

**Solar Turbines**

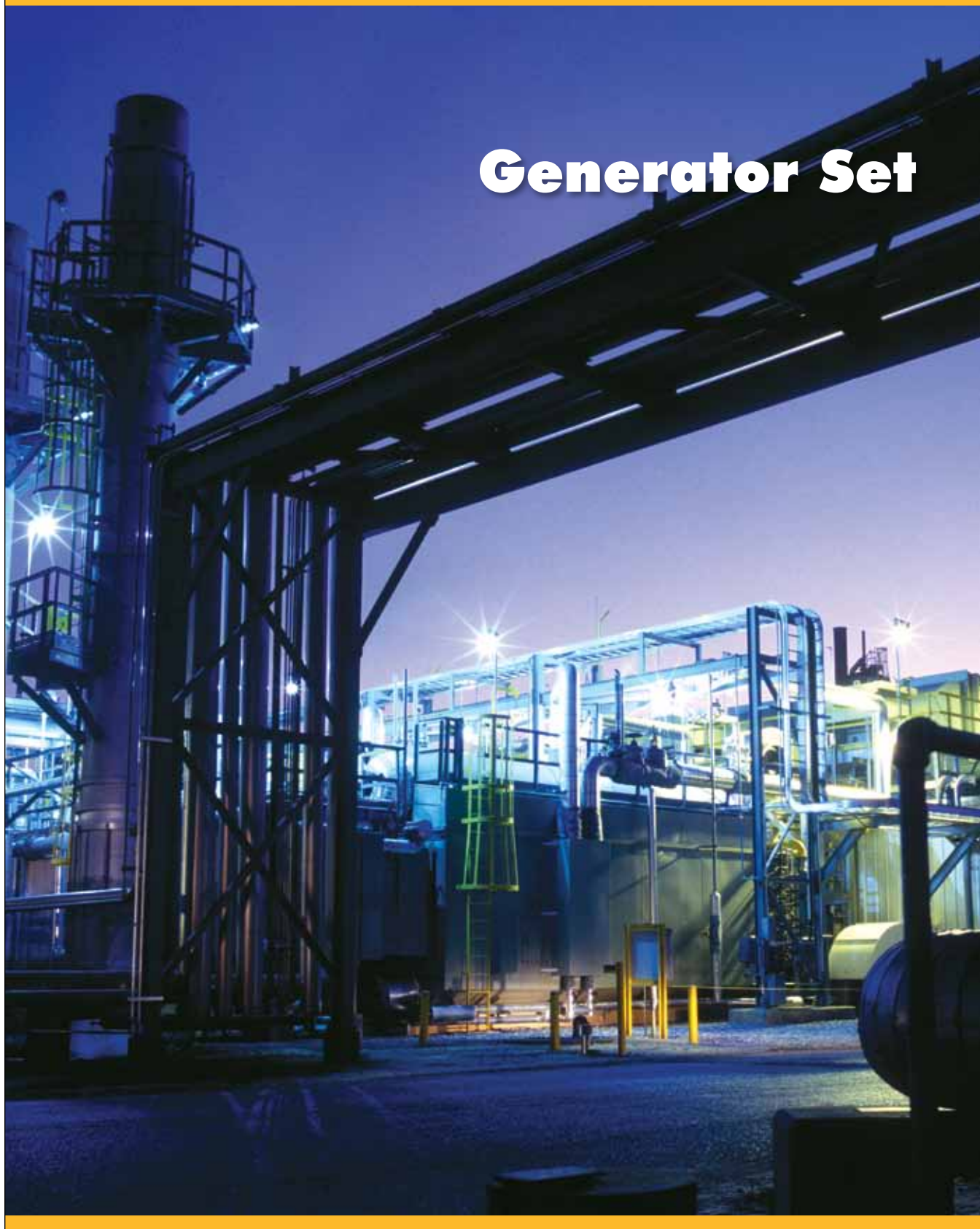
*A Caterpillar Company*

**TITAN 250**

**Turbomachinery Package Specification**

*Oil & Gas and Power Generation Applications*

# Generator Set



# **Solar<sup>®</sup> Turbines**

*A Caterpillar Company*

## **TURBOMACHINERY PACKAGE SPECIFICATION**

### ***Titan*<sup>™</sup> 250 Generator Set**

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# 1 Introduction

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## 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 92 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 operational systems that require a minimum of site preparation prior to installation.

The *Titan 250* generator sets 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

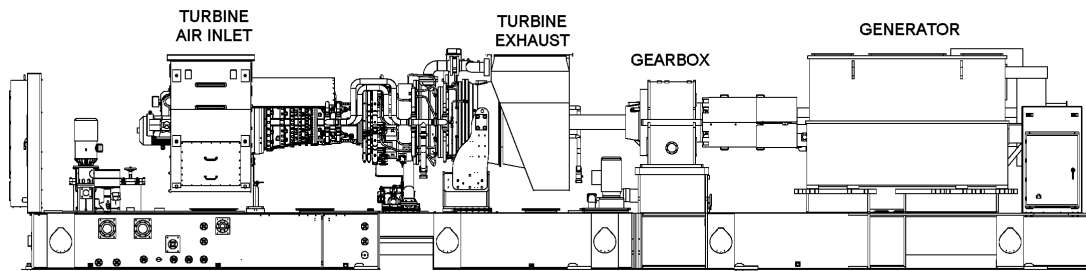
This document describes product features and provides product specification information for the *Titan 250* generator sets. Included are basic package configurations, ancillary descriptions, installation requirements, and a list of customer support services available at the time of publication. Please note that changes in equipment, service descriptions, and specifications may occur without prior notice.

## 2 Titan 250 Gas Turbine Generator Set

### 2.1 General Description

The *Titan 250* gas turbine generator set (Figure 1) is a completely integrated and fully operational package equipped with all accessories and auxiliary systems required for operation. In addition to the standard package features, a wide array of optional equipment is available to meet the customer's installation and operation requirements. Designed specifically for industrial service, Solar's gas turbine generator sets are compact, lightweight, and require minimal floor space for installation. Proven packaging designs greatly reduce installation costs, time, materials, and labor.

The package features a radial exhaust resulting in a short overall package length that conserves valuable mounting space.



**Figure 1. Typical Titan 250 Gas Turbine Generator Set**

### 2.2 Package Description

The gas turbine generator set consists of an axial-flow gas turbine engine, generator, and reduction-drive gearbox. These components are installed in-line on a two-piece heavy-steel base frame referred to as the skid. The skid is a structural steel assembly with beam sections and cross members welded together. The two sections of the skid can be separated to facilitate handling and shipment but when bolted together they form a rigid structure suitable for three-point mounting. 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 onskid junction boxes. Machined mounting surfaces on the skid facilitate component alignment. The gearbox is bolted directly to the engine and coupled by means of a splined interconnecting drive shaft that eliminates the need for field alignment. The gearbox and generator are connected by means of a flexible dry-disk, shear-type coupling enclosed in a coupling guard. Jacking points are provided to facilitate alignment of the generator to the gearbox.

