" in a freestanding console (Figure 15).

The onskid design is approved for use in areas classified as Class I, Group D, Division 2, by the National Electrical Code (NEC) and in areas classified as Zone 2, Group IIA, under the Committee for Electrotechnical Standardization (CENELEC) standards. An auxiliary display and monitoring system is available, mounted in either an optional console or a desktop computer. Control connections between the package and the auxiliary display are through a pair of redundant network cables. A limited set of hardwired cables may also be required depending on the configuration.

For NEC Division 1 and CENELEC Zone 1 applications, the offskid design must be used. This design requires a full set of hardwired interconnect cables between the package, the control console, the motor control center (MCC) and any other controlled items.

An independent backup shutdown system provides additional protection. This shuts the package down in a safe and orderly manner in the event of malfunction of the primary control system.

10.2 System Architecture

Key system components include:

- ControlLogix controller (Allen-Bradley)
- RSLogix 5000 programming software (Rockwell Automation)
- 1794 Flex I/O input/output modules (Allen-Bradley)
- 1701 FieldMonitor vibration monitoring system (Bently Nevada)
- ControlNet network (ControlNet International)
- TT4000 offskid display and monitoring system (Solar Turbines)
- Offskid operator control panel* (Solar Turbines)
- TT4000S onskid local operator interface (Solar Turbines)
- Onskid operator control panel (Solar Turbines)
- Fire and gas monitoring and control system (Det-tronics)
- Independent backup shutdown system (Solar Turbines)

* Included with standard offskid configuration, optional with onskid configuration

Figure 16 provides an overview of the principle control system elements. The ControlNet network provides primary communications between components. Hardwire backup is provided for critical circuits. The TT4000S and onskid operator panel are located on the package skid. The TT4000 and offskid operator panel are located in a non-hazardous area such as a control room. The variable speed frequency drive (VFD) for the start motors is typically located in a motor control center. All other components are rated NEC Class 1, Division 2 or CENELEC Zone 2 for hazardous area duty and are located on the package skid for the onskid controls configuration or in a console for the offskid configuration.

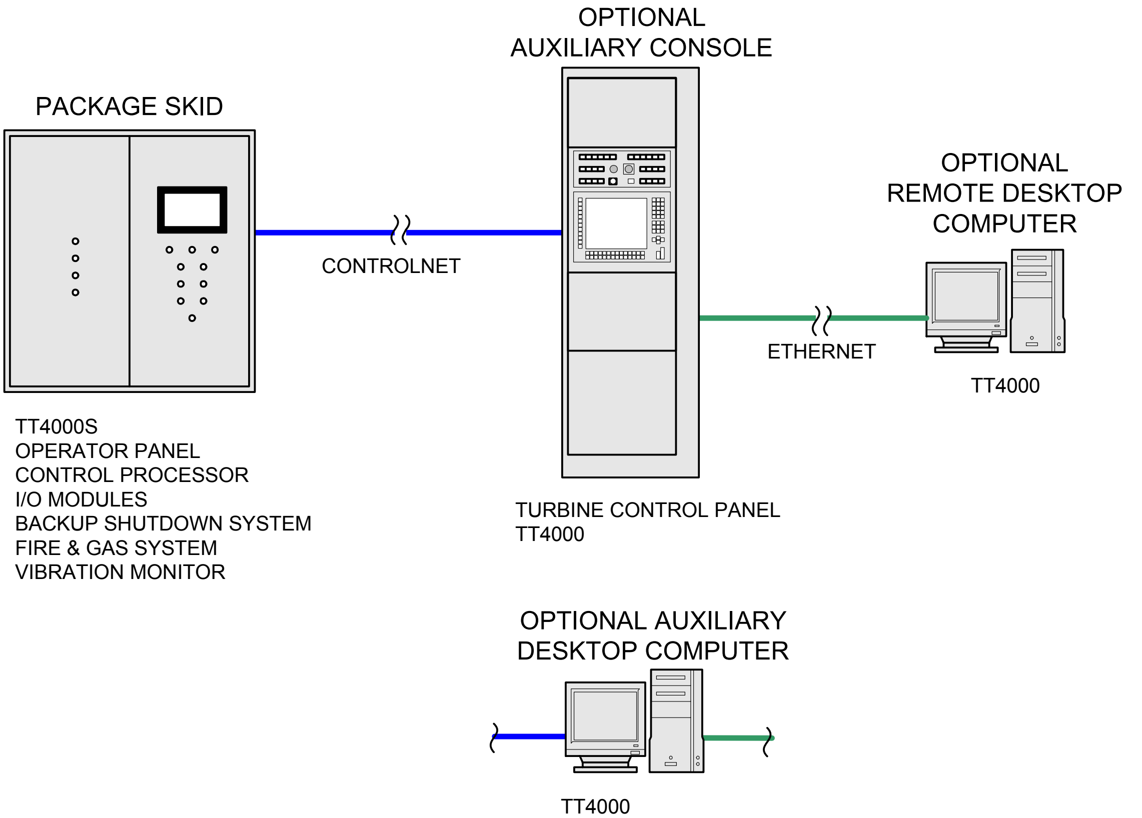


Figure 14. Typical Onskid Control System

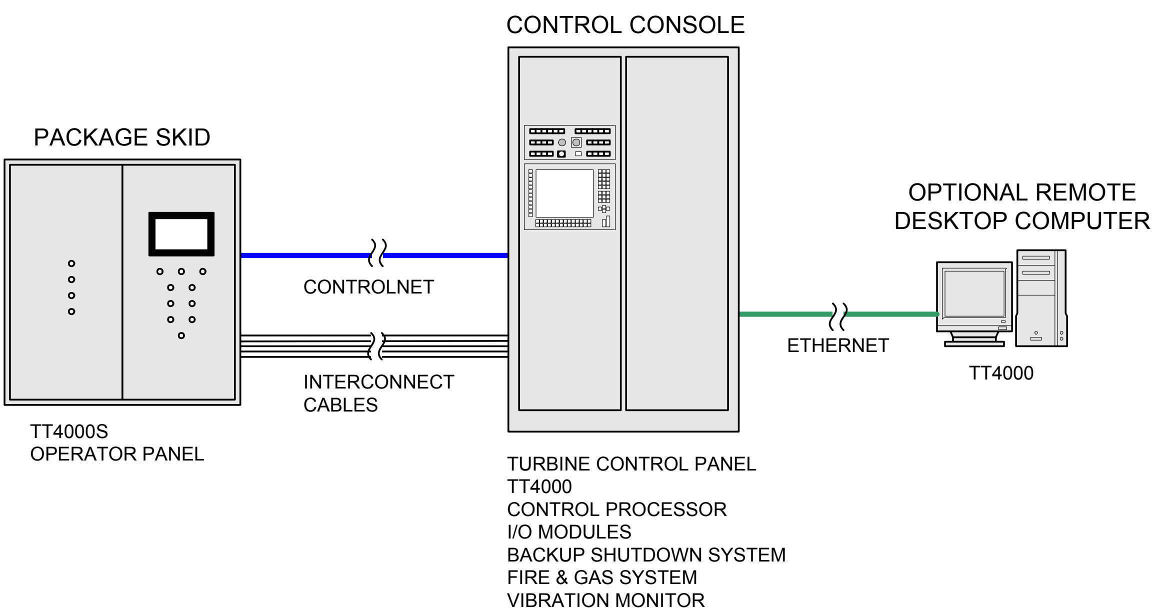


Figure 15. Typical Offskid Control System

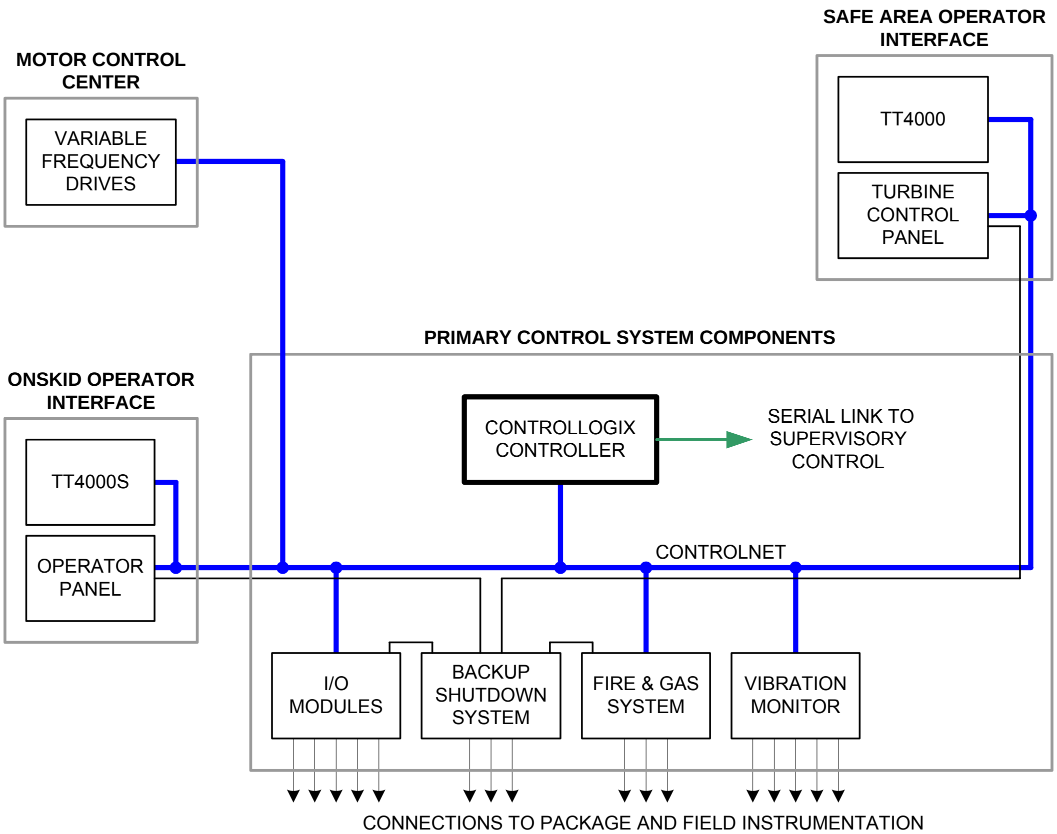


Figure 16. Turbotronic System Architecture

10.3 Component Descriptions

10.3.1 Controller

The ControlLogix controller, running RSLogix 5000 software, provides primary control. Project-specific programs are created in a Windows-based system and uploaded to the controller. The RSLogix 5000 software supports ladder and function block programming and complies with the International Electrical Code (IEC) 61131-3 standard for programmable controllers.

10.3.2 ControlNet 1.5

Operating at 5 Mbps, the network is repeatable and deterministic. Cabling is redundant with two separate channels carrying the same information. The maximum total length of the network is 1000 meters without the use of repeaters. However, this length decreases based on the number of nodes on the network. A practical design limit is 800 meters.

10.3.3 Input/Output Modules

Flex I/O modules provide an interface between the package instrumentation and the processor. Specific modules handle discrete inputs, analog inputs, temperature inputs, speed inputs, discrete outputs and analog outputs.

10.3.4 Vibration Monitoring System

The system uses 1701 FieldMonitors and associated sensing devices from Bently Nevada. The capacity of each monitor is eight vibration channels plus a keyphasor input.

The system is configurable from the control processor. It detects preprogrammed alarm and shutdown levels. See the specification tables for a list of monitored channels.

10.3.5 Backup Shutdown System

The backup shutdown system shuts the package down in a safe and orderly manner without damage to the equipment in the event of a failure in the primary system. The control processor is monitored by both an internal watchdog circuit and by an external watchdog device. If either circuit detects a processor failure, the backup system takes control. It depressurizes the compressor (if applicable), closes the fuel valves, and initiates a post lube cycle to protect the turbine bearings. Once a backup shutdown is initiated, operation can only be restored manually from the control panel after all faults have been cleared. The emergency stop push-button switches are wired to both the primary and backup systems.

10.3.6 Fire and Gas System

Enclosed packages require fire and gas control protection. The Eagle Quantum Premier system from Det-Tronics detects combustible gas and/or fire inside the enclosure based on inputs from gas, thermal, and optical flame detectors. If fire is detected, the system releases an extinguishing agent into the enclosure. If a fire or an unacceptable gas level is detected, the system instructs the *Turbotronic* control processor to initiate a package shutdown. The system is also wired directly to the backup shutdown system. See Enclosure Section 12 for a more complete description.

10.3.7 Control System Power Supplies

The control system operates on 24 VDC power. The standard battery charge system provides 120 VDC power to the control system. The control system includes a 120 to 24 volt DC-to-DC converter to supply 24 VDC power to the control system. For a more detailed description of the battery charger system, refer to Section 15, Accessory Equipment.

10.3.8 Interconnect Cables – Offskid Control Systems

With the offskid controls configuration, interconnect cabling must be provided between the package skid and the control console. This cabling is not in Solar's standard scope of supply. Solar's standard wiring recommendations are based on a cable length of 76 m (250 ft). For interconnects over 76 m, the wire gages must be adjusted to maintain the equivalent loop resistance of the *Turbotronic* 4 standard design, and must not exceed a 5% voltage drop. This may require a larger wire gage. For interconnects over 76 m, low capacitance wire (0.03 µF/m; 0.01 µF/ft) must be used for the speed signal and vibration cables.

10.4 System Monitoring and Control Functions

The control system provides sequencing control during gas turbine startup, steady state operation, and shutdown. Protective functions are provided during all stages of operation.

10.4.1 Starting and Loading

The **Start** command initiates the sequence. Prior to rotation, the lube oil pump undergoes a test cycle, the enclosure fans (if applicable) are started, and the fuel valves undergo a test cycle with fuel pressure verification.

The starter then rotates the gas turbine and the compressor develops airflow to purge any accumulated gas in the gas turbine, air inlet, and exhaust duct. The purge cycle is tailored to the exhaust duct volume.

When the engine has reached the required speed and temperature, a small amount of fuel is introduced into the combustor from the gas torch and ignited by the ignitor plug.