### 2.3 Major Components and Systems

Major components and systems of the gas turbine generator set typically include:

- Gas turbine
- Reduction-drive gearbox
- Generator
- 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 system

### 2.3.1 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
- European Committee for Electrotechnical Standardization (CENELEC)

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

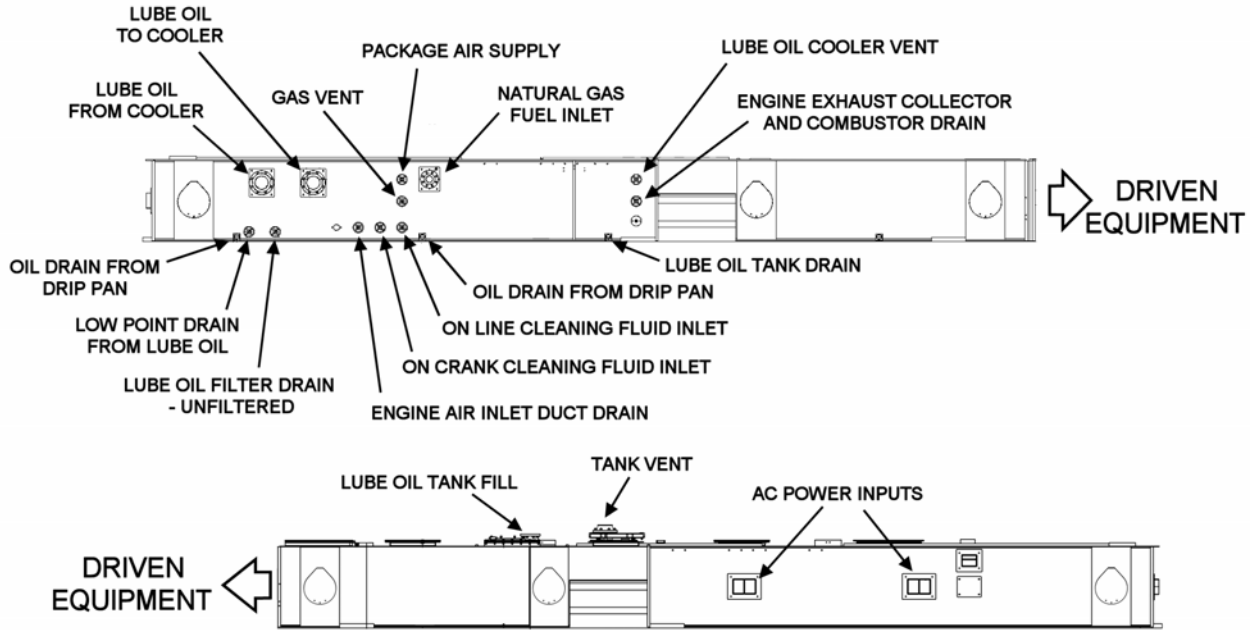
#### Three-Phase Motor Voltage

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

### 2.3.2 Service Connections

The *Titan 250* generator set is supplied with self-contained systems for starting, fuel, lube oil, and control. All service connections (Figure 2) are conveniently located on the outer edges of the skid.





**Figure 2. Typical Titan 250 Generator Set Service Connections (Driver Skid)**

**Table 1. Package Specifications**

Dimensions		
Approximate Package Measurements		
Height, Unenclosed	3.89 m	(12 ft 9 in.)
Height, Enclosed	4.12 m	(13 ft. 6 in.)
Width (to skid edges)	3.37 m	(11 ft 1 in.)
Width (including lifting bollards)	3.60 m	(11 ft 10 in.)
Length, Engine Skid	10.29 m	(33 ft 9 in.)
Length, Generator Skid		
Approximate Package Weights		
AC Start Motor Assembly	450 kg	(990 lb)
Gas Turbine Assembly	19 050 kg	(42,000 lb)
Total Driver (unenclosed package, without oil)	49 900 kg	(110,000 lb)
Total Driver (enclosed package, without oil)	57 600 kg	(127,000 lb)
Generator (unenclosed)		
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 (0.50 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	

<b>Construction Materials</b>	
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	Aluminum
<b>Electrical System Certifications</b>	
NEC	Class 1, Group D, Division 1 or 2
CENELEC	Zone 1 or 2, Group II
CE, ATEX	Zone 2, Group II
<b>Three-Phase Package Motors</b>	
Optional Motor Voltage Ratings	380, 400, or 415 VAC, 50 Hz 460 VAC 60 Hz
<b>Single-Phase Battery Charger</b>	
Optional Battery Charger Voltage Ratings	220, 230, 240, 380, 400, 415, 440, 460, or 480 VAC, 50 Hz or 60 Hz
<b>Single-Phase Lighting and Space Heater Voltage</b>	
Optional Package Lighting and Space Heater Voltage Ratings	120, 220, 230, or 240 VAC, 50 Hz or 60 Hz
<b>Ingress Protection (IP) Ratings</b>	
Onskid Junction Boxes	IP56 to IP66
Control Console	IP50
Battery Charger, NEC	IP22
Battery Charger, CE	IP31
<b>Solar's Applicable Engineering Specifications</b>	
ES 9-56	Fusion Welding
ES 9-58	Standard Paint Program – Turbomachinery
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
<b>Solar's Applicable Product Information Letters</b>	
PIL 127	Product Certification

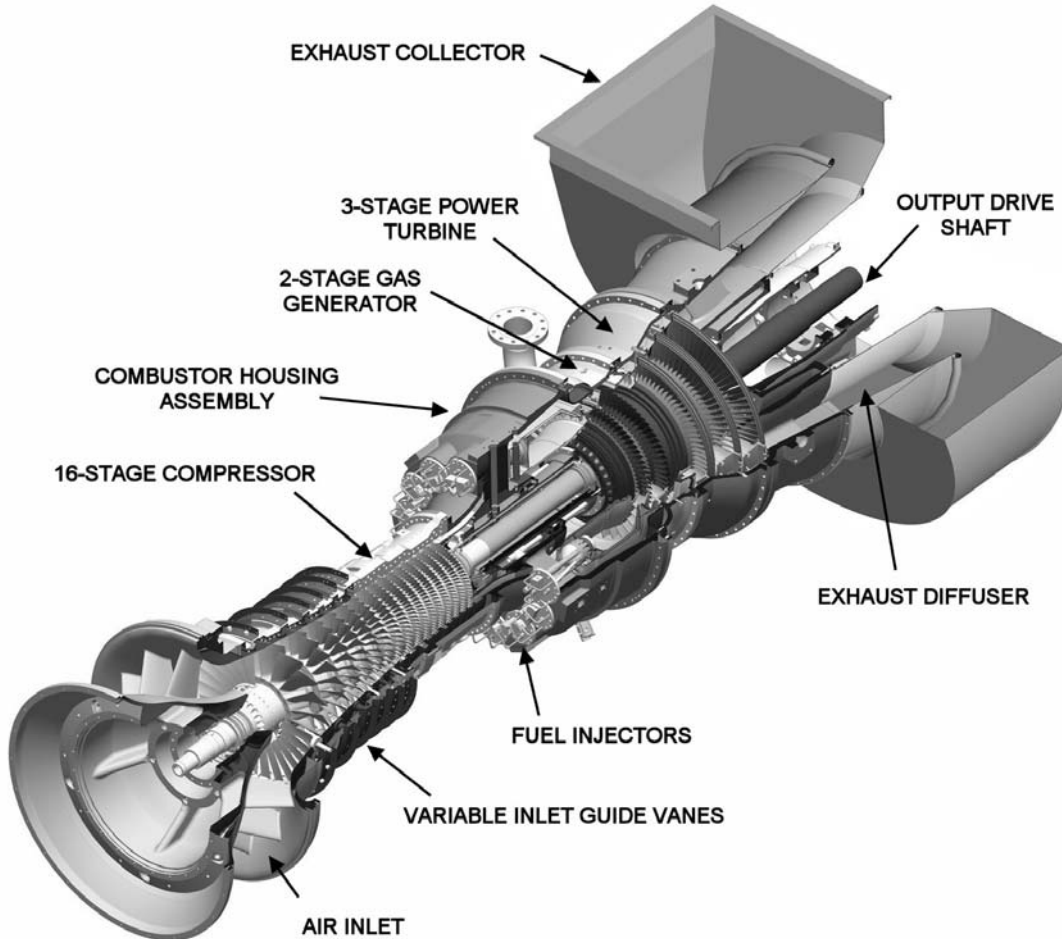
**Notes:**

- (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 Titan 250 Gas Turbine

### 3.1 General Description

The two-shaft *Titan 250* gas turbine (Figure 3) is a completely integrated and self-contained prime mover. The *Titan 250* 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 *Titan 250* gas turbine is designed for a high degree of compliance with American Petroleum Institute (API) requirements.

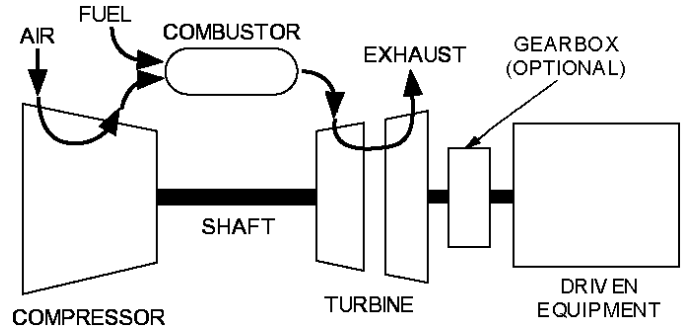


**Figure 3. Titan 250 Two-Shaft Gas Turbine Cutaway**

#### 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**

The *Titan 250* incorporates Solar's proprietary *SoLoNOx* dry emissions system that 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 will work with the customer to meet local permitting emission requirements.

**Table 1. Titan 250 Gas Turbine Specifications**

<b>Compressor</b>	
Type	Axial Flow
Number of Stages	16
Compression Ratio	24:1
Flow (Nominal)	67.3 kg/sec (148 lb/sec)
Speed, Maximum	10,500 rpm
<b>Combustion Chamber</b>	
Type	Annular
Ignition	Torch
Number of Fuel Injectors	14 ( <i>SoLoNOx</i> , Low Emissions)
<b>Gas Generator</b>	
Type	Axial
Number of Stages	3
<b>Power Turbine</b>	
Type	Axial
Number of Stages	2
Speed	7000 rpm
<b>Bearings</b>	
Radial	5 Tilt Pad with Proximity Probes
Thrust	2 Tilt Pad with Resistance Temperature Device Probes

<b>Construction Materials</b>	
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
<b>Protective Coatings</b>	
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
<b>Approximate Weight</b>	
Gas Turbine Assembly	19 050 kg (42,000 lb)
<b>Performance</b>	
Output Power <b>Note (a)</b>	22 370 kW (30,000 hp)
Heat Rate	9000 kJ/ kW-hr (6360 Btu/ kW-hr)
Exhaust Flow	245 660 kg/hr (541,590 lb/hr)
Exhaust Temperature	465°C (865°F)
<b>Temperature Monitoring</b>	
Turbine T5	(12) Thermocouples
<b>Vibration Monitoring</b>	
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
Gas Producer Rotor Shaft	Displacement Probe, Axial Position
Power Turbine Rotor Shaft	Displacement Probe, Axial Position
Gas Producer Rotor Shaft	Keyphasor
Power Turbine Rotor Shaft	Keyphasor
Accessory Gearbox	Velocity Pickup

**Notes:**

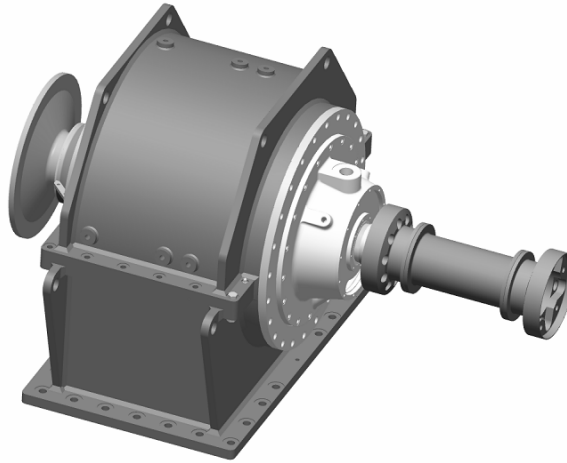
- (b) Performance is calculated under the following conditions:  
 Nominal Rating - ISO at 15°C (59°F), Sea Level  
 No Inlet/Exhaust Losses  
 Relative Humidity at 60%  
 LHV = 31.5 to 43.3 MJ/nm<sup>3</sup> (800 to 1,100 Btu/scf)

## 4 Reduction-Drive Gearbox

### 4.1 General Description

The reduction-drive gearbox (Figure 5) is an industrial, epicyclic, star-gear design selected specifically for generator set applications. The gearbox uses few moving parts, which provides high reliability and ease of assembly and disassembly. The reduction gearbox is designed for continuous-duty operation and reduces the output speed of the turbine to the required operating speed of the generator. The gearbox is coupled to the gas turbine through a balanced high-speed shaft, splined at both ends. The output shaft is coupled to the generator through a flexible disk-type dry coupling enclosed in a coupling guard. The design of the gearbox facilitates straight-through shafting, avoiding offset problems and permitting engine, gear, and generator alignment from a common base. Gear lubrication is provided by the package lube oil system.

The gearbox is designed to provide 99% reliability between major inspections and overhauls.



**Figure 5. Typical Reduction Gearbox for the Titan 250 Generator Set**

**Table 2. Reduction-Drive Gearbox Specifications**

<b>Approximate Weight</b>	
Gearbox	7300 kg (16,100 lb)
<b>Output Speed</b>	
50 Hz Service	1500 rpm
60 Hz Service	1800 rpm
<b>Inspection and Overhaul Intervals</b>	
Major Inspection Interval	30,000 hours
Overhaul Interval	100,000 hours
<b>Compliance</b>	
American Petroleum Institute (API)	613 Compliant With Exceptions, Refer to Solar's Standard List of Exceptions
<b>Ratings</b>	
American Gear Manufacturers Association (AGMA)	In Excess of 1.10 for Generator Applications
<b>Vibration Monitoring</b>	
Gearbox	Acceleration Probe

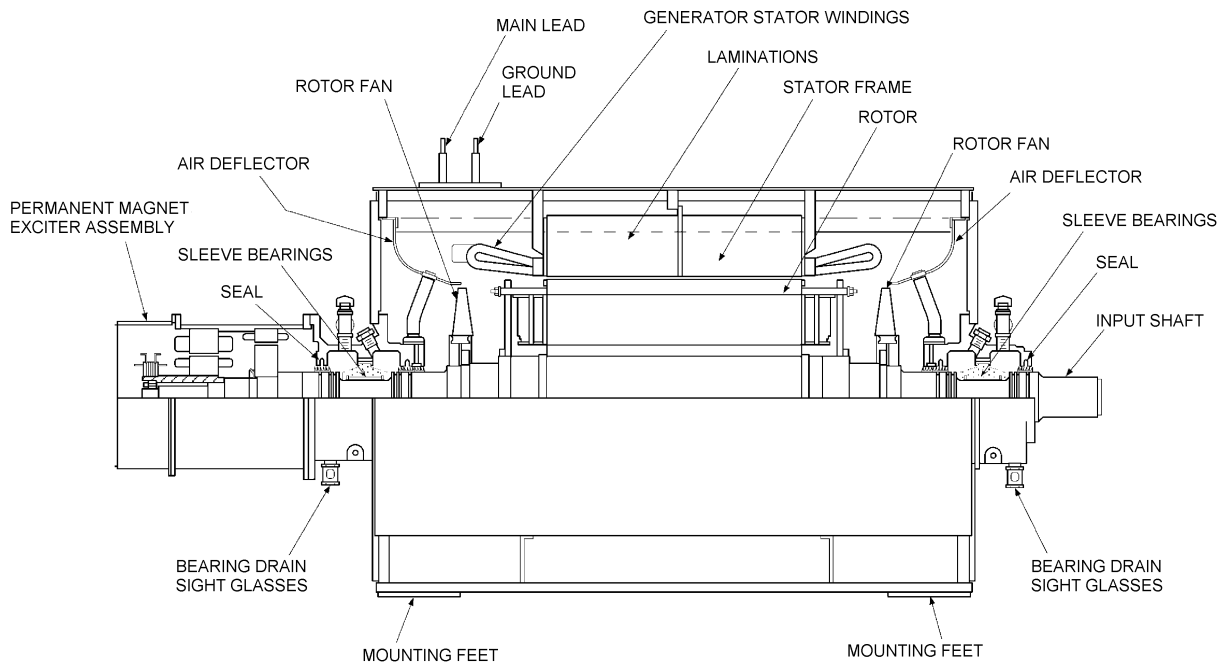
## 5 Generator and Associated Equipment

### 5.1 General Description

For maximum flexibility, the gas turbine package can be provided with several different generator types and voltage outputs to accommodate a broad range of application requirements. The generator, exciter, and control system are integrated to provide optimal performance.