The fuel control valve gradually opens and admits fuel into the combustor through the injectors. The inlet guide vanes open and the bleed valve gradually closes. Fuel flow, engine temperature, and turbine speed all increase. Once starter dropout speed is exceeded, the starter freewheels and is de-energized. The engine continues to accelerate under its own power.

10.4.2 Steady-State Control

During steady-state operation, the control system keeps the equipment within specified operating conditions. The maximum power limit is determined by engine temperature and speed.

Temperature control is based on the third-stage nozzle temperature (T5). Six thermocouples are used and the values averaged. If one thermocouple has a value that deviates from the average by more than a preset amount, an alarm is generated by the control system. If two thermocouples deviate, the package is shut down.

Special sensors continuously monitor the gas turbine speed and the control system makes adjustments to meet operating requirements and to keep the speed within specified limits. A separate backup overspeed detection system provides additional protection by automatically shutting the engine down if a preset overspeed limit is reached.

10.4.3 Stopping

The gas turbine may be shutdown either manually or automatically.

The **Normal Stop** command initiates a cooldown stop. The gas compressor is depressurized (if applicable) and the gas producer runs at idle speed for a preset time to allow the gas turbine and driven equipment to cool, then the fuel valves close. The **Emergency Stop** command results in the immediate depressurization of the gas compressor and closure of the fuel valves without a cooldown period.

In the event of a hazardous condition or equipment malfunction, the control system will shut the package down automatically. These shutdowns are divided into four categories:

- Cooldown stop nonlockout (CN)
- Cooldown stop lockout (CL)
- Fast stop nonlockout (FN)
- Fast stop lockout (FL)

Cooldown and fast stops correspond to the manual normal and emergency stops respectively. Lockout stops inhibit operation of the control system and prevent restarting until the malfunction is reset. Lockout stops result from serious malfunctions that require corrective action before the system can be restarted. Nonlockout stops result from an operational disruption or abnormal condition and can be reset when conditions return to normal.

In all cases, after the package has come to a complete stop and the rundown timer has timed out, the control system initiates and supervises a post-lube cycle to protect the gas turbine and driven equipment bearings from thermal damage. If the shutdown is the result of a fire being detected, start of the post lube cycle is delayed for 10 minutes unless an operator intervenes.

10.4.4 Vibration and Temperature Monitoring

In addition to the T5 thermocouples, the system provides continuous monitoring of temperature and vibration levels at key package locations. Refer to the Specification Table for details.

10.5 TT4000 Display and Monitoring System

The TT4000 display and monitoring system provides extensive data collection and display capabilities. On a typical project, two standard versions of the product are used.

TT4000 is the fully featured version with extensive data collection and display capability. It is installed in a high performance industrial grade personal computer (PC), in either a desktop or a console panel mounted version. It runs on the Windows® 2000 operating system. The hardware is not rated for hazardous areas and must be installed in a non-hazardous area, typically a control room.

TT4000S is a reduced version of the product specifically designed for the onskid interface. It is installed in a special industrial grade PC that is approved for use in both NEC Division 2 and CENELEC/ATEX Zone 2 areas. It runs on the embedded Windows® NT operating system. Due to the environment, it uses no moving media such as disk drives, so data storage is limited. It displays data but without the graphics features of the full TT4000 version.

10.5.1 TT4000 Display Screens

A menu bar at the left of each screen allows navigation to any other screen. A status bar at the top of every screen displays up to four alarm conditions. Standard display screens include:

- Operation Summary (complete package data, see Figure 17 for typical screen)
- Temperature Summary (all monitored temperature values)
- Vibration Summary (all monitored vibration values)
- Lube Oil Summary
- Turbine Vibration
- Compressor Vibration (if applicable)
- Seal System (if applicable)
- Program Constants
- Strip Chart Display (real time data, see Figure 18 for typical screen)
- Yard Valves
- Maintenance
- Alarm Summary
- Discrete Event Log
- Historical Data Display (strip chart format)

Optional Display Screens:

- Gas Turbine Performance
- Compressor Performance
- Process Control
- Surge Control

Customized screens can be provided to display other product specific information.

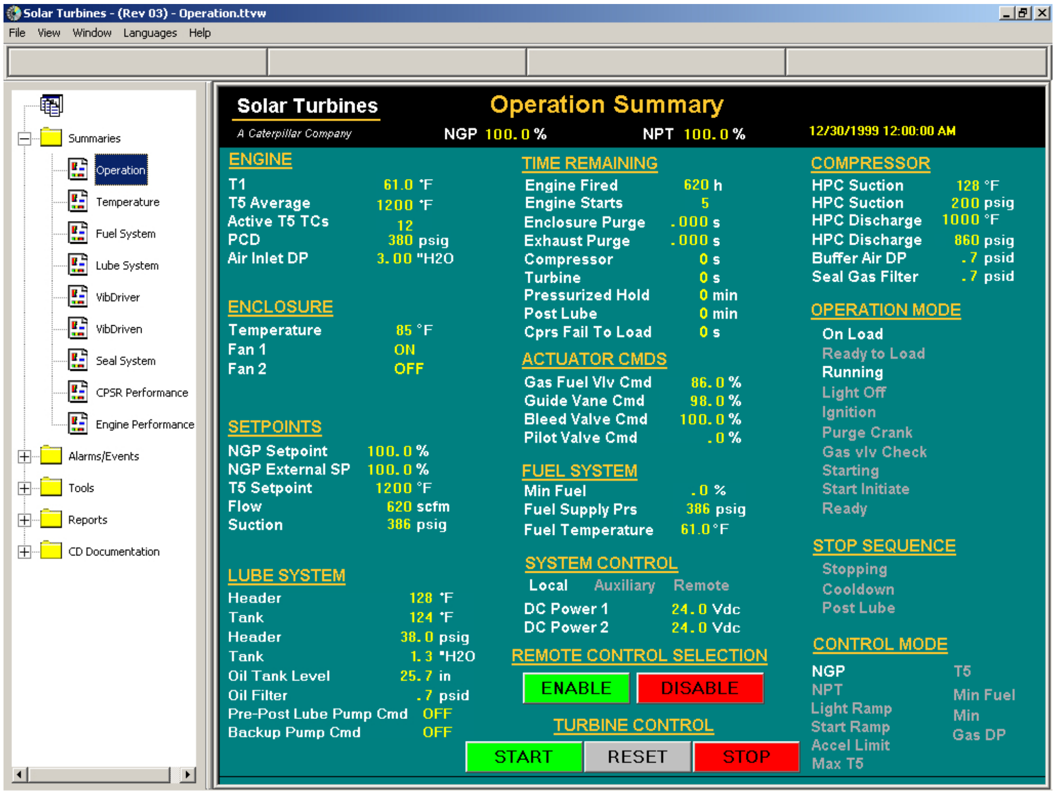


Figure 17. Typical TT4000 Operation Summary Screen

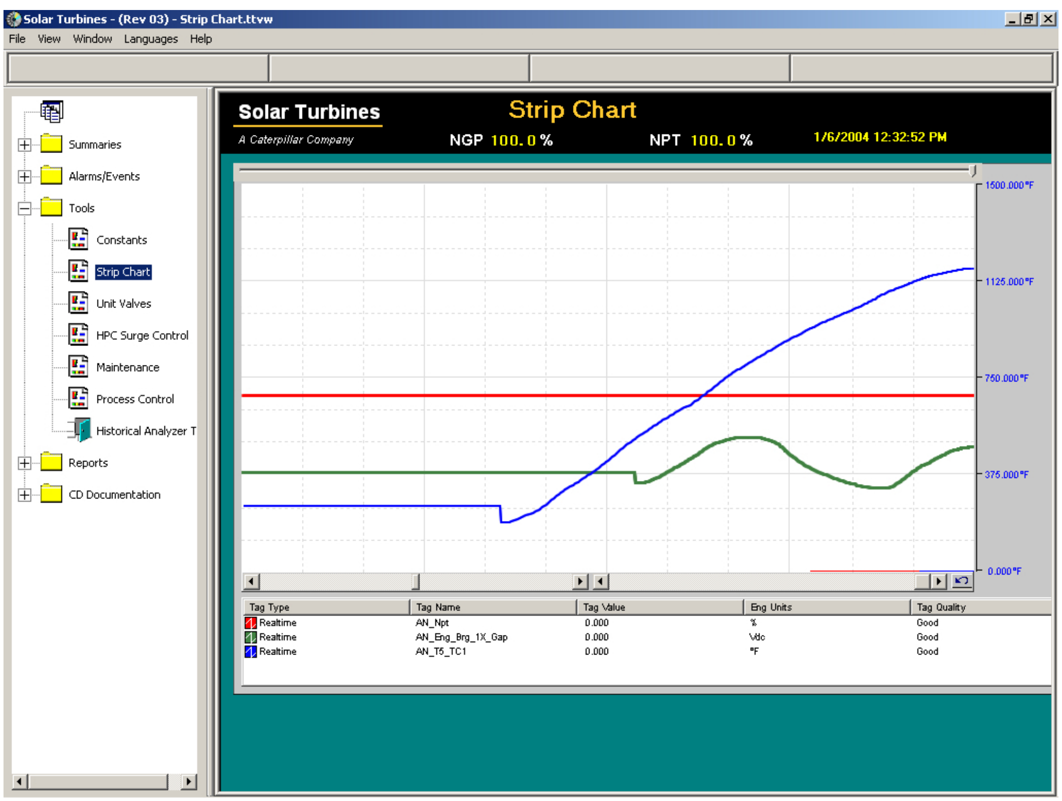


Figure 18. Typical TT4000 Strip Chart Screen

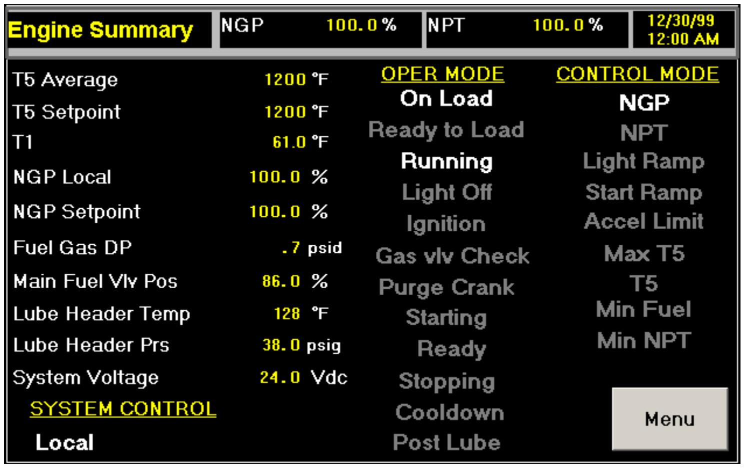


Figure 19. Typical TT4000S Engine Summary Screen

10.5.2 TT4000S Display Screens

The TT4000S displays a comparable set of screens to the full TT4000 except that the data is in numerical form and graphics are limited (Figure 19).

10.5.3 TT4000 Data Collection and Display

The Discrete Event Log records changes in status for all defined discrete inputs, including operator commands, alarms and shutdown annunciations, and key sequencing and status signals. Up to 5000 events are stored and can be viewed and sorted by heading.

Analog Data are collected and saved to disk. The standard data files are:

Hourly Log - data are read at hourly intervals for 2 years. Each year's data are stored in a separate file. Data are recorded whether or not the equipment is operating.

Minute Log - data are read and stored at one-minute intervals for the previous 62 days, one file for each day.

10 Second Log - data are read at 10-second intervals for the previous 31 days, one file for each day.

Trigger Log - data are read at one-second intervals for 6 minutes before a "trigger" event that is defined in the software. The standard trigger is a shutdown. Six minutes before the trigger of data are written to a file. Up to 50 trigger logs files can be stored.

10.5.4 TT4000 Display Language

In addition to English, dual language screens are available with English and Spanish (Latin America), Portuguese (Brazil), French, German or Chinese (simplified). Other languages can be provided as custom features.

10.5.5 TT4000 Operating Modes

There are two operating modes for the TT4000 software: Design Time and Run Time. Design Time is used to create or modify a project's working files. Run Time uses those files in the normal equipment operation.

10.5.6 Supervisory Control Interfaces

The *Turbotronic* 4 control system can transmit data to, and receive control instructions from, a supervisory control system. All analog data and the status of all discrete values are available for transmittal. Interface modules mount in the controller rack and connect through the rack's backplane. Available connections are:

- ControlLogix 1.5
- Ethernet
- Data Highway Plus
- Modbus

10.5.7 System Programmability

The *Turbotronic* 4 system is fully programmable in the field. Programming requires a licensed copy of Rockwell Automation's RSLogix 5000 software installed on a suitable computer with the corresponding interface card installed. Solar offers two standard options:

Software, instruction manual, interface card, and connecting cable.