The standard generator type supplied is open drip-proof (ODP) (Figure 6). However the following other enclosure types are available to meet a variety of environmental conditions and cooling requirements:

- Closed air circuit air cooled (CACAC)
- Closed air circuit water-to-air cooled (CACW)
- Totally enclosed air-to-air cooled (TEAAC)
- Totally enclosed water-to-air cooled (TEWAC)



**Figure 6. Typical Open Drip-Proof Generator with Permanent Magnet Exciter System**

### 5.2 Functional Description

During generator operation, three-phase AC power generated by the exciter armature is converted to DC power by a rectifier. The DC output from the rectifier is applied as field excitation current to the generator rotor windings to create magnetic flux. The generator voltage output is controlled by the generator field current and the generator field current is controlled by a brushless exciter. The amount of DC current applied to the exciter field determines the exciter output voltage. A potential transformer senses the bus potential and provides a signal to the combined generator control module (CGCM) for excitation control.

Any variations in bus potential will also be sensed and corrected by this circuit. After voltage builds, the generator accelerates to 100% speed and excitation and voltage control is assumed by the CGCM. A crosscurrent-compensating transformer provides the signal to the CGCM for reactive loadsharing between multiple paralleled units.

It should be noted that the generator rotor windings rotate and the generator armature is stationary. The exciter field coils are also stationary and the exciter armature rotates with the main generator rotor shaft. As a result, a single rotating assembly consisting of the exciter armature, exciter rectifier, and the generator rotor windings is formed. This single rotating assembly greatly simplifies all electrical connections within the generator.

### 5.2.1 Standard Features

Generators include the following standard features:

- Sleeve bearings with pressure fed sumps
- Terminal box
- Form wound stator windings
- Amortisseur windings
- Rotor balance to 125% rated speed
- Anti-condensation space heaters
- Permanent magnet generator (PMG)
- Rotating armature-type VAC exciter
- Full-wave rectifier assembly

Special order generators are available to meet unique customer requirements including non-U.S. specifications.

### 5.2.2 Rotor

The salient, four-pole, forged rotor is dynamically balanced to minimize vibration. Motor fans move cooling air through the generator and around the rotor. The rotors have layer-wound field windings cemented with a high-strength resin and are baked to cure the resin. The rotor is in electrical and mechanical balance at all speeds up to 125% of rated speed.

### 5.2.3 Stator

The stator is built with high-grade silicon steel laminations that are precision-punched and individually insulated. Windings are typically form-wound and treated with thermosetting synthetic varnish or vacuum pressure impregnated (VPI) epoxy for maximum moisture resistance, high dielectric strength, and high bonding qualities. The windings are braced to withstand shock loads such as motor starting and short circuits. Space heaters can be supplied to minimize condensation during shutdowns.

### 5.2.4 Shaft

The shaft diameter provides the necessary stiffness to avoid torsional vibration. The turbine-driven generator set is given a complete torsional analysis.

### 5.2.5 Frame

The frame is heavy-duty steel and is fabricated with deep welds and internal reinforcing for extra rigidity and strength. The frame also includes lifting lugs.

### 5.2.6 Exciter

Excitation current for the generator field coils is provided by a brushless rotating exciter with a PMG pilot exciter. The exciter is mounted directly on the generator rotor shaft. The exciter consists of two basic parts, a small three-phase, AC generator with rotating



armature and a three-phase, full-wave, diode-type bridge rectifier that rotates with the armature. The pilot exciter is a PMG that rotates with the main generator rotor shaft. It feeds the exciter field windings with excitation current and is controlled by the CGCM.

### 5.2.7 Bearing Lubrication System

The generator is supplied with a force-fed bearing lubrication system consisting of onskid piping and a filter strainer. Oil is supplied from the package lube oil system.

**Table 3. Generator and Associated Equipment Specifications**

<b>Approximate Weight</b>	
Generator (Typical Open Drip Proof)	45 000 kg (99,200 lb)
<b>Construction Types</b>	
Open Drip Proof (OPD), Air Cooled	Standard
Closed Air Circuit Water-to-Air Cooled (CACW)	Optional
Closed Air Circuit, Air Cooled (CACA)	Optional
Totally Enclosed Air-to-Air Cooled (TEAAC)	Optional
Totally Enclosed Water Air Cooled (TEWAC)	Optional
<b>Generator</b>	
Optional Voltage Ratings <b>See Note (a)</b>	11,000, 12,470, or 13,800 VAC,
Frequency Ratings	50 or 60 Hz
Number of Poles	4
Number of Leads	6
Connection	Wye
Stator Windings	Form Wound
Insulation	National Electrical Manufacturers Association (NEMA) Class F
Temperature Rise <b>See Note (b)</b>	NEMA Class B,
Overload Capacity	-150% Rated Current for One Minute -110% Rated Current for Two Hours
Overload Compliance	NEMA
Short Circuit Capability	300% For 10 seconds
Rotor Balance	To 125% of Rated Speed
Maximum Wave Form Deviation	10%
Maximum Harmonic Content	3%
Telephone Influence Factor (TIF)	
Balanced	100
Residual	75
Efficiency	The combined generator, exciter, and regulator efficiency at full load is nominally 97%.
Space Heater	
Voltage	120, 220, 230, or 240 VAC
Frequency	50 or 60 Hz
Phase	1 Phase
<b>Vibration Monitoring</b>	
Generator Bearing Driven End	Displacement Probes, X and Y axis
Generator Bearing Exciter End	Displacement Probes, X and Y axis

**Notes:**

- (a) Other voltages can be provided to meet specific customer requirements.
- (b) A 80°C (144°F) temperature rise is based on the generator nameplate rating at 40°C (104°F) and a power factor of 0.8 for continuous duty service.

## 6 Start System

### 6.1 General Description

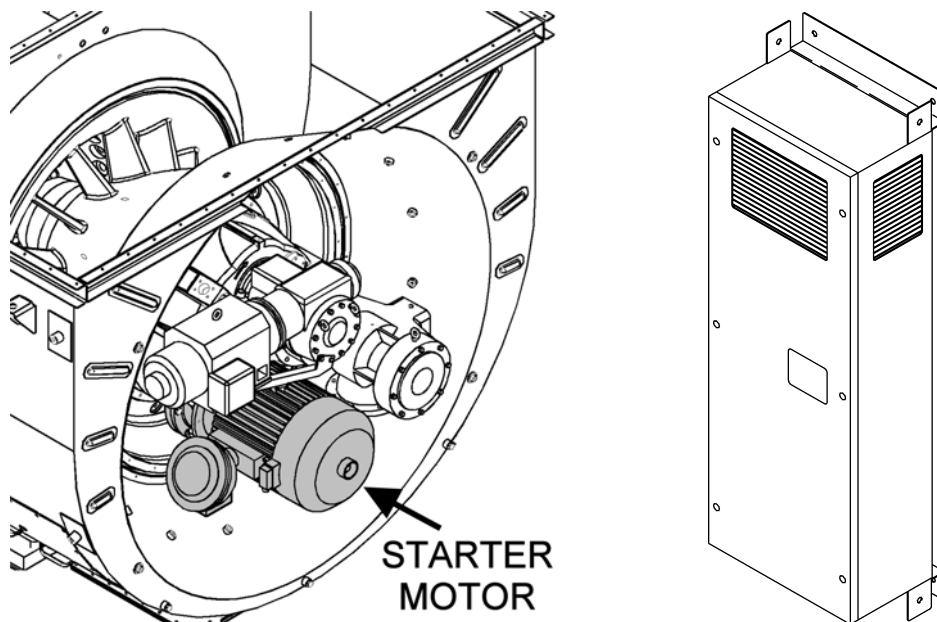
The start system includes a direct-drive AC starter motor driven by a solid-state variable frequency drive (VFD). The start system provides torque to initiate engine rotation and to assist the engine in reaching a self-sustaining speed. The starter motor is mounted directly on the gas turbine accessory drive gearbox. The VFD regulates voltage and frequency to the starter motor for engine rotation as commanded by the *Turbotronic 4* control system.

### 6.2 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.

#### 6.2.1 Starter Motor

The starter motor (Figure 7) 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 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. After a shutdown, the starter motor rotates the turbine at low speed to prevent deformation of the rotor during cool down.



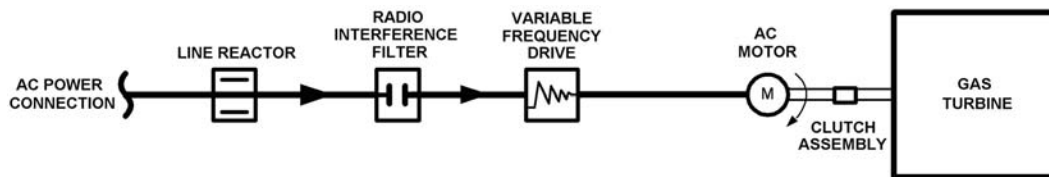
**Figure 7. Direct-Drive AC Starter Motor and VFD Cabinet**

### 6.2.2 Variable Frequency Drive

The VFD (Figure 7) 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.

### 6.2.3 Power Wiring

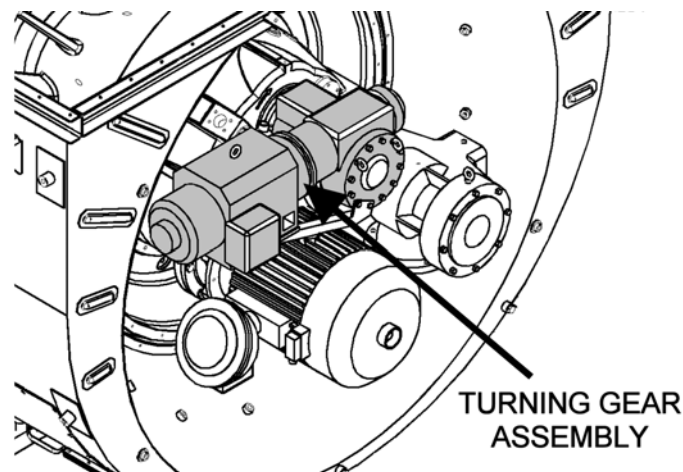
The start system (Figure 8) requires customer-furnished, three-phase AC input. Additional three-phase AC power wiring is required to connect the VFD to the starter motors. A start contactor is not required for VFD operation. A customer-furnished fused disconnect at the VFD input is recommended. Optional motor space heater wiring is available.



**Figure 8. Typical Direct-Drive AC Start System**

### 6.3 Backup Slow Rotation System

The Titan 250 package is equipped with a DC powered turning gear system (Figure 9) to ensure low speed rotation of the turbine as backup for the DAC starter motor in the event of loss of AC power to the package. The system engages the decelerating turbine at low speed and maintains rotation for a specified time.



**Figure 9. Turning Gear Assembly**

**Table 4. Start System Specifications**

<b>Variable Frequency Drive</b>	
Optional Voltage Input Ranges <b>See Note (a)</b>	380 to 460 VAC, (48 to 62 Hz) 500 to 600 VAC, (48 to 62 Hz)
Minimum Input Current	
- 380 to 460 VAC Input	525 amps
- 500 to 600 VAC Input	342 amps
Voltage Output Range	0 to 460 VAC, (0 to 240 Hz)
Maximum Line Distribution Capacity	1000 kVa
Maximum Fault Current Capacity <b>See Note (b)</b>	30 000 amps
Maximum Breakaway Amperage	383 amps
Maximum Breakaway Torque	918 N-m (677 ft-lb)
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	7350 watts
- 500 to 600 VAC Input	9485 watts
Input Fuse Rating	600 amp
Approximate Measurements	
- Height	220 cm (87 in.)
- Width	69 cm (24 in.)
- Depth	60 cm (28 in.)
Approximate Weight	28 831 kg (850 lb)
- Length	73 cm (29 in.)
- Diameter	46 cm (18 in.)
<b>Starter Motor</b>	
Motor Type	Squirrel-cage Induction
Motor Voltage Rating	380 AC, (0 to 133 Hz)
Power	93 kW (125 hp)
Operating Speed	0 to 7000 rpm
Maximum Breakaway Amperage	659 amps
Maximum Breakaway Torque	488 N-m (360 ft-lb)
Minimum/Maximum Operating Temperature	-40 to 60°C (-40 to 140°F)
Space Heater Voltage	115 VAC, 60 Hz
Approximate Measurements	
- Length	66 cm (26 in.)
- Diameter	45.7 cm (18 in.)
Approximate Weight	
- AC Starter Motor Assembly	450 kg (990 lb)
<b>Power Wiring</b>	
VFD to Starter Motors Power Cable Length	38 m (123 ft), <b>See Note (c)</b>
<b>Turning Gear Motor</b>	
Motor Type	Squirrel-cage Induction
Motor Voltage Rating	240 VDC
Power	3.73 kW (5 hp)
Operating Speed	2500 rpm
Turbine Rotation Speed	300 rpm

<b>Applicable Engineering Specifications</b>	
Solar's Engineering Specification ES 1593	Guidelines for NEC Compliance of <i>Solar</i> Product Lines: Class I, Group D, Division 1 and Division 2
Solar's Engineering Specification ES 1762	Standards and Practices for Electrical Systems For Gas Turbine Packages Installed in Hazardous Areas (CENELEC Standards)
<b>Applicable Product Information Letters</b>	
Solar's Product Information Letter PIL 149	Direct-drive AC Start Systems

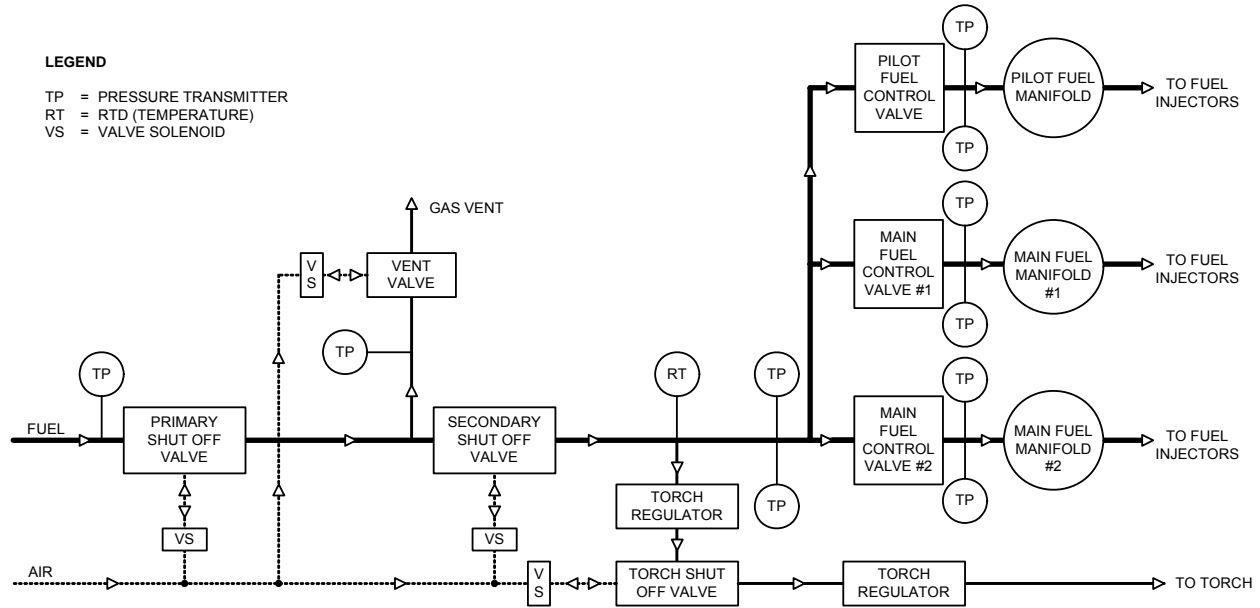
**Notes:**

- (a) If the customer-furnished input voltage is greater than 600 VAC  $\pm 5\%$ , a step-down transformer is recommended.
- (b) 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.
- (c) Longer cable runs may require an onskid marshalling box and/or output line reactor.

## 7 Fuel System

### 7.1 General Description

The fuel system (Figure 10), in conjunction with the control system, includes all necessary components to control ignition and fuel flow during all modes of operation.