Fully configured portable computer with the software, instruction manual, interface card, and connecting cable

10.5.8 Engineering Units

The following engineering unit options are available for the screen displays:

	Metric 1	Metric 2	Metric 3	English
Pressure	kPa	bar	kg/cm3	psig
Temperature	°C	°C	°C	°F

Table 10. Turbotronic 4 Control System Specifications

Temperature Monitoring	
Resistance Temperature Device (RTD)	100 ohm Platinum
Turbine T5	6 Thermocouples
Turbine Air Inlet	Resistance Temperature Device (RTD)
Turbine Lube Oil Header	RTD
Turbine Lube Oil Tank	RTD
Turbine Gas Producer Thrust Bearing	RTD (1 connected and 1 spare)
Turbine Power Turbine Thrust Bearing	RTD (1 connected and 1 spare)
Turbine #1 Bearing Drain	RTD (1 connected and 1 spare)
Turbine #2 and #3 Bearing Drain	RTD (1 connected and 1 spare)
Turbine #4 and #5 Bearing Drain	RTD (1 connected and 1 spare)
Compressor Driver End Bearing (If Applicable)	RTD (1 connected and 1 spare)
Compressor Driven End Bearing (If Applicable)	RTD (1 connected and 1 spare)
Vibration Monitoring	
Turbine Bearing #1	Displacement Probes, X and Y axis
Turbine Bearing #2	Displacement Probes, X and Y axis
Turbine Bearing #3	Displacement Probes, X and Y axis
Turbine Bearing #4	Displacement Probes, X and Y axis
Turbine Bearing #5	Displacement Probes, X and Y axis
Turbine Rotor Shaft	Displacement Probe, Axial Position
Turbine Gas Producer Rotor Shaft	Keyphasor
Turbine Power Turbine Rotor Shaft	Keyphasor
Compressor Bearing Driven End	Displacement Probes, X and Y axis
Compressor Bearing Driver End	Displacement Probes, X and Y axis
Gearbox (If Applicable)	Acceleration Probe Displacement Probes, X and Y Axis (Optional)

Offskid Control Console Dimensions	
One-Bay Control Console	
Height	2286 mm (90 in.)
Width	914 mm (36 in.)
Depth	800 mm (32 in.)
Approximate Weight	570 kg (1250 lb)
Two-Bay Control Console	
Height	2286 mm (90 in.)
Width	1448 mm (57 in.)
Depth	800 mm (32 in.)
Approximate Weight	680 kg (1500 lb)
Supervisory Interface Modules	
ControlNet 1.5	
Cables	RG-6U Coaxial
Maximum Cable Length	1000 m (3300 ft)
Transmission Protocol	Common Industrial Protocol (CIP)
Transmission Speed	5 Mbps
Ethernet	
Cables	10BaseT
Network Length	100 m (330 ft) To Nearest Hub
Transmission Protocol	CIP Protocol with TCP/IP
Transmission Speed	10 Mbps
Data Highway Plus	
Cables	DH+ Twisted Pair
Maximum Cable Length	3000 m (10,000 ft)
Transmission Protocol	CIP or DF1 Protocol
Transmission Speed	57.6 bps
Modbus	
Cables	RS232C, RS422, or RS485
Cable Length	RS232C: 15 m (50 ft) RS422 and RS485: 1200 m (4000 ft)
Transmission Protocol	Subset of Modbus RTU Protocol
Package End Devices	
Transmitters	4-20 mA
Switches	0-24VDC
Thermocouples	Type K
RTDs	100 ohm Platinum
Proximitors	3300XL

Solar's Applicable Engineering Specifications	
ES 9-56	Fusion Welding
ES 1593	Guidelines for NEC Compliance of *Solar* Product Lines: Class I, Group D, Division 1 and Division 2
ES 1762	Standards and Practices for Electrical Systems for Gas Turbine Packages Installed In Hazardous Areas (CENELEC/IEC Standards – European ATEX Directive 94/9/EC)
ES 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cables Installed In Class 1, Division 2 Hazardous Areas

11 Compressor Control and Monitoring

11.1 General Description

The following sections outline the control and monitoring options available for compressors and mechanical drives.

11.1.1 Process Control

The process control options provide unit control based on the gas compressor suction pressure, discharge pressure, and flow (or combinations of these parameters). Local and remote setpoint adjustments are included. If prime, Solar will provide the necessary transmitters. If the driven equipment supplier is prime, the following input signals are required depending on the type of control:

- 4-to-20 mA pressure signal
- 4-to-20 mA flow element differential pressure
- Temperature at flow element (100-ohm platinum RTD preferred)

11.1.2 Suction Pressure, Discharge Pressure, and Flow Shutdowns

The basic package may be supplied with driven equipment suction pressure, discharge pressure, and flow transmitters and associated control system logic to provide for indication, warning alarm, and unit shutdown when the suction pressure, discharge pressure, or flow exceeds a preset value.

- Suction pressure transmitter – shipped separately for installation by purchaser
- Discharge pressure transmitter – shipped separately for installation by purchaser
- Suction flow transmitter – shipped separately for installation by purchaser

11.1.3 Gas Compressor Surge Detection System

The surge detection system detects gas compressor discharge pressure pulsations and initiates a gas turbine shutdown if pulsations exceed a preset value within a predetermined time period. For applications without an anti-surge control system supplied by Solar, a gas compressor surge detection system is recommended.

11.1.4 Anti-Surge Control

Surge at a given gas compressor speed is caused by excessive head across the gas compressor (isentropic head) for a given suction flow rate. Therefore, surge in the gas compressor may be controlled by decreasing the head across the gas compressor and/or by increasing the flow rate of the gas to the suction side of the gas compressor. The anti-surge control system prevents surge by modulating a surge control (bypass) valve to lower head and increase suction flow. A typical system consists of pressure and temperature transmitters on the gas compressor suction and discharge lines, a flow differential pressure transmitter across the suction flowmeter, an algorithm in the control system, and a surge control valve with corresponding accessories to keep the gas compressor from going into surge.

The following components and information are required from the purchaser in order to facilitate the surge control system design and onsite operation:

- Expected gas compressor operating conditions range for suction pressure (P_1), suction temperature (T_1), discharge pressure (P_2), flow and gas specific gravity
- Flow meter specification sheet

- Purchaser piping and instrumentation diagram including suction and recycle pipe size and schedule
- Anti-surge control (recycle) valve and specification sheet, unless included in Solar's scope
- Suction and discharge gas temperature signal (100-ohm platinum resistance temperature devices (RTDs) preferred)

Typical system scope includes the following:

- Engineering to determine the optimum control algorithms
- Control software programmed and tested for the selected gas compressor staging
- Engineering to specify the anti-surge control valve and accessories, including valve performance evaluation over the gas compressor performance map at varying valve positions
- Engineering to specify the flow meter type and size
- Automatic override of manual control mode
- Evaluation of user piping and instrumentation diagram
- Documentation, including all surge control calculations and program constants
- Gas compressor flow versus differential pressure control with suction pressure and temperature compensation
- Speed setpoint decoupling
- Surge detection with step valve opening
- On-screen, real-time graphic displays
- On-screen, real-time control parameter setting
- All surge control parameters are available for remote monitoring via serial link

11.1.5 Anti-Surge Recycle Valve

When included in Solar's scope of supply, the anti-surge recycle valve is supplied as a complete and functionally tested assembly, shipped separately for field installation. The assembly includes the valve and the following accessories and features:

- Spring-return, diaphragm-type, pneumatic actuator
- Position transmitter with valve fully open and fully close relay outputs and 4-to-20 mA proportional to percentage closed
- Pressure regulator
- 3-way 24-VDC solenoid valve
- Electropneumatic valve positioner
- ½-in. NPT actuator pressure port
- Carbon steel body per ASTM A352
- Interconnecting 316L stainless steel tubing and compression-type fittings
- Temperature Limits:
  - Process gas: - 6.7° to 218°C (20 to 425°F)
  - Ambient: -28.9° to 60°C (-20 to 140°F)

The assembly requires clean, dry regulated air or natural gas, 552 to 862 kPag (80 to 125 psig), -28.9° to 60°C (-20° to 140°F), dew point -40°C (-40°F)

Successful operation of the anti-surge control system is dependent on correct valve selection. The following anti-surge recycle valve is selected based on the application data available at the time of this proposal. It may be necessary to select a different valve, or possibly a combination of valves, once complete compressor system design information is received. Any such change will have a commercial impact.

11.1.6 Compressor Vibration and Temperature Monitoring

X and Y proximity probes are mounted in the compressor driven and non-driven bearings. These probes are monitored continuously by the control system. Alarm and shutdown levels are set to protect the compressor from excessive vibration levels. Axial probes are also provided for position monitoring (except C505J).

Resistance temperature devices (RTDs) are mounted in the compressor bearing drains (except for the C505J model) and thrust bearing. Alarm and shutdown levels are set to protect the compressor bearings from excessive temperature levels.

12 Enclosure

12.1 General Description

The enclosure housing, Figure 20, is a completely self-contained, weatherproof, insulated, and sound-attenuated system. The enclosure is mounted on the package skid and supported by a heavy-duty frame. The enclosure sides include removable panels and/or doors to allow access to major components for inspection and maintenance and to permit removal of components by forklift or overhead crane. The engine area is furnished with bi-fold type doors to facilitate engine removal from either side of the package. All enclosure doors include a three-point heavy-duty door locking mechanism, handles, hinges, latching mechanism, internal lock override release, restraining device, and attaching hardware.

The enclosure panels are treated with fiberglass material for sound attenuation and thermal insulation. Weather stripping is installed between all panels for sealing and sound attenuation. The enclosure is normally factory assembled on the package skid prior to shipment, but can be drop shipped pre-assembled for site installation or shipped as a kit for site assembly and installation. The following standard features are included with the basic enclosure:

- Inlet and exhaust ventilation silencers
- Single fan ventilation system
- Pressurization system
- AC lighting
- Equipment handling system
- Stainless steel door hardware
- IP 34 ingress protection rating

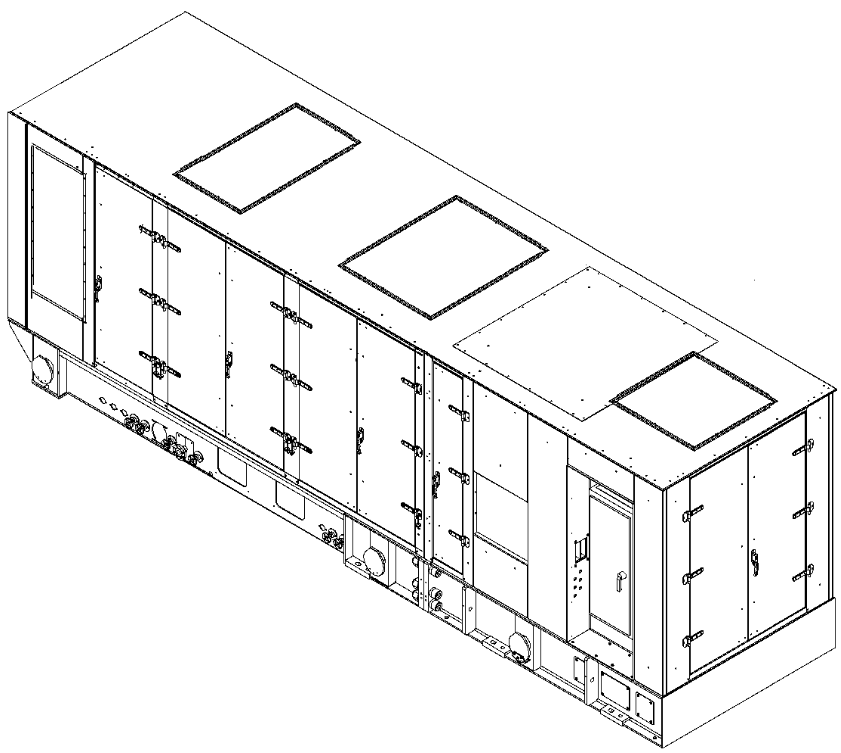


Figure 20. Typical Taurus 60 Enclosure

12.2 Standard Features

12.2.1 Inlet and Exhaust Ventilation Silencers

The enclosure ventilation openings are equipped with silencers with weather louvers.

12.2.2 Single-Fan Ventilation

A single high efficiency motor-driven fan provides enclosure ventilation. The ventilation fan provides airflow to ensure the enclosure internal air temperature remains within acceptable limits. Fan size can vary depending on the ventilation system filtration configuration. Fan motor wiring is terminated at the motor junction box. Enclosure ventilation openings are provided to facilitate airflow circulation. For additional ventilation or certification requirements, a dual fan ventilation system may be selected as an option.

12.2.3 Enclosure High Temperature Alarm

A heat sensor, completely separate from the fire system thermal detectors, is mounted in the enclosure. The sensor is set to activate an alarm if enclosure temperature is abnormally high.

12.2.4 Pressurization System

For completely enclosed packages, the driver section of the enclosure has a negative pressure to prevent the escape of the internal atmosphere through the enclosure seams. The driven section of the enclosure has a positive pressure to prevent the entry of potentially hazardous external atmospheres. A differential pressure switch is provided to indicate an alarm when low enclosure pressure is detected.

12.2.5 Lighting

Fluorescent lighting is provided to illuminate the enclosure interior. Lighting on/off switches are provided on the enclosure exterior.

12.2.6 Equipment Handling Kit

An internal gas turbine and component handling kit is provided that consists of the following:

- Internal maintenance frame trolley rails
- 3048-mm (10-ft) external extensions to the maintenance frame trolley rails with support frame (shipped separately)
- Rail hugger chain-fall hoists and trolley
- Internal vertical support beams (shipped separately)

The trolley beam extension allows gas turbine removal through the side of the enclosure. One end of the beam extension attaches to the inside trolley rail; the other end is floor-standing. The gas turbine can be removed through either enclosure side and placed on a truck bed or cart.

12.2.7 Sound Attenuation

The sound-attenuated enclosure is intended for use with suitable gas turbine air inlet and exhaust silencing systems in environments where low noise levels are required. Enclosure ventilation openings are equipped with silencers to achieve maximum sound attenuation. The actual achievable noise reduction is a function of the noise source, installation considerations, other equipment in close proximity, and the acoustical characteristics of existing buildings and barriers.

The intent of the enclosure design is to comply with U.S. Occupational Safety and Health Administration (OSHA) standards for eight-hour employee exposure. Transmission loss of the panels in decibels is available upon request. Further information is available in Solar's publication SPNP, "Noise Prediction Guidelines for Industrial Gas Turbines."

12.2.8 Exterior Connections

Connections for oil vent line, fire and gas suppression systems, and gas turbine air inlet and exhaust are terminated outside the enclosure.

12.2.9 Fire and Gas Detection System

Enclosed packages must include a fire and gas control system. The fire and gas system shown in Figure 21 provides gas monitoring, fire detection, and extinguishing agent release using an advanced distributed architecture to monitor gas, heat, and optical flame detectors. The system communicates with the *Turbotronic* 4 control system to initiate a shutdown if a fire or a high gas level is detected. On the package exterior, indicator lights, strobe lights, and an alarm horn provide system status. A keyswitch is provided to inhibit the system and a push button switch is provided to manually release the fire-extinguishing agent.