**Figure 10. Typical Fuel System Schematic**

#### 7.1.1 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.

#### 7.1.2 Fuel System

The SoLoNOx 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 valves (2)
- Torch with shutoff valve and pressure regulators
- Main fuel manifold
- Fuel injectors

- 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 valves and 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. The three 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 5. Fuel System Specifications**

Gas Fuel System	
Acceptable Gas Fuels <b>See Note (a)</b>	Natural Gas Propane Butane
Fuel Quality	Refer to Solar's Engineering Specification ES 9-98
Compliance	National Association of Corrosion Engineers (NACE) Compliant
Minimum/Maximum Gas Fuel Supply Pressure	2240 to 3447 kPag (325 to 500 psig), <b>See Note (b)</b>
Minimum Flow Rate	3513 to 5480 kg/hr (7746 to 12086 lbm/hr), <b>See Note (b)</b>
Minimum/Maximum Fuel Supply Temperature	-40 to 93°C (-40 to 200°F), <b>See Note (c)</b>
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 <i>SoLoNOx</i> Fuel Pilot Control Valve	Actuator Valve
Actuator Voltage	120 VDC
Valve Discrete Signals	0 to 24 VDC
Valve Analog Signals	4 to 20 mA
Maximum Operating Pressure	4137 kPag (600 psig)
Maximum Operating Temperature	93°C (200°F)
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
Offskid Coalescing Filter Module ( <i>SoLoNOx</i> Units Only)	
Maximum Operating Pressure	3447 kPag (500 psig)
Maximum Flow	122 m <sup>3</sup> /min (4300 ft <sup>3</sup> /min)
Minimum/Maximum Operating Temperatures	-29 to 100°C (-20 to 212°F)
Filtration Efficiency	β <sub>0.3</sub> > 200 per ISO 4572

<b>Customer-Furnished Pilot Air System</b>	
Fluid	Clean-Dry Air
Air Quality	<b>See Note (d)</b>
Minimum/Maximum Regulated Pressure Range	689 to 1379 kPag (100 to 200 psig)
Pilot Air Filter	10 micron
<b>Construction Materials</b>	
Piping, Manifolds, and Tubing	316L Stainless Steel
<b>Applicable Engineering Specifications</b>	
Solar's Engineering Specification ES 9-98	Fuel, Air, and Water (or Steam) for <i>Solar</i> Gas Turbine Engines
Solar's Engineering Specification ES 1593	Guidelines for NEC Compliance of <i>Solar</i> Product Lines: Class I, Group D, Division 1 and Division 2
Solar's Engineering Specification 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)
<b>Applicable Product Information Letters</b>	
Solar's Product Information Letter PIL 148	LPG and NGL Fuels
Solar's Product Information Letter PIL 162	Recommendations for the Sourcing, Handling, Storage and Treatment of Fuels for <i>Solar</i> Gas Turbines
Solar's Product Information Letter 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 ( $\Delta T$ ) of at least 27°C (50°F) above fuel dew point temperature.
- (d) The particle size in the air stream should not exceed 10 $\mu$ . Since it is impractical to remove 100% of all particles larger than 10 $\mu$ , this is defined as  $\beta_{10} > 100$ , 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 Lubrication System

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### 8.1 General Description

The lubrication system, (Figure 11) 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
- Oil tank heater
- 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
- Stainless steel oil tank and tank covers
- Stainless steel filter system

#### 8.1.1 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.

#### 8.1.2 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.

#### 8.1.3 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.

#### 8.1.4 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

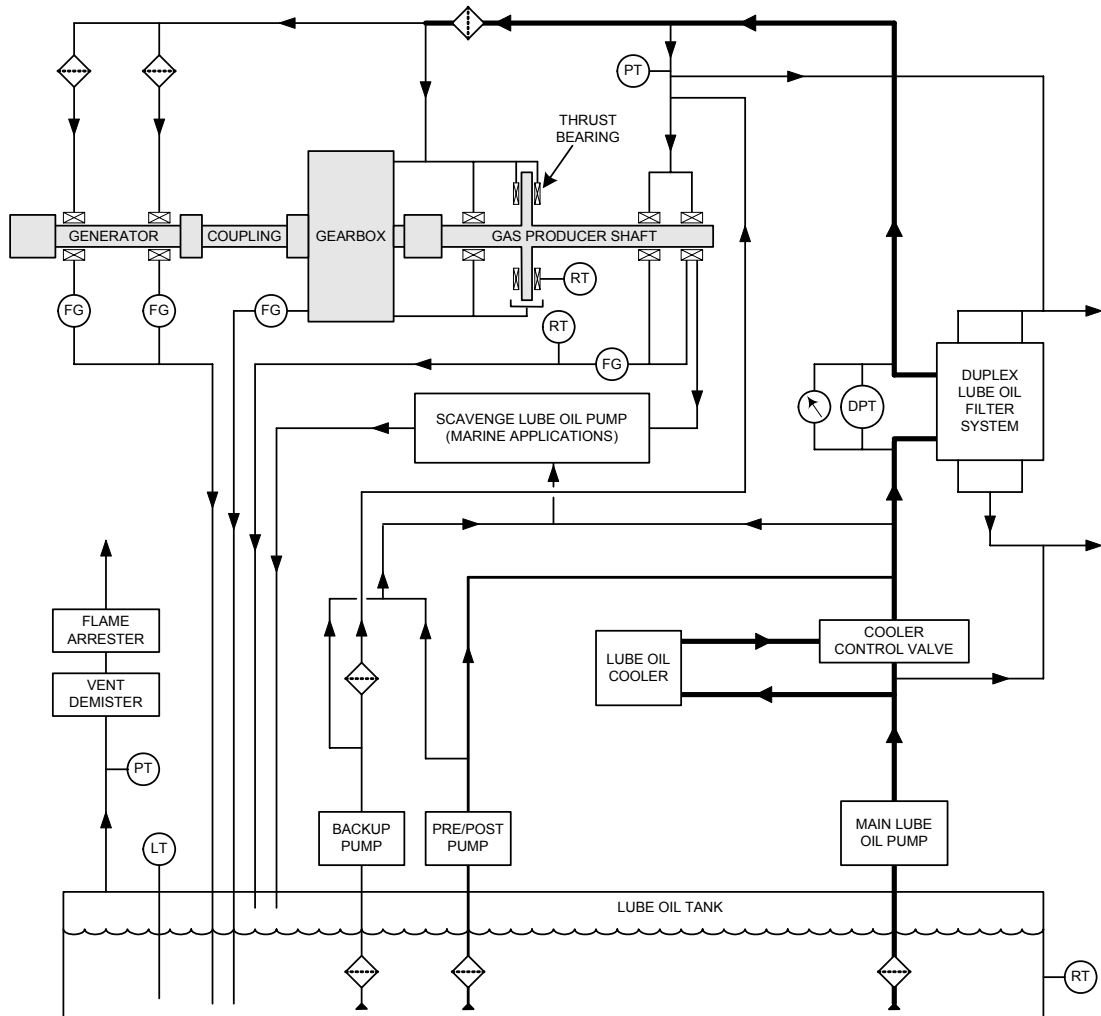
fire, control system failure, emergency stop, or if a turbine over-speed is detected by the backup system.

**8.1.5 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.

**8.1.6 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**

DPT	DIFFERENTIAL PRESSURE TRANSMITTER	FG	FLOW GAUGE (SIGHT GLASS)
LT	LEVEL TRANSMITTER	RT	TEMPERATURE DEVICE (RTD)
PT	PRESSURE TRANSMITTER	◇	FILTER

**Figure 11. Typical Lube Oil System****8.1.7 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.

**8.1.8 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 4.4°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 6. Lubrication System Specifications**

<b>Main Lube Oil Pump</b>	
Pump Type	Engine-Driven Rotary Screw
Flow	1999 lpm (528 gpm)
Discharge Pressure	690 kPag (100 psig), <b>See Note (a)</b>
<b>Pre/Post Lube Oil Pump</b>	
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	7.45 kW (10 hp)
<b>Backup Lube Oil Pump</b>	
Pump Type	DC Motor-Driven Centrifugal
Motor Voltage Rating	120 VDC
Motor, Power	7.45 kW (10 hp)
<b>Lube Oil Cooler</b>	
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, <b>See Note (b)</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), <b>See Note (c)</b>
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)
<b>Lube Oil Tank Immersion Heater, See Notes (d) and (e)</b>	
Optional Voltage Ratings	380 VAC, 400 VAC, and 415 VAC (50 Hz) 460 VAC and 575 VAC (60 Hz)
Power	3-Phase VAC, 40 kW
Minimum/Maximum Regulated Supply Pressure	100 to 225 psig (689 to 1551 kPag)