The primary fire detection system uses multispectrum infrared (MIR) detectors. The system includes an automatic optical integrity feature to provide a continuous check of the optical surfaces, detector sensitivity, electronic circuitry of the detector-controller system, and automatic fault identification with digital display of system status in numerical code. The secondary detection system consists of rate-compensated thermal detectors. The two detection systems act independently in detecting and reporting a fire.

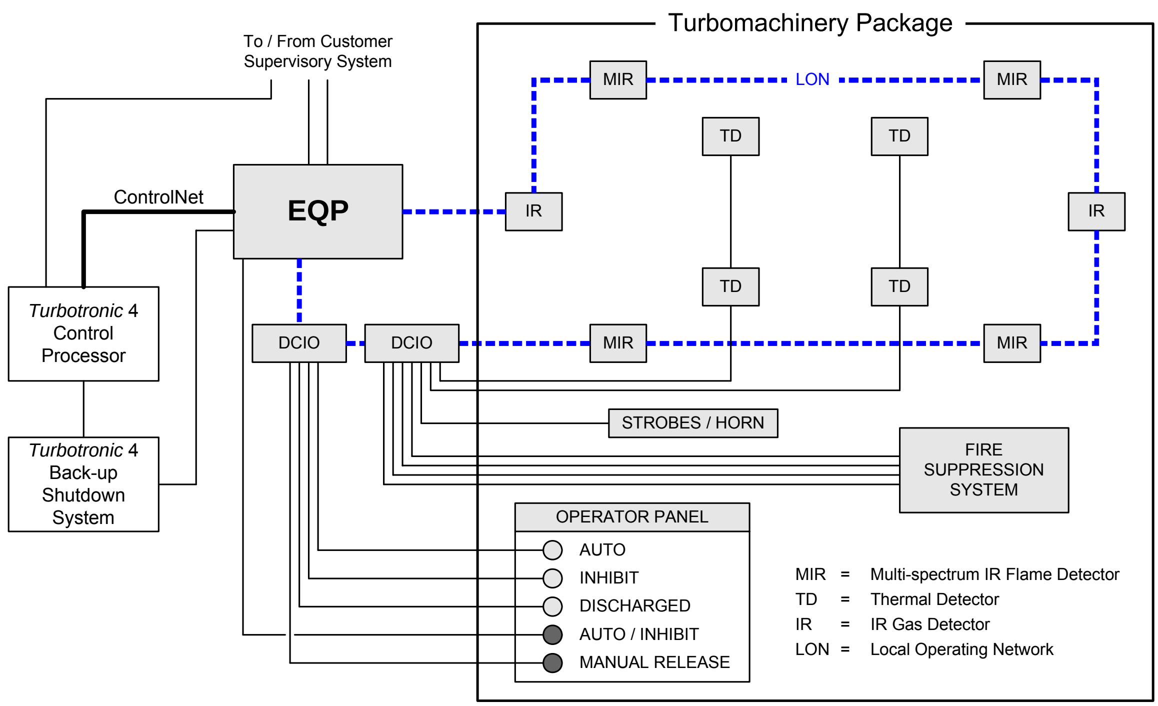


Figure 21. Typical Fire and Gas System

The fire system control panel provides system supervision (for open circuit, ground fault, or loss of integrity), initiates alarm and release of fire suppression agent, and visual display of system status. The suppression system agent release is activated automatically with release solenoids located on the fire suppression skid. The optional CO_2 or water mist suppression system can also be activated manually by switches mounted on the gas turbine enclosure or at the suppression skid. If a fire is detected, the fire detectors transmit an electrical signal to the fire system control panel to activate the fire alarm and suppression system.

The enclosure is also equipped with two gas detectors: one at the gas turbine enclosure ventilation air inlet and the other at the ventilation exhaust to provide continuous monitoring of combustible gases. The detectors consist of IR hydrocarbon sensors that provide input to the logical operating network (LON) module. The gas turbine start signal is interlocked with the combustible gas monitoring system to ensure the atmosphere is safe prior to initiating a turbine engine start. An alarm is initiated if the gas monitor fails.

12.3 Optional Features

12.3.1 Enclosure Configuration

An enclosure can be selected to house both the gas turbine and driven equipment or only the gas turbine.

12.3.2 Dual Fan Ventilation

The enclosure can be ventilated with a dual AC motor-driven fan system. The fan motor wiring is terminated at the motor junction box. Openings are provided to ensure adequate airflow is circulated through the enclosure. For Conformité Européenne (CE) Mark certification, the second or backup ventilation fan is mandatory and must be powered by an AC source independent from the package power system. This independent power source is not provided by Solar.

12.3.3 Dust Protection System

The enclosure ventilation inlets are equipped with a single-stage, disposable, barrier-type filter unit equipped with a differential pressure alarm switch. The ventilation exhaust openings are equipped with back-draft dampers to prevent the entry of dust when the unit is not running.

12.3.4 Dust and Moisture Protection System

The enclosure ventilation inlet can be equipped with a two-stage filter unit consisting of a first-stage vane separator and a second-stage filter. The moisture eliminator section is hinged for filter access. The unit is equipped with a differential pressure alarm switch and gauge. The ventilation exhaust opening is equipped with back-draft dampers to prevent the entry of dust and water when the unit is not running.

12.3.5 Standby Lighting

Standby lights provide emergency, automatic, and backup lighting inside the enclosure in the event of an AC power loss. Power is supplied from the package battery system. To avoid battery system drainage, the circuitry includes a shutoff timer.

12.3.6 Door Open Alarm

The enclosure doors can be equipped with a door position switch that will initiate an alarm when any enclosure door is not closed securely.

12.3.7 CO_2 Fire Suppression System

The enclosure can be equipped with a CO_2 fire suppression system consisting of a primary total flooding distribution system and a secondary metered distribution system to extend the design concentration of 37% CO_2 for 20 minutes.

On fire detection by the optional fire and gas detection system, the detectors transmit an electrical signal via the fire control panel to activate the fire suppression system release solenoids located in the CO_2 fire suppression cylinder cabinets, Figure 22. On receipt of this signal, the solenoid actuated control heads activate the CO_2 cylinders, releasing CO_2 into the enclosure. CO_2 pressure actuates the pressure trip operated dampers that close all vent openings. CO_2 release control heads are also provided with manual release levers.

12.3.8 Water Mist Fire Suppression System

The enclosure can be equipped with a water mist (fine water spray) fire suppression system consisting of a high-pressure distribution system to provide approximately 10 minutes continuous water discharge. The typical water mist fire suppression cylinder cabinet, Figure 23, consists of two high-pressure nitrogen cylinders used as a propellant and five water bottles.

On detection of a fire by the optional fire and gas detection system, the fire control panel activates the fire suppression system release solenoids located on the water mist suppression skid. On receipt of this signal, the solenoid actuated control heads activate the discharge valves on the water cylinders, releasing a water mist into the enclosure. A pressure switch in the water mist discharge piping transmits an electrical signal to the fire control panel to activate a release solenoid to close pressure-operated dampers on all vent openings. The water mist nitrogen actuator valve is also provided with a manual release lever.

12.3.9 Fire Cylinder Cabinets

When installed outdoors, weatherproof fire cylinder cabinets are available to house the extinguishing agent. The cabinets are equipped with service doors. The manual pull levers are routed by cable to the exterior wall of the cabinet.

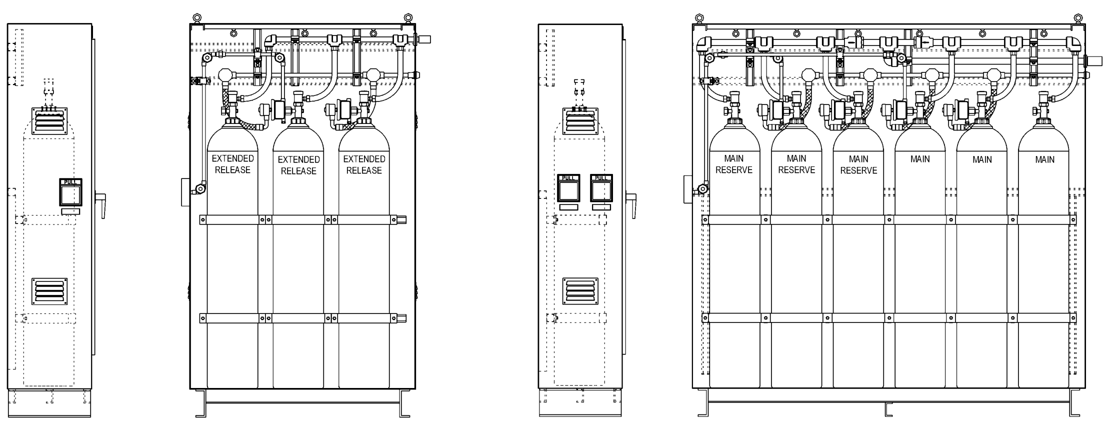


Figure 22. Typical CO_2 Suppression Fire Cylinder Cabinets

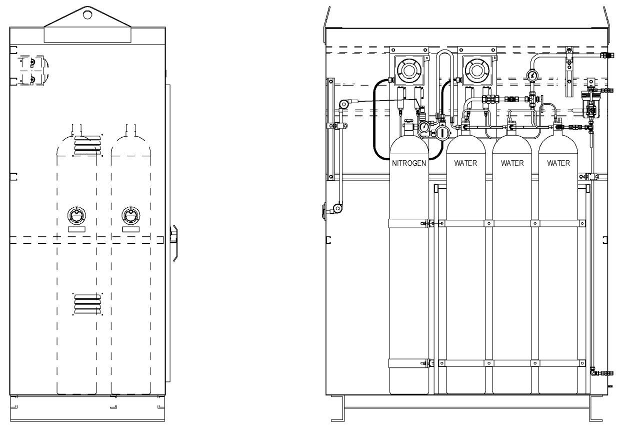


Figure 23. Typical Water Mist Suppression Fire Cylinder Cabinet

Table 11. Enclosure Specifications

Enclosure	
Optional Ventilation Fan Motor Voltage Ratings	380 VAC, 400 VAC, and 415 VAC (50 Hz) 460 VAC and 575 VAC (60 Hz)
Primary Enclosure Lighting Voltage	220 VAC (50 Hz) or 110 VAC (60 Hz)
Standby Enclosure Lighting Voltage	120 VDC
Sound Pressure Level	**See Note (a)**
Enclosure Roof Load	244 kg/m^2 (50 lb/ft^2)
Enclosure Wind Load	193 kph (120 mph)
Approximate Measurements	
Height	2.6 m (8 ft 6 in.), Does Not Include Ventilation Ducting
Width	6.4 m (21 ft), With Enclosure Doors Open and Engine Removal Hoist Attached
Driver Length	6.1 m (20 ft)
Driven Length (Single Body Compressor)	4 m (13 ft)
Approximate Weights	
Gas Turbine Enclosure	3054 kg (6750 lb)
Compressor Enclosure (Single Body)	1656 kg (3660 lb)
Fire Suppression System Compliance	
CO_2 Fire Suppression System	U.S. National Fire Protection Association (NFPA) 12 United States Coast Guard (USCG) CFR 46
Water Mist Fire Suppression System	U.S. NFPA Code 750 USCG CFR 46
Water Mist Fire Suppression System	
Minimum Operating Temperature	4°C (40°F), Optional Heater Available
CO_2 Fire Cylinder Cabinets	
Fire Cylinder Cabinet, Main	
Height	213 cm (84 in.)
Width	152 cm (60 in.)
Depth	53 cm (21 in.)
Approximate Cabinet Weight	429 kg (946 lb), Without Cylinders
Approximate Cylinder Weight	45 kg (100 lb)

CO_2 Fire Cylinder Cabinets (Cont'd)	
Fire Cylinder Cabinet, Extended Release	
Height	213 cm (84 in.)
Width	152 cm (60 in.)
Depth	53 cm (21 in.)
Approximate Cabinet Weight	429 kg (946 lb), Without Cylinders
Approximate Cylinder Weight	45 kg (100 lb)
Water Mist Fire Cylinder Cabinet	
Fire Cylinder Cabinet	
Height	241 cm (95 in.)
Width	165 cm (65 in.)
Depth	61 cm (24 in.)
Approximate Cabinet Weight	1297 kg (2859 lb), Without Cylinders
Approximate Cylinder Weight	1697 kg (3741 lb)
Construction Materials	
Enclosure Housing	Carbon Steel
Enclosure Door Hardware	316L Stainless Steel
Fire Cylinder Cabinets	Carbon Steel 316L Stainless Steel (Optional)
Dust and Moisture Protection System	Carbon Steel 316L Stainless Steel (Optional)

Solar's Applicable Engineering Specifications	
ES 1593	Guidelines for NEC Compliance of *Solar* Product Lines: Class I, Group D, Division 1 and Division 2
ES 1762	Standards and Practices for Electrical Systems for Gas Turbine Packages Installed In Hazardous Areas (CENELEC/IEC Standards – European ATEX Directive 94/9/EC)
Solar's Applicable Product Information Letters	
PIL 054	OSHA Noise Requirements
PIL 058	Package Sound Levels
PIL 150	Fire and Gas Detection and Control System

Notes:

(a) The estimated A-weighted sound pressure level is 85 dBA at a distance of 1 m (3 ft) from the enclosure wall and a height of 1.5 m (5 ft). This value is based on an average of multiple readings taken around the perimeter of the package. This level applies only to the enclosed equipment and is exclusive of sound generated by piping, unenclosed driven equipment (if applicable), other equipment, reflected sound, or contributing site conditions. Sound levels at a specific site will depend on existing walls, barriers, equipment in close proximity, multiple units, and other installation considerations.

13 Air Inlet System

13.1 General Description

The gas turbine combustion process requires a steady and consistent flow of clean air. Proper gas turbine inlet air filtration is critical to gas turbine life. Careful consideration should be given to selecting the appropriate air filtration system. Solar offers several air filtration systems that conform to a broad range of operating requirements. For unenclosed packages, the turbine air inlet can be mounted on the right-hand or left-hand side of the package in a vertical or 45-degree angle to vertical position. For enclosed packages, the air inlet must be in the vertical position. Figure 24 shows typical *Taurus 60* inlet systems and support structures.

13.1.1 Prefilter and Barrier Inlet Air Filter

The prefilter and barrier inlet air filter system is suitable for moderate environments. This system features vertical moisture eliminators, prefilter elements, and high efficiency barrier filters. Access doors are provided in the filter housing for servicing. A weather hood and insect screens are available as options. The filter house has a back outlet and requires ducting and a support frame.

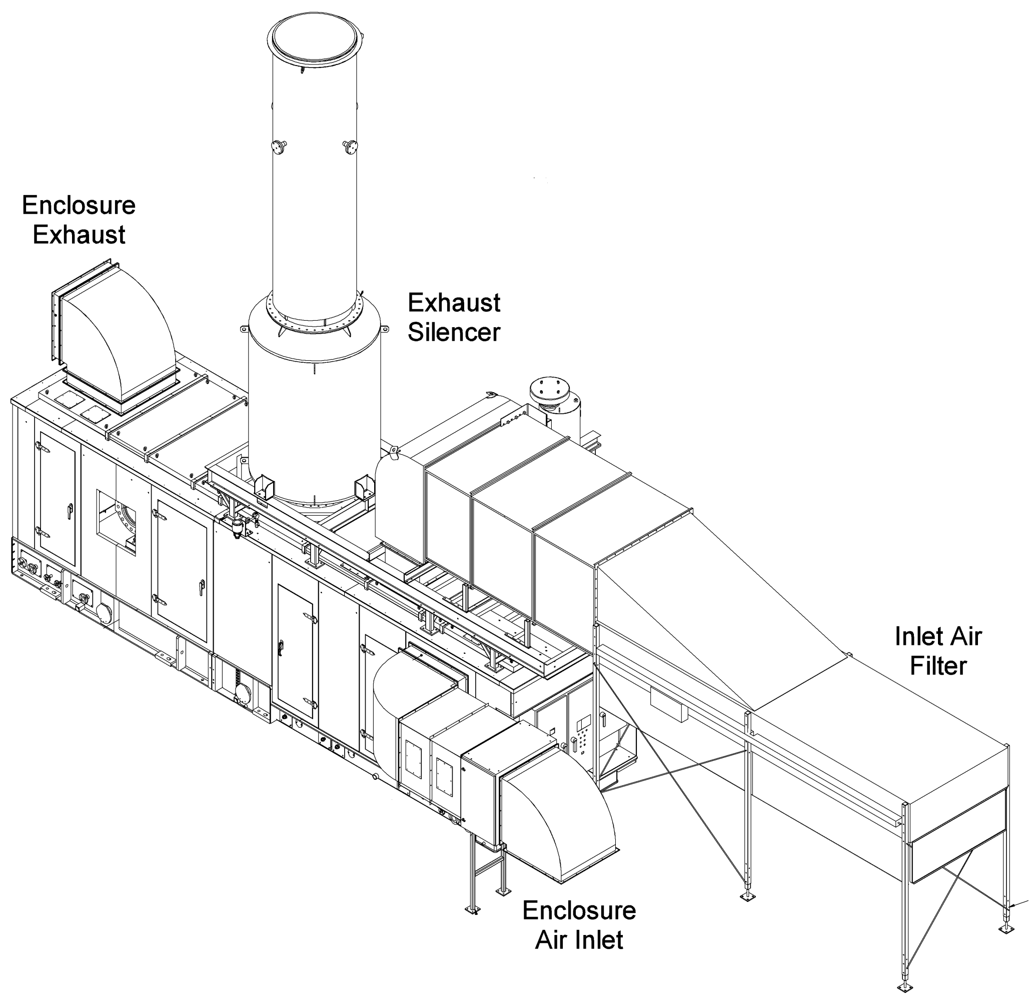


Figure 24. Typical Enclosed Taurus 60 Package with Exhaust and Inlet Systems

13.1.2 Self-Cleaning Barrier Type Air Filter

The self-cleaning barrier type air filter system is suitable for extreme environments where dust loading or cold-weather operation is a concern. This system is available in an updraft configuration. This system requires a suitable supply of cleaning air. Cleaning air can be provided by the customer or supplied using turbine compressor discharge pressure (Pcd) bleed air. If bleed air is used, an air heat exchanger is provided for mounting in the air inlet ducting between the air inlet filter and the turbine air inlet. Standard features include:

- Support leg kit (Filter house only)
- Dual differential pressure alarm and shutdown switch
- Filter elements
- Air treatment module
- Differential pressure gauge
- Electrical connections prewired to a common junction box
- Access to change filter elements from below must be provided

13.1.3 Marine / Offshore-High Velocity Type Air Filter

The marine and offshore high velocity air filter system (Figure 25) is suitable for use in many offshore applications. This system provides removal of salt, water, and particulates. This system consists of:

- First stage marine vane separator/moisture eliminator
- Second stage prefilter
- Third stage bag filters
- Fourth stage marine vane separator/moisture eliminator

Access doors are provided in the first stage marine vane separator/moisture eliminator for filter removal. Standard features include:

- Drainage system
- Transition outlet flange
- Lifting lugs
- Instrumentation panel
- Differential pressure gauge
- Quad Certified Differential Pressure Transmitter
- 2 Different Final Filter element types available (HVL, HVX)

HVX filter elements allow for a higher level of filtration. This is recommended for environments with moderate dust loading expectations. The pressure drop on HVX filter elements will be higher than HVL elements.

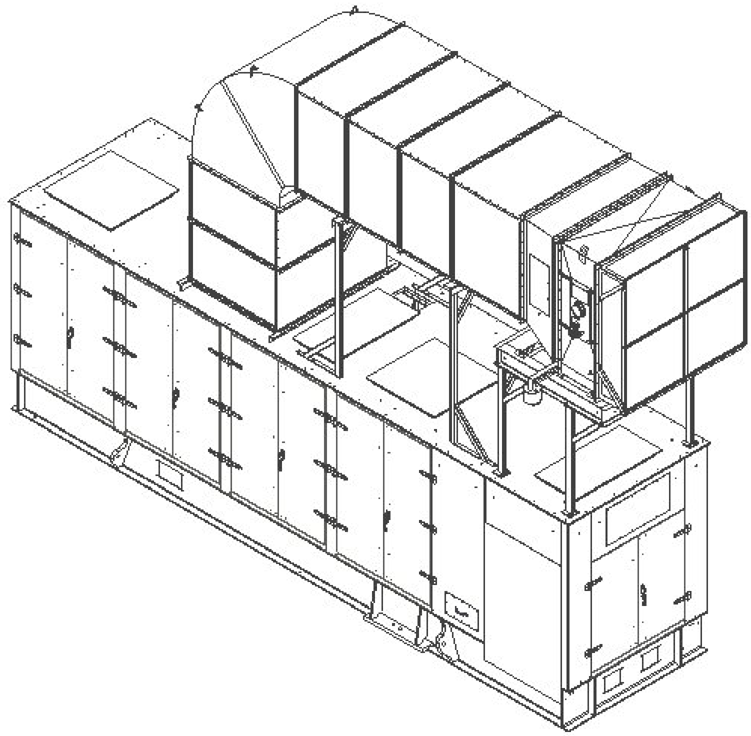


Figure 25. Typical Taurus 60 High Velocity Air Inlet System

13.1.4 Offshore / Coastal Medium Velocity Type Air Filter

The offshore and coastal medium velocity type air filter system (Figure 26) is suitable for use in offshore and coastal applications. This system provides high efficiency removal of salt, water, and particulates. This filter is recommended in extreme conditions (reference ES 9-98) or when higher efficiencies and / or availability is desired. This system consists of:

- First stage marine vane separator/moisture eliminator
- Second stage pre-filter
- Third stage high efficiency HEPA filters
- Optional Fourth stage High Efficiency Filters

Access doors are provided to change out the 2nd, 3rd and optional 4th stage filters. Standard features include:

- Transition outlet flange
- Lifting lugs
- Differential pressure gauge
- Quad Certified Differential Pressure Transmitter
- LH / RH Access Door

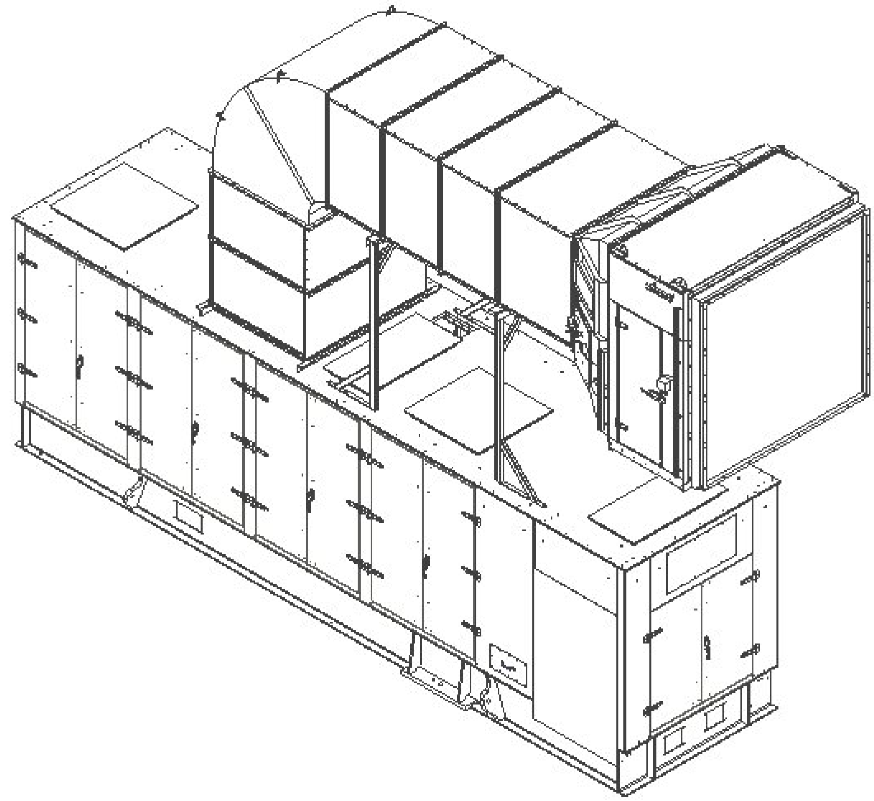


Figure 26. Typical Taurus 60 Medium Velocity Air Inlet System

13.1.5 Insect Screens

Optional insect screens can be installed on the air inlet filters (except for self-cleaning filters). This option is used when large numbers of insects are present. The screen is designed to reduce the velocity of the air stream sufficiently to allow most insects to fly away. Use of the screen helps to avoid clogging and premature filter replacement. During cold weather operation, the screens should be removed and stored due to a potential for ice or snow to clog the screens.

13.1.6 Air Inlet Gas Detection

Gas detection in the air inlet system can be provided with either one or three gas detectors. For enclosed packages, the signals from the detectors are integrated into the enclosure's fire and gas system via that system's local network. For unenclosed packages, the detectors provide a 4-20mA signal directly to the control system.

13.1.7 Air Inlet Silencer

Optional air inlet silencers can be incorporated into the air inlet ducting to reduce noise levels. Typical installations include one air inlet silencer..

13.1.8 Air Inlet Ducting and Support

An optional support structure and ducting can be provided for offskid support of the air inlet filter and silencer assembly. Attaching hardware and a tube of sealant are provided for one flange per duct.

Table 12. Air Inlet System Specifications

Air Inlet System	
Pressure Drop	Less Than 102 mm (4 in.) H_2O with a Clean Air Filter
Ducting Loads	Should Not Be Applied In Any Direction
Prefilter and Barrier Inlet Air Filter	
Air Flow	17 m^3/s (36,000 cfm)
Approximate Measurements	
Height	229 cm (90.0 in.)
Width	225 cm (88.6 in.)
Length	167 cm (65.8 in.)
Weight	1406 kg (3100 lb)
Pressure Drop	
Clean	44 mm (1.75 in.) water
Fouled	127 mm (5 in.) water
Self-Cleaning Barrier Type Air Filter	
Fluid	Clean-Dry Air
Air Quality	See Note (a)
Minimum/Maximum Regulated Pressure Range	552 to 758 kPag (80 to 100 psig)
Intermittent Flow Rate (Est.)	0.25 nm^3/min (9 scfm)
Pressure Drop	
Clean	25 mm (1.0 in.) water
Fouled	76 mm (3.0 in.) water
Air Flow	17 m^3/s (36,000 cfm)
Approximate Measurements	
Height	239 cm (94.0 in.)
Width	232 cm (91.3 in.)
Length	620 cm (244.1 in.)
Weight	2500 kg (5500 lb) with filter elements
Marine / Offshore High Velocity Type Air Filter	
Pressure Drop (Clean), HVL	53 mm (2.1 in.) water
Pressure Drop (Clean), HVX	61 mm (2.4 in.) water
Air Flow	17 cms (36,000 cfm)
Approximate Measurements	
Height	206 cm (81.1 in.)
Width	198 cm (78.1 in.)
Length	153 cm (60.4 in.)
Weight	739 kg (1630 lb) with filter elements
Offshore / Coastal Medium Velocity Type Air Filter	
Pressure Drop (Clean) - 3 stage	33 mm (1.3 in.) water
Pressure Drop (Clean) - 4 stage	53 mm (2.1 in.) water
Air Flow	17 cms (36,000 cfm)
Approximate Measurements	
Height	280 cm (110.3 in.)
Width	280 cm (110.3 in.)
Length	312 cm (122.7 in.)
Weight	2056 kg (4532 lb) with filter elements (4 stage)

Construction Materials	
Prefilter/Barrier	Carbon Steel (Standard); 316L Stainless Steel (Optional)
Insect Screen (Optional)	316L Stainless Steel
Self Cleaning Barriers	Carbon Steel (Standard); 316L Stainless Steel (Optional)
Marine High Velocity Air Cleaner	316L Stainless Steel
Offshore / Coastal Medium Velocity Type Air Filter	316L Stainless Steel (Standard), Carbon Steel (Optional for mild coastal environments)
Air Inlet Silencer	Carbon Steel (Standard); 316L Stainless Steel (Optional)
Air Inlet Support Structure	Carbon Steel (Standard)

Solar's Applicable Product Information Letters	
PIL 054	OSHA Noise Requirements
PIL 178	Salt Ingress Protection for Gas Turbines

Notes:

(a) The particle size in the compressed air stream should not exceed 10µm. Since it is impractical to remove 100% of all particles larger than 10µm, this is defined as ß10 > 100, or 99% efficient. Oil or hydrocarbon content should not exceed 1 ppm. The dew point at line pressure shall be at least 6°C (10°F) below the minimum temperature to which any part of the air system is exposed or between 1.6°C and 60°C (35°F and 140°F). Air should be free of all corrosive contaminants, hazardous gases, flammables, and toxics.