Maximum Flow Demand Rate	4.67 nm <sup>3</sup> /min. (165 scfm)
<b>Main Lube Oil Duplex Filters</b>	
Type	Self-Supporting Pedestal
Duplex Filters	10 Micron
Certification	ASME, Section VIII, Division 1
<b>Backup Lube Oil Pump Filter</b>	
Type	Bowl Filter
Minimum/Maximum Operating Temperatures	-54 to 135°C (-65 to 275°F)
Simplex Filter	$\beta X \geq 75$ Micron
<b>Lube Oil Vent Coalescer</b>	
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)	198.1cm x 121.9 cm (77.9 in. x 48 in.)
Approximate Weight	1093 kg (2,410 lb)
<b>Lube Oil Vent Flame Arrestor</b>	
Orientation	Vertical, <b>See Note (f)</b>
Approximate Dimensions (Height x Width x Diameter)	32 cm x 23 cm x 22 cm (13 in. x 9 in. x 9 in.)
Approximate Weight	11 kg (25 lb)
<b>Strainers</b>	
Tank Fill	20 mesh
Gearbox Breather Vent (If Applicable)	40 mesh
Gas Producer Start-Up Strainer	70 Micron, <b>See Note (g)</b>
Gearbox Start-Up Strainer (If Applicable)	70 Micron, <b>See Note (g)</b>
Compressor Driven End Start-Up Strainer	70 Micron, <b>See Note (g)</b>
Compressor Exciter End Start-Up Strainer	70 Micron, <b>See Note (g)</b>
<b>Lube Oil</b>	
Viscosity Grade ISO VG 32 (C32)	Use When Ambient Temperature is < 110°F
Viscosity Grade ISO VG 46 (C46)	Use When Ambient Temperature is > 110°F
Pour Point	Must Be At Least 6°C (11°F) Below The Lowest Ambient Temperature)
Lube Oil Tank Capacity	11 450 L (3025 gal), <b>See Note (h)</b>
Weight	1995 kg (4,400 lb)
<b>Construction Materials</b>	
Piping, Manifolds, and Tubing	316L Stainless Steel
Lube Oil Tank and Tank Covers	Carbon Steel (Standard) 316L Stainless Steel (Optional)
<b>Construction Materials (Cont'd)</b>	
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	Aluminum

<b>Applicable Engineering Specifications</b>	
Solar's Engineering Specification ES 9-224	Fuel, Air, and Water (or Steam) for <i>Solar</i> Gas Turbine Engines
Solar's Engineering Specification ES 1593	Guidelines for NEC Compliance of <i>Solar</i> Product Lines: Class I, Group D, Division 1 and Division 2
Solar's Engineering Specification 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)
<b>Applicable Product Information Letters</b>	
Solar's Product Information Letter PIL 058	Package Sound Levels
Solar's Product Information Letter PIL 161	Lube Oil System Cleanliness

**Notes:**

- (a) A pressure control valve regulates main lube oil supply pressure to 241 kPag (35 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 50 psid (345 kpad) 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).

## 9 Turbotronic 4 Control System

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### 9.1 Overview

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 generator, vibration and, when required, fire and gas monitoring and control subsystems.

In the standard onskid configuration (Figure 12) the primary control system components are mounted on the package skid with a local operator interface. An auxiliary display and monitoring system is available, mounted either in an optional console or desktop computer, and connected to the package by redundant network cables. In the standard offskid configuration, the entire control system is mounted in an offskid console with a full set of hardwired cables connecting to the package as illustrated in (Figure 13).

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.

### 9.2 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)
- Combination generator control module (Allen-Bradley/Basler Electric)
- 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)

Figure 14 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 starter motor 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 an auxiliary console for the offskid configuration.