14 Exhaust System

14.1 General Description

The exhaust system typically consists of all components installed downstream of the engine exhaust bellows expansion joint, including silencers, expansion joints and ducting, that are necessary to ensure a smooth flow of exhaust gas from the engine. The exhaust duct system must be terminated in a manner that precludes recirculation of exhaust products through the engine air inlet or oil cooler. Exhaust considerations include the relative height of the exhaust duct above the air inlet, building roof design, direction of prevailing winds, and the proximity of adjacent structures. The importance of having an exhaust system properly designed cannot be overemphasized. When exhaust silencing is required, provisions must be made to adequately mount and support the equipment and limit the exhaust silencer pressure loss, with no loads transmitted to the turbine exhaust. Exhaust systems should be designed to meet the following requirements:

- Where two or more units exhaust into a common header, such as used for heat recovery equipment, provisions must be made to prevent hot gas from flowing into the non-operating unit (common exhaust ducting is not recommended).
- Final termination of ducting must not allow exhaust gas to be drawn into the gas turbine inlet.
- Capability to purge the complete exhaust system prior to gas turbine lightoff. For short simple exhaust systems, purging should be designed to accomplish three air volume changes. For large complex exhaust systems, purging should be designed to accomplish five air volume changes either through gas turbine cranking or supplementary exhaust blowers.

14.1.1 Exhaust Silencer

This exhaust silencer is designed for use with radial exhaust gas turbines. A support structure and ducting can be provided to support the exhaust silencer assembly. Brackets are available for mounting the silencer in a vertical or horizontal position. Figure 24 shows a typical *Taurus 60* mechanical drive with a radial exhaust silencer.

14.2 Turbine Exhaust Heat Recovery System

High thermal efficiencies can be obtained by using the gas turbine exhaust heat energy. There are several methods for using the exhaust heat and attaining greater than 80% fuel utilization. The methods used and the efficiencies achieved are primarily dependent on the type of application. The most common uses are:

1. Producing steam with a heat recovery steam generator (HRSG) or heating a process fluid with a heat recovery fluid heater.
2. Using the gas turbine exhaust as a source of preheated combustion air in a boiler or furnace (the gas turbine exhaust contains 15-18% oxygen).
3. Using the gas turbine exhaust directly for a drying or heating process in which high temperature air is necessary. A mixture of gas turbine exhaust and fresh air can be used in a reduced air temperature process. An air-to-air heat exchanger is required when the process involves any products in the human food chain.

Solar can design and provide a complete exhaust heat recovery system to meet specific application requirements. The system must be designed to minimize the backpressure imposed on the gas turbine exhaust and provide a smooth flow transition into the exhaust heat recovery device.

Table 13. Exhaust System Specifications

Exhaust System	
Temperature Class	T2
Total System Pressure Loss	Should Not Exceed 152 mm (6 In.) of Water
Exhaust Temperature	538°C (1000°F)
Nominal System Back Pressure	203 mm (8 in.) of water, **See Note (a)**
Construction Materials	
Exhaust Silencers	Carbon Steel 316L Stainless Steel (Optional)
Exhaust Ducting	Carbon Steel 316L Stainless Steel (Optional)
Exhaust Bellows Expansion Joint	Carbon Steel 316L Stainless Steel (Optional)
Solar's Applicable Engineering Specifications	
ES 1632	Exhaust Silencers for *Solar* Turbine Engines

Notes:

(a) Higher backpressures can be accommodated. The exhaust backpressure should be less than 254 mm (10 in.) water column during gas turbine starting.

15 Accessory Equipment

15.1 Battery Charger System

The battery charger system consists of a battery charger (Figure 27) and batteries to provide 120 VDC emergency power to the control console, fuel valve, bleed valve and variable guide vane actuators, and the DC backup lube oil pump. The control console 120 to 24 volt DC-to-DC converter provides 24 VDC power for the control system. The battery charger system is designed for indoor installation in a nonhazardous area. Battery options include:

- Valve Regulated Lead Acid
- Nickel Cadmium

15.1.1 Valve Regulated Lead Acid

The batteries are mounted on a freestanding two-tier, two-row rack. The batteries are shipped fully charged and ready for use.

15.1.2 Nickel Cadmium

The batteries are mounted on a freestanding, four-step rack. The batteries are shipped wet, fully charged, and ready for use.

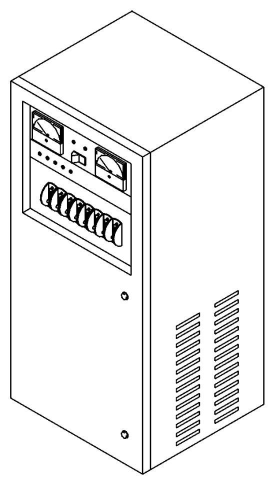


Figure 27. Typical Battery Charger

15.2 Turbine Cleaning System

The optional turbine compressor cleaning system (Figure 28) facilitates periodic cleaning of the turbine compressor. The cleaning system is designed for use in salt-laden or dusty environments or where compressor contamination from hydrocarbon vapors is possible. The turbine compressor cleaning system is composed of the following systems:

- On-crank cleaning system
- On-line cleaning system

Both cleaning systems are independent of each other and include a separate distribution manifold with pressure atomizing spray nozzles in the engine air inlet collector, onskid piping, strainer, and solenoid shutoff valves to deliver water or approved cleaning fluid to the manifold. Both systems require an external source of clean-filtered air to pressurize the cleaning solutions.

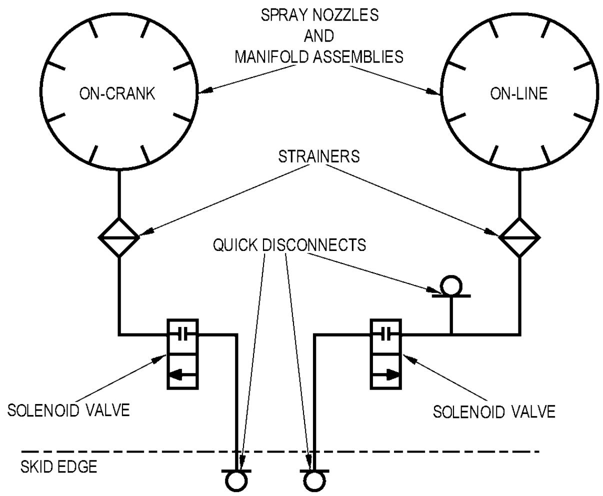


Figure 28. Turbine Cleaning System

15.2.1 On-Crank Cleaning System

The on-crank cleaning system only operates at gas turbine cranking speed with the fuel system and ignition system deactivated. The gas turbine cranking and cleaning solution activation can be initiated from the control console or turbine control junction box.

15.2.2 On-Line Cleaning System

The on-line cleaning system only operates when the gas turbine speed is between 90 and 100% gas producer speed and with or without load. Cleaning solution activation can be initiated from the control console or turbine control junction box. This system is intended to supplement the on-crank system by increasing the time intervals between periodic on-crank cleaning.

15.2.3 Turbine Cleaning Cart (Optional)

A portable offskid cleaning tank (Figure 29) can be provided to supply cleaning fluid to the skid edge cleaning system connection. The cleaning tank can be used to mix, hold, and pressurize the turbine cleaning solution. The tank comes with wheels that are removable for stationary installation.

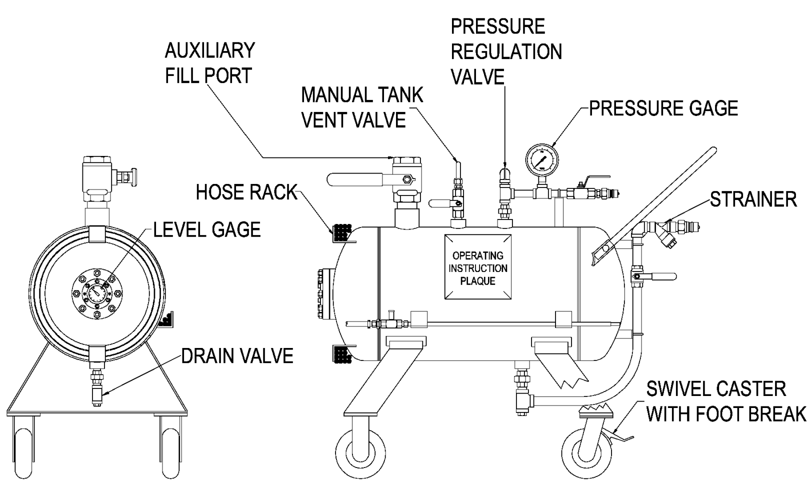


Figure 29. Turbine Cleaning Cart

15.2.4 Package Lifting Kit (Optional)

A package lifting kit can be shipped separately that contains slings, spreader bars, and assorted hardware to facilitate separate lifting of the driver and driven equipment modules with or without an export crate.

Table 14. Accessory Equipment Specifications

Battery Charger System	
Charger Type	Wall Mounted, Bottom Entry, IP30
Supply Voltage	240, 380, and 480 VAC, 50 or 60 Hz.
Output	Single Phase, 120 VDC, 20 amps
Operating Temperature	-10° to 50°C (14° to 122°F)
Approximate Measurements	
Height	90.2 cm (35.5 in.)
Width	40.4 cm (15.9 in.)
Depth	39.7 cm (15.63 in.)
Weight	56.7 kg (125 lb)
Ampere Hours	
Valve Regulated, Sealed Gas-Recombination Lead Acid	100 Hours
Nickel Cadmium	131 Hours
Turbine Cleaning System	
Water/Solvent Supply Pressure	85 to 100 psig (586 to 689 kPag)
Water/Solvent Supply Min. Temperature	Ambient (Except In Extreme Cold)
On-Line Water/Solvent Flow Rate	2.3 – 4.5 L/min (0.6 – 1.2 gpm)
On-Line Propulsion Air Flow Rate	0.026 nm^3/min (0.98 SCFM)
Package On-Line Triple Stage Strainer	300/200/100 Micron
On-Crank Water/Solvent Flow Rate	9.1 – 12.9 L/min (2.4 – 3.4 gpm)
On-Crank Propulsion Air Flow Rate	0.080 nm^3/min (3.0 SCFM)
Package On-Crank Triple Stage Strainer	300/200/100 Micron
External Air Supply	Clean Filtered Air
Air Supply Pressure	586 to 690 kPag (85 to 100 psig)
Turbine Cleaning Cart	
Capacity	98 L (26 gal)
Tank Discharge Strainer	100 Micron
External Air Supply	Clean Filtered Air
Air Supply Pressure	586 to 690 kPag (85 to 100 psig)
Approximate Measurements	
Height	102 cm (40.2 in.)
Width	55 cm (21.7 in.)
Length	121.6 cm (47.87 in.)
Approximate Weight	86 kg (190 lb)
Tank Material	316L Stainless Steel
Certification	American Society of Mechanical Engineers (ASME) or Pressure Equipment Directive (PED)
Electrical Certifications	
CSA	LR 77954
Solar's Applicable Engineering Specifications	
ES 9-62	Ingestive Cleaning Solar Gas Turbine Engines
ES 9-98	Fuel, Air, and Water (or Steam) for Solar Gas Turbine Engines
ES 2416	DC Supply Systems

16 Marinization

16.1 General Description

The *Taurus 60* Compressor Set and Mechanical Drives may be operated in offshore oil and gas applications. Depending upon operating conditions and movement of the underlying support structure, optional package modifications may be required. *Solar* turbomachinery packages operate successfully on the following types of offshore installations:

- Fixed Platform (FP)
- Tension Leg Platform (TLP)
- Compliant Tower (CT)
- Spar Platform (SP)
- Semi-submersible Platform (SSP)
- Floating Production Systems (FPS)
- Floating Production, Storage and Offloading (FPSO)
- Mini-Tension Leg Platform (Mini-TLP)

Applications are evaluated based on the expected motion severity and the degree of package mounting surface flexing. Solar offers the following package modifications to achieve successful long-term operation. Refer to Solar’s Engineering Specification ES2379 for additional information.

16.1.1 Gimbals (Optional)

Gimbals provide protection against G-forces generated by vessel pitch and roll movements and against deflection, twisting, and thermal growth of the mounting deck. Gimbals may be used for three-point package mounting.

16.1.2 Anti-Vibration Mounts (Optional)

Anti-vibration mounts (AVMs) are used to isolate the mounting surface from package-generated vibrations. AVMs do not provide the same level of motion protection as gimbals. AVMs may be used for three-point package mounting.

16.1.3 Internal Package Modifications

Moderate or severe package motion can potentially interfere with lube oil system operation. To prevent interference, modifications may be made to the lube oil system to ensure proper lube oil circulation.

16.1.4 Inclinometers

For moderate and severe duty applications, an inclinometer is furnished to provide alarm annunciation and equipment shutdown inputs when maximum allowable angular displacements are exceeded. Alarm levels are typically set 2 degrees below shutdown levels.

16.1.5 Certification

Certification is typically required to demonstrate offshore turbomachinery compliance with applicable rules for a fixed or mobile offshore installation. Solar can provide the necessary certification or assist the customer in obtaining certification. Involvement of one of the following certifying authorities is usually required:

- Det Norske Veritas (DNV)

- Bureau Veritas (BV)
- Lloyd's Register (LR)
- American Bureau of Shipping (ABS)

16.1.6 Deck Deflection Limits

The package supporting deck structure must have sufficient stiffness to maintain alignment of the turbine and driven equipment under dynamic vessel motion. Solar's engineering specification ES 2379, "Offshore Product Motion Requirements for Oil & Gas Package Designs," lists the maximum allowable deflections measured between the furthest mounting points. With analysis, these limits may be extended through the use of gimbals or AVMs.

16.1.7 Angular Displacement and Acceleration

ES 2379 lists the maximum allowable angular displacement and acceleration limits for marine applications. The Basic Duty category is met by the standard package without any additional modification. Moderate Duty and Severe Duty categories require modification.

16.1.8 Main and Auxiliary Service

The information provided in this section does not apply to equipment used in "Main and Auxiliary Service". If equipment is intended for this type of service, please contact Solar Turbines Incorporated for guidance to ensure the correct application and certification requirements are meet.

17 Quality Assurance and Testing

17.1 Quality Assurance

Solar is an Industry Standards Organization (ISO) 9000 company with ISO 9001:2000 and 9002 certification. Several *Solar* gas turbine models and manufacturing processes have been "type" certified. In recognition of Solar's commitment to quality, Solar has received Manufacturing Resource Planning (MRP) II Class A certification and the Malcolm Baldrige National Quality Award. Solar has developed a comprehensive set of processes to address areas such as engineering requirements, manufacturing and assembly standards, and test procedures and acceptance criteria.

Upon request, Solar will evaluate customer-required standards to assess Solar's ability to comply. Project inspection, testing, and quality assurance (QA) documentation, along with customer or third-party involvement in the QA process, is defined in the inspection and test plan (ITP). The ITP is the controlling quality assurance document for a project. Since advance procurement is involved in Solar's production process, special inspection and documentation milestones may be missed if these requirements are not defined at the project outset.

All testing operations are conducted under the direct control of Solar's QA department, which ensures compliance with specified test procedures. In addition to in-plant testing of the finished package, quality control engineers survey the manufacture of all purchased parts and subassemblies and are responsible for functional testing of incoming components. The same rigid standards applied to parts manufactured both in and outside of Solar.

17.2 Testing

Factory testing is in accordance with Solar's test specifications and as outlined below. The customer or customer's designated representative can observe factory production tests listed in the production and testing schedules. However, production tests will not be delayed due to the unavailability of the customer or customer's representative. The production test facilities provide a comprehensive test program using simulators to perform static testing of package systems to verify control, system operation, and component calibration. Calibrated engine test cells feature a computerized real-time data acquisition system that collects digital and analog data from the engine during acceptance testing to facilitate a comprehensive test report.

17.2.1 Test Phases

Solar's production test facilities provide a three-phase test program. The first phase uses simulation equipment to perform static testing of the control console and package systems to verify electrical and fluid system continuity and calibration. The second phase consists of interconnecting the package and control console (if applicable) to undergo additional simulated systems testing of the total package. In the final phase, the package is controlled and monitored by its own control console and the computerized test facility.

17.2.2 Acceptance Testing

The basic package assembly, which includes the gas turbine, package-mounted accessories, and control console, are tested to ensure proper integration and function in accordance with Solar's test specifications. Results are recorded and maintained by Solar. Acceptance testing generally includes the following:

- Starting and combustion cycles
- Lubricating oil system temperature and pressure measurements
- Vibration measurements

- Power and heat rate measurements at partial and full load under ambient conditions
- Turbine and driven equipment temperature measurement
- Variable guide vane adjustment
- Malfunction and safety devices testing

Items excluded from standard package testing are inlet and exhaust systems, ancillary equipment such as filters, silencers, ducting, battery systems, oil coolers, ancillary skid, and any customer-furnished hardware.

17.2.3 Compressor Testing (If Applicable)

Prior to assembly of the internal components, all compressor casings are subjected to hydrostatic testing per API 617. The gas compressor is then tested following a procedure similar to the gas turbine run-in test. For an aerodynamic test, the gas compressor is driven by a facility turbine or electric motor at the air equivalent of the design speed, and the head-versus capacity characteristics of the machine are determined. Surge points are determined at various speed points to validate the surge flow estimate for the entire operating range of speed. Extensive instrumentation validates mechanical and aerodynamic performance. The gas compressor dry gas system is tested statically by pressurizing with nitrogen.

17.2.4 Acceptance Test Data

Acceptance test data are reviewed and approved by Test Engineering and the project manager prior to submittal to the customer. With this review and approval cycle, the test data are furnished approximately four weeks after completion of acceptance testing. The test data includes test result comparisons to Solar's acceptance test specifications using calculations, graphs, strip charts, and descriptions. Data are provided for each turbine compressor set and mechanical drive. The acceptance test data generally includes the following:

- Turbine fuel consumption rates – a comparison of measured fuel consumption versus specified fuel consumption that shows a correlation between fuel consumption, power output, and turbine gas temperature at full load.
- Operating values – a chart that includes the following operating parameters at each step load from no load to full load (full load data only available from engine test on facility skid.):
  - Lubricating oil pressure, temperature and flow
  - Package temperatures
  - Engine compressor discharge pressure
  - Package vibration levels

17.2.5 Additional Testing

As an option, additional testing can include an unloaded string test, factory emissions testing, and field performance testing.

17.2.6 Source Inspection

As an option, Solar can conduct a final product inspection at the supplier facility for the following contract-specific items:

- Inlet system filter
- Inlet system silencer
- Exhaust system silencer
- Lube oil cooler

17.2.7 Customer Participation

As an option, the customer may observe specified tests on a noninterference basis and/or hold point basis.

17.2.8 Weld Radiography

As an option, radiographic welding inspections can be performed on a higher percentage of the gas fuel and/or lube oil system piping and manifolds.

18 Preservation, Installation, and Documentation

18.1 General Description

This chapter describes preservation, general installation requirements, and project documentation.

18.2 Preservation

Long term or short term preservation can be provided for the engine and package. The type of preservation required is dependent on the following:

- Type of transportation (sea, air, or truck)
- Climatic conditions during transport and storage
- Storage period
- Storage facilities
- Static and dynamic loads imposed during shipment

Refer to Solar's Product Information Letter 097 "Package Preservation and Preparation for Shipment" for additional guidelines.

18.2.1 Long-Term Preservation

Long-term preservation is required if:

- Equipment will be stored in an unimproved storage area for greater than 6 months before installation
- Transportation is by ship
- Transportation includes transshipment (package will go from truck to barge to truck, etc., e.g., rigorous loads will be encountered during shipment)
- Package will be exposed to severe weather conditions during transport

18.2.2 Short-Term Preservation

Short-term preservation may be acceptable if:

- Equipment will be stored in an improved storage area for less than 6 months before installation
- Transportation is not by ship
- Transportation does not include transshipment (package will not go from truck to barge to truck, etc., e.g., rigorous loads will not be encountered during shipment)
- Package will not be exposed to severe weather conditions during transport

18.3 Site Requirements

Solar's gas turbine compressor sets and mechanical drives require minimal site preparation. The package is supplied with self-contained systems for starting, fuel, lube oil, and control, minimum piping and wiring connections are required for installation. All service connections are conveniently located on the outer edge of the skid.

18.4 Mechanical Installation

18.4.1 TPIM-1010

Solar's document TPIM-1010 "Package Installation Guideline – Compressor Sets and Mechanical Drives" outlines the responsibilities of the Customer and Solar regarding installation of the package. It provides guidelines for the installation of the standard package design and the interface with the turbine driven equipment.

18.4.2 Mounting

Correct mounting of the gas turbine package is vital to successful package installation and requires adequate preparation by the user. The site pad thickness is governed by soil condition and the weight of the gas turbine package, air inlet system, and exhaust system. Mounting pad locations and loads will differ with each package, depending upon selected options, and will be clearly shown on the installation drawings. The equipment layout should provide adequate floor space for major components with sufficient room around the package for routine maintenance access.

18.4.3 Alignment Tooling

As an option, alignment tooling can be provided to align the turbine or gearbox output shaft hub to the driven equipment input shaft hub. The alignment tooling includes a dial indicator kit, alignment tool, axial distance gauge, and custom storage container.

18.4.4 Lube Oil Cooler(s)

The lube oil cooler(s) can be mounted on an ancillary support frame on top of the enclosed package or located offskid.

18.4.5 Gas Turbine Air Inlet System

The gas turbine air inlet should be located so that entry of gas turbine exhaust, oil tank vent vapor, or other contaminants is minimized. The air inlet duct must be free of accumulated water prior to starting the gas turbine.

18.4.6 Gas Turbine Exhaust System

The importance of having an exhaust system properly installed cannot be overemphasized. A poorly installed exhaust system can cause a loss of power and impose severe mechanical strains on the gas turbine. The exhaust duct system must be terminated in a manner that precludes recirculation of exhaust products through the gas turbine air inlet or oil cooler. Exhaust installation considerations include the relative height of the exhaust duct above the air inlet, building roof design, direction of prevailing winds, and the proximity of adjacent structures. When exhaust silencing is required, provisions must be made to adequately mount and support the equipment and limit the exhaust silencer pressure loss.

18.5 Documentation

Solar provides extensive documentation for its Turbomachinery projects. This includes electrical and mechanical drawings, quality control data books, and operation and maintenance manuals. Details of this documentation and its delivery timetable are contained in Solar's Product Information Letter 184 "Order Fulfillment & Documentation for Oil & Gas Projects."

18.5.1 Torsional Analysis Report (Optional)

A torsional analysis can be performed on the entire drive train to determine if there are any significant torsional resonance conditions within ±10% of the operating speed range.

If a resonance condition (interference) is found, then a fatigue analysis is performed to confirm the resonance will not cause fatigue failure in the shafting.

18.5.2 Lateral Analysis Report (Optional)

A lateral forced response analysis of the driven equipment can be performed to confirm that any lateral critical speeds aren't close enough to the operating speed range to cause lateral vibration problems.

Table 15. Preservation, Installation, and Documentation Specifications

Mechanical Installation Requirements	
Mounting	
Space Between Units In Multiple-Unit Installations	A Minimum of 2.4 m (8 ft)
Lube Oil Cooler(s)	
Top of The Lube Oil Cooler(s)	Not Be More Than 9.1 m (30 ft) Above The Bottom of The Package Frame, **See Note a**
Total oil volume of “Outgoing and Return” Lines	1282 L (340 gal)
Total Combined Pressure Drop of The Supply and Return Lines and Lube Oil Cooler(s)	Should Not Exceed 345 kPag (50 psig)
Start, Fuel, Lube, Air/Drain System Schematics	
Compliance	American National Standards Institute (ANSI) Y32.10
Solar's Applicable Engineering Specifications	
ES 9-4	Interpretation of Drawing Requirements
ES 9-76	Traceability Requirements Critical Parts, Engine and Related Systems
ES 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cables Installed In Class 1, Division 2 Hazardous Areas
ES 9-414	Leveling and Installing of Package Bases
Solar's Applicable Product Information Letters	
PIL 097	Package Preservation and Preparation for Shipment
PIL 181	Package Tie-down Options
PIL 184	Order Fulfillment & Documentation for Oil & Gas Projects
Solar's Applicable Guidelines	
TPIM-1010	Package Installation Guidelines – Compressor Sets and Mechanical Drives

Notes:

(a) This is to prevent oil tank flooding in the event of a drain back.

19 Certification

19.1 General Description

Solar's leadership in the gas turbine industry is supported by its ability to comply with regulations, codes, and standards required by industry and/or regional authorities around the world. Solar continually evaluates compliance requirements to ensure conformance to the following standards:

- National Electrical Code (NEC)
- Canadian Electrical Code (CEC)
- Conformité Européenne (CE) Mark
- International Electrotechnical Commission (IEC) Safety Assessment
- Australian/New Zealand Standard (AS/NZS) 3000 Wiring Rules
- Offshore Marine Applications

19.2 National Electrical Code

For installations that require National Electrical Code (NEC) certification, Solar complies with the NEC codes and standards adopted by local authorities and government entities. Sources for these codes and standards include:

- Occupational Safety and Health Administration (OSHA)
- National Fire Protection Association (NFPA)
- Underwriters Laboratories Incorporated (UL)
- American Society of Mechanical Engineers (ASME)
- National Association of Corrosion Engineers (NACE)

The following OSHA approved Nationally Recognized Testing Laboratories (NRTLs) provide approval for codes and standards:

- Underwriters Laboratories Incorporated (UL)
- Factory Mutual (FM)
- Canadian Standards Association (CSA), when certifying to U.S. standards
- Entela Incorporated (ENTELA)

(CSA and UL also develop and promulgate standards).

The NEC establishes classification of hazardous sites in terms of Classes, Divisions, Zones, and material Groups. Class I covers locations where flammable gases may be present in quantities sufficient to ignite. Division 1 covers situations where flammable gases may be present as part of a process, while Division 2 covers locations where flammable gas is less likely to be present.

19.3 Canadian Electrical Code

For installations that require Canadian Electrical Code (CEC) certification, Solar complies with the CEC codes and standards adopted by local authorities and government entities. Sources for these codes and standards include:

- Canadian Standards Association (CSA), electrical requirements only
- Entela Inc. (ENTELA), when certifying to Canadian standards
- Underwriters Laboratories Inc. (UL), when certifying to Canadian standards

19.4 Conformité Européenne Mark

For installations that require Conformité Européenne (CE) Mark certification, Solar complies with the CE Mark codes and standards adopted by local authorities and government entities. Sources for these codes and standards include the following European Union (EU) directives:

- Explosive Atmospheres (ATEX) Directive 94/9//EC
- Pressure Equipment Directive 97/23/EC
- Machinery Safety Directive 98/37/EC
- Electromagnetic Compatibility Directive 89/336/EEC
- Low Voltage Directive 73/23/EEC

19.4.1 Methods of Establishing Conformity

To ensure compliance with applicable directives, Det Norske Veritas (DNV), an approved Notified Body, supports Solar's efforts to comply with directives by providing consultation and, where applicable, certification. Solar also has a program to obtain "type certification" for standard turbomachinery packages for ATEX and PED directives.

With the exception of ATEX and PED directives, Solar self-certifies for CE Mark requirements. This self-certification process includes the following:

- The package is designed and manufactured to European Committee for Electrotechnical Standardization (CENELEC) and European Committee for Standardization (CEN) standards.
- A hazard analysis is performed to define any and all conceivable hazards.
- Tests are performed to verify proper operation and functionality of components and systems.
- Operation and Maintenance Instruction (OMI) manuals, package labels, and control system display screens are produced in the operator's native language.
- Prior to application of the Conformité Européenne (CE) Mark, the Test Facilities, Production, Quality, and a Compliance Engineer perform an audit of the completed package.
- A Declaration of Conformity is then issued for each CE Marked package.

19.4.2 Solar Compliance

International Electrotechnical Commission (IEC) / Electrotechnical Standardization (CENELEC) (60079-10) categorizes hazardous areas in terms of Zones shown in Table 16.

Table 16. Zone Classifications

Zone	Definition
0	Explosive atmosphere continuously present
1	Explosive atmosphere often present
2	Explosive atmosphere may be present under fault conditions

While electrical systems can be provided to meet Zone 1 or Zone 2, under ATEX, compressor sets and mechanical drives can only be certified for Zone 2 due to the hot surface temperature of the gas turbine.

19.5 International Electrotechnical Commission Safety Assessment

International Electrotechnical Commission (IEC) 61508 is an international standard that describes a standardized approach to Asses the functional safety of electric, electronic, and programmable electronic safety-related systems. This standard is based on a life-cycle evaluation of system reliability and safety level determination. Safety integrity levels are categorized as SIL1, SIL2, SIL3, and SIL4. Levels are established by assessing the potential for personnel injury, equipment damage, and environmental damage. The installation site design and operating requirements will determine the applicable SIL level. Solar can provide reliability data on its equipment to assist customers in their overall safety assessments.

19.6 Offshore Marine Applications

For installations that require offshore marine certification, Solar conforms to the rules and standards established by certification authorities and/or customer specifications. Certification can be performed by one of the following authorities:

- Det Norske Veritas (DNV)
- American Bureau of Shipping (ABS)
- Lloyd’s Register (LR) of Shipping
- Bureau Veritas (BV)

Solar can provide certification or provide supporting information to permit certification by another party.

19.6.1 Det Norske Veritas Certification

Det Norske Veritas (DNV) certification includes design verification and a manufacturing survey. DNV witnesses the fabrication and testing of engines and packages. Operations witnessed by DNV are defined in the inspection and test plan (ITP) that is prepared by Solar’s Quality department and approved by DNV at the beginning of a project.

To eliminate redundant inspections, Solar has established a manufacturing survey arrangement (MSA) with DNV for a specific group of products. This MSA is based on a DNV audit of Solar's Quality System. The MSA authorizes Solar to carry out a specific level of inspections and tests without the presence of a DNV representative.

19.6.2 American Bureau of Shipping

The American Bureau of Shipping (ABS) performs design appraisals and inspections. Typically, ABS certification is performed according to ABS “Guide for Building and Classing Facilities on Offshore Installations,” 1991. ABS certification of *Solar's* gas turbines is based on compliance with the American Petroleum Institute (API) Standard 616, with standard exceptions.

19.6.3 Lloyd’s Register of Shipping

Typically, Lloyd’s Register (LR) of Shipping performs design appraisals and manufacturing surveys. LR recognizes engine type approvals provided by DNV. LR’s test and inspection witness points are defined in the project Inspection and Test Plan (ITP).

19.6.4 Bureau Veritas

Bureau Veritas (BV) performs design appraisals and manufacturing surveys. Typically, BV certification is performed according to BV publication “Floating Production, Storage and Offloading Units Ch 10 NR456 April 1998.” Certification of *Solar's* gas turbines is based on compliance with the American Petroleum Institute (API) Standard 616, with specified exceptions.

19.7 Summary

Solar has a continuing program to support customers in ensuring that Solar's products conform to applicable codes and regulations. Solar also has the resources to provide customer guidance and assistance in this process.

Table 17. Certification Specifications

Solar's Applicable Engineering Specifications	
ES 1593	Guidelines for NEC Compliance of Solar Product Lines: Class I, Group D, Division 1 and Division 2
ES 1762	Standards and Practices for Electrical Systems for Gas Turbine Packages Installed in Hazardous Areas (CENELEC Standards)
ES 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cables Installed In Class 1, Division 2 Hazardous Areas
Solar's Applicable Product Information Letters	
PIL 127	Product Certification

20 Support Services

20.1 Construction Services

Solar's Construction Services organization offers a comprehensive range of equipment and services to successfully meet power system expectations and needs. Our experience takes us to many parts of the world, onshore and offshore, managing various types of power configurations. Our services are based on years of experience and expertise in power system engineering and complete project management that include:

- Feasibility studies
- Proposal preparation
- Design and engineering
- Material procurement
- Fabrication
- Onsite construction
- Quality control
- Scheduling
- Budget control
- Shipping
- Installation, testing, and commissioning

Material procurement, for example, can include prime movers, driven equipment, associated mechanical process equipment, and electric power generation equipment. Construction Services is uniquely qualified worldwide to provide complete fluid compression, liquid pumping, and power generation systems, with single-source responsibility, engineering expertise, optimal economic designs, and real attention to quality and safety to ensure complete power system satisfaction

20.2 Customer Services

Solar's Customer Services organization is dedicated to the support of *Solar's* equipment worldwide. Customer Services support includes technical training, field service personnel, service parts, overhaul and repair services, and customized operation and maintenance programs. Customer Services also offers gas turbine uprates and updates, retrofit conversions to low emission *SoLoNOx* turbine configurations, and complete package refurbishments, all of which provide cost-effective life-cycle solutions.

Solar's Customer Services organization is known for its excellent service and support that no other gas turbine service company can compare in:

- Product knowledge and experience with more than 12,500 units in 93 nations
- In-depth technical support via Solar's global Customer Information Network
- Factory-qualified repair and overhaul procedures
- Genuine Solar Certified Parts
- Worldwide field service personnel and service facilities
- Around-the-clock response
- Exchange engine program to minimize your downtime

Solar stands behind each of our customers with uncompromising commitment to the success of their turbomachinery installations throughout the equipment's life cycle.

20.3 Contract Power and Leasing Services

Solar offers numerous financing options. All or part of a project can be financed, offered under a lease agreement, or installed on a service tariff with a performance contract. Financing or leasing terms can extend from short-term rentals to long-term leases of 10 years or more. Financing can be structured as full-payout financing instruments that lead to ownership or as off-balance sheet operating leases that can allow for the return of the equipment at the end of the lease.

Under a performance contract, Solar may supply, install, operate, maintain, and own the equipment, as well as auxiliary components required to provide the service, such as electric power, steam, or compressed gas. The tariff charged by Solar is based on the amount of service delivered. Solar has extensive worldwide background in financing and in providing power contracts to assist you in determining the best financial option to optimize your economic return from the turbomachinery project.

20.4 Solar's Worldwide Locations

Solar maintains sales and service facilities throughout the world. For a list of the current locations, please visit Solar on the Internet at www.solarturbines.com.

Conversion Chart

Conversion Factors				
To Convert From English	**To S.I. Metric**	**Multiply By**	**To Convert To Old Metric**	**Multiply By**
Btu	kJ	1.0551	kcal	0.252
Btu/h	W	0.2931	kcal/h	0.252
Btu/scf	kJ/nm^3	39.3694	$kcal/nm^3$	9.382
cfm	m^3/min	0.028317	m^3/min	0.028317
cfm	m^3/s	0.00047195	m^3/s	0.00047195
cu ft	m^3	0.028317	m^3	0.028317
°F	°C	(°F-32) 5/9	°C	(°F-32) 5/9
°F (Interval)	°C (Interval)	5/9	°C (Interval)	5/9
ft	m	0.3048	m	0.3048
ft-lb_f/lb_m	mJ/kg	0.0029891	kJ/kg	0.002989
ft/s	m/s	0.3048	m/s	0.3048
gal. (U.S.)	L	3.7854	L	3.7854
hp	kW	0.7457	kW	0.7457
in.	mm	25.400	cm	2.540
in. Hg	kPa	3.3769	cm Hg	2.540
in. H_2O	kPa	0.2488	cm H_2O	2.540
kcal	kJ	4.1868		
lb	kg	0.4536	kg	0.4536
lb/cu ft	kg/m^3	16.0185	kg/m^3	16.0185
lb_f-in.	Nm	0.1129848		
MMSCFD	Nm^3/min	18.62	Nm^3/h	1117
mph	km/h	1.6093	km/h	1.6093
psi	kPa	6.8948	kg/cm^2	0.070
psia	kPa (a)	6.8948	bars Abs	0.068948
psig	KPa (g)	6.8948	Ata	0.070
scfm	Nm^3/min	0.0268	Nm^3/h	1.61
sq in.	mm^2	645.16	cm^2	6.4516
sq ft	m^2	0.0929	m^2	0.0929
yd	m	0.914	m	0.914
To Convert From Old Metric	**To S.I. Metric**	**Multiply By**		
Atm	kPa	101.325		
Bar	kPa	100.0		
cm	mm	10		
cm Hg	kPa	1.3332		
cm H_2O	kPa	0.09807		
kcal/h	W	1.16279		
kg/cm^2	kPa	98.0665		
Nm^3/h	Nm^3/min	0.0167		

List of Abbreviations

Abbreviations	
ABS_1	American Bureau of Shipping
ABS_2	Absolute
AGMA	American Gear Manufacturers Association
API	American Petroleum Institute
AS/NZS	Australian/New Zealand Standard
ASME	American Society of Mechanical Engineers
Ata	Atmosphere Absolute
ATEX	Atmosphere Explosive
AVM	Anti-Vibration Mount
AVR	Automatic Voltage Regulation
Btu	British Thermal Unit
Btu/h	British Thermal Units/Hour
BV	Bureau Veritas
CACA	Closed Air Circuit Air Cooled
CACW	Closed Air Circuit Water-To-Air Cooled
CE	Conformité Européene
CEC	Canadian Electrical Code
CEN	European Committee for Standardization
CENELEC	Comité Européen de Normalisation Électrotechnique
cfm	Cubic Feet/Minute
CGCM	Combination Generator Control Module
cm	Centimeter
cm^2	Square Centimeter
cm^3	Cubic Centimeter
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSA	Canadian Standards Association
CT	Compliant Tower
Cu ft	Cubic Feet
°C	Degrees Celsius
dBA	Decibels (Acoustic)
DNV	Det Norske Veritas
ENTELA	Entela Incorporated
ES	Engineering Specification
EU	European Union
FM	Factory Mutual
FP	Fixed Platform
fps_1	Feet Per Second
FPS_2	Floating Production Systems
FPSO	Floating Production, Storage and Offloading
ft-lb	Foot-Pound
$ft\text{-}lb_f/lb_m$	Foot-Pound Force/Pound Mass
ft/s	Feet/Second
°F	Degrees Fahrenheit
gal.	Gallon

Abbreviations (Cont'd)	
hp	Horsepower
HRSG	Heat Recovery Steam Generator
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
in.	Inch
in. Hg	Inches of Mercury
in. H_2O	Inches of Water
IP	Ingress Protections
IR	Infrared
IS	Intrinsically Safe
ISO	International Standards Organization
Isoch	Isochronous
ITP	Inspection and Test Plan
kcal	Kilocalorie
kg	Kilogram
kJ	Kilojoule
kPa	Kilopascal
ksi	1000 pounds/square inch
kw	Kilowatt
L	Liter
LR	Lloyd's Register
m	Meter
mm	Millimeter
MMSCFD	Millions of Standard* Cubic Feet/Day
MPa	Mega Pascal
Mph	Miles per Hour
MRP	Manufacturing Resource Planning
MSA	Manufacturing Survey Arrangement
m^2	Square Meter
m^3	Cubic Meter
m^3/min	Cubic Meters/Minute
N	Newton
N/m^2	Pascal
NACE	National Association of Corrosion Engineers
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	U.S. National Fire Protection Agency
Ngp	Speed, Gas Producer
Nm^3/h	Normal** Cubic Meters/Hour
Npt	Speed, Power Turbine
NOx	Nitrogen Oxides
NRTL	Nationally Recognized Testing Laboratory
ODP	Open Drip Proof
OMI	Operation and Maintenance Instruction
OSHA	U.S. Occupational Safety and Health Administration
QA	Quality Assurance
QC	Quality Control
Pcd	Pressure, Compressor Discharge
PED	Pressure Equipment Directive

Abbreviations (Cont'd)	
PF	Power Factor
PIL	Product Information Letter
PMG	Permanent Magnet Generator
psi	Pounds/Square Inch
psia	Pounds/Square Inch Absolute
psig	Pounds/Square Inch Gauge
rpm	Revolutions Per Minute
RTD	Resistance Temperature Device
scf	Standard* Cubic Foot
scfd	Standard* Cubic Feet/Day
scfm	Standard* Cubic Feet/Minute
sm^3/h	Standard*** Cubic Meters/Hour
SoLoNOx	*Solar* Proprietary Low Emissions System
SP	Spar Platform
sq	Square
TEAAC	Totally Enclosed Air-To-Air Cooled
TEWAC	Totally Enclosed Water-To-Air Cooled
TLP	Tension Leg Platform
UHC	Unburned Hydrocarbon
UL	Underwriters Laboratories Incorporated
UPS	Uninterruptible Power Supply
USCG	United States Coast Guard
UV	Ultraviolet
VAC	Voltage, Alternating Current
VAR	Volt Amp Reactive
VDC	Voltage, Direct Current
VFD	Variable Frequency Drive
VPI	Vacuum Pressure Impregnated

* "Standard" = 60°F, 14.7 psia

** "Normal" = 0°C, 1.01325 x 10^5 Pascals

*** "Standard" = 15°C, 760 mm Hg