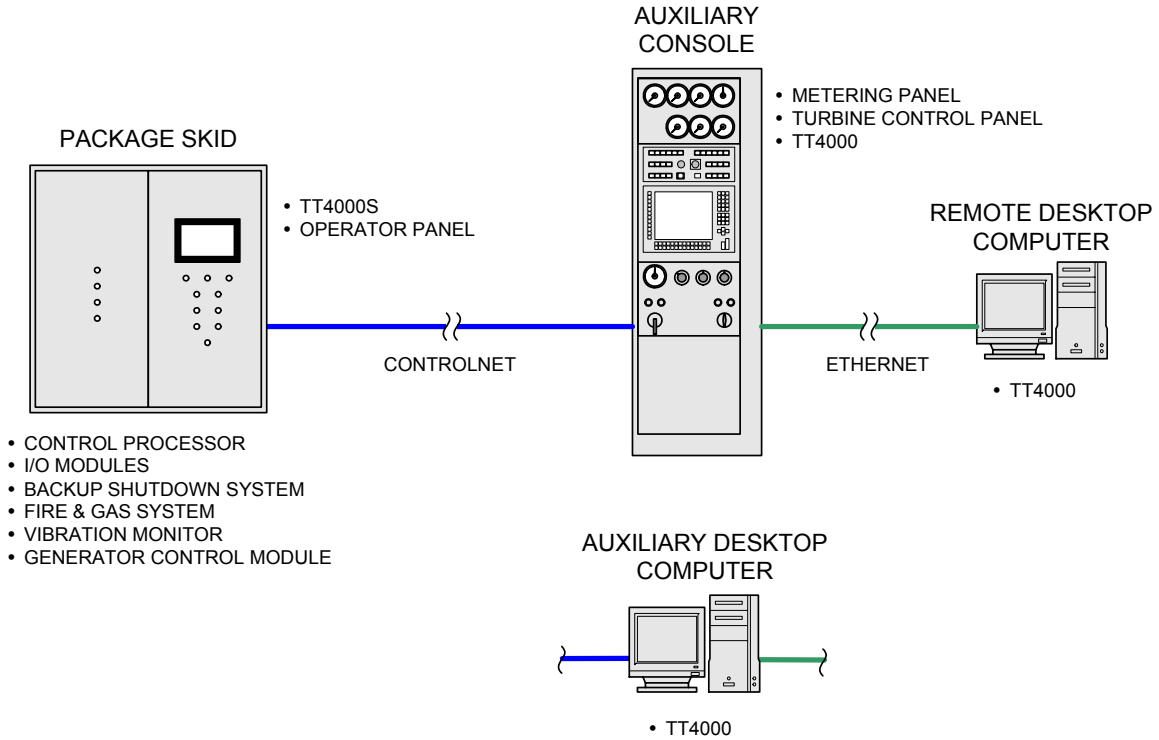


Figure 12. Typical Onskid Control System

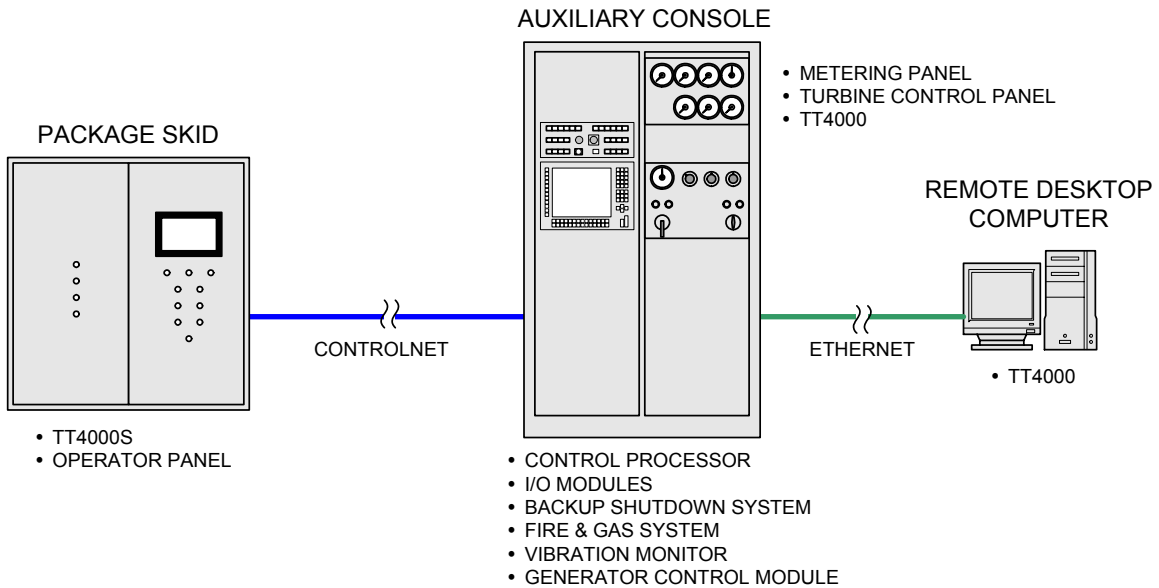
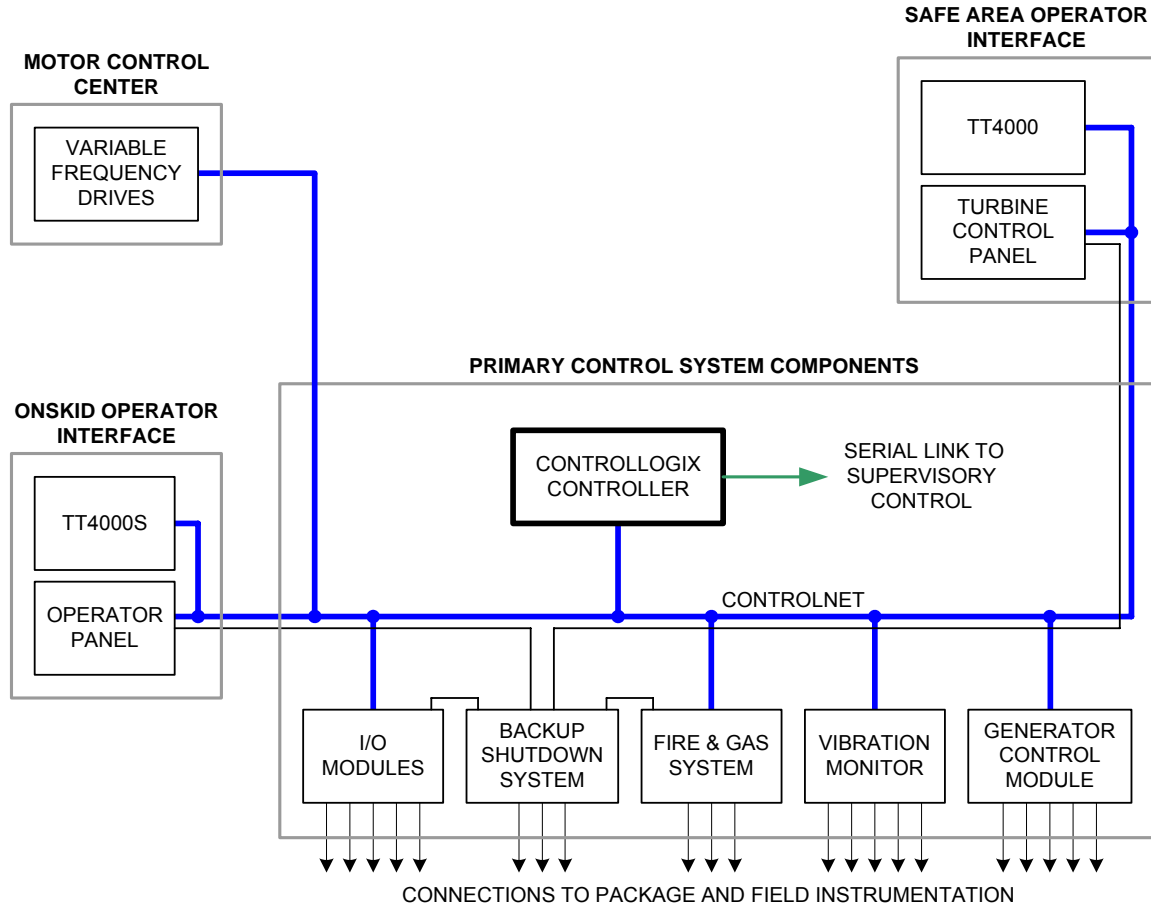


Figure 13. Typical Offskid Control System



**Figure 14. Turbotronic 4 System Architecture**

## 9.3 Component Descriptions

### 9.3.1 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.

### 9.3.2 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.

### 9.3.3 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.



### 9.3.4 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.

### 9.3.5 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 opens the generator circuit breaker, 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.

### 9.3.6 Fire and Gas System

Enclosed packages require fire and gas control protection. The Eagle Quantum Premier system from Det-Tronics detects 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 11 for a more complete description.

### 9.3.7 Combination Generator Control Module

The combination generator control module (CGCM) provides voltage regulation, automatic breaker synchronization, excitation control, power metering, load sharing, and protective relay functions. For a more detailed description of the CGCM capabilities, refer to Section 10, Generator Control and Monitoring.

### 9.3.8 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 14, Accessory Equipment.

## 9.4 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.

### 9.4.1 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.

The generator is loaded by closing the generator circuit breaker. The circuit breaker can be closed to a dead (de-energized) or a hot (energized) bus. If a dead bus is detected, the circuit breaker may be closed without synchronization. If a hot bus is detected, the system must synchronize the generator output to the bus before the circuit breaker is closed. Typically, synchronization and closing of the breaker are done automatically. Manual synchronization is available as an option.

#### 9.4.2 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). A set of thermocouples arranged circumferentially around the turbine 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.

#### 9.4.3 Stopping

The gas turbine may be shutdown either manually or automatically.

The **Normal Stop** command initiates a cooldown stop. The generator circuit breaker is opened 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 opening of the generator circuit breaker 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.

To protect the rotor from deformation and to enable a prompt restart of the package, the turbine does not come to a complete stop unless the shutdown is the result of fire being detected. The starter motor, or the DC backup turning gear mechanism in the case of loss of AC power, engages the turbine at low speed and maintains rotation until the cooldown cycle is complete. At the same time, 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 fire being detected, the turbine is brought to a complete stop and the start of the post lube cycle is delayed for 10 minutes, unless an operator intervenes.

#### 9.4.4 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.

### 9.5 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. Note: this full TT4000 version is required for the engine performance map option.

**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 XP 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.

#### 9.5.1 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, Figure 15)
- Generator Summary (generator operating data)
- Temperature Summary (all monitored temperature values)
- Vibration Summary (all monitored vibration values)
- Alarm Summary
- Discrete Event Log
- Strip Chart Display (real time data, Figure 16)
- Historical Data Display (strip chart format)
- Program Constants

Optional Display Screens:

- Gas Turbine Performance

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



Figure 15. Typical TT4000 Operation Summary Display Screen



Figure 16. Typical TT4000 Strip Chart Display

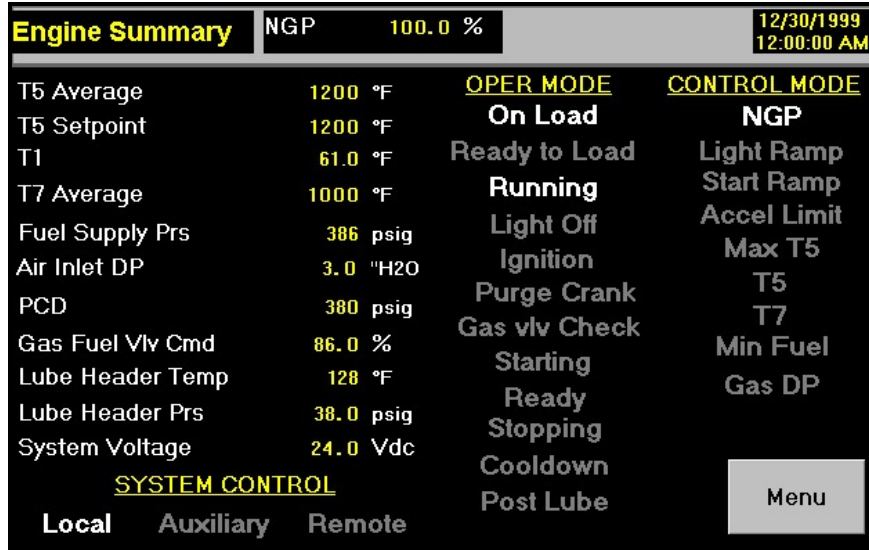


Figure 17. Typical TT4000S Engine Summary Screen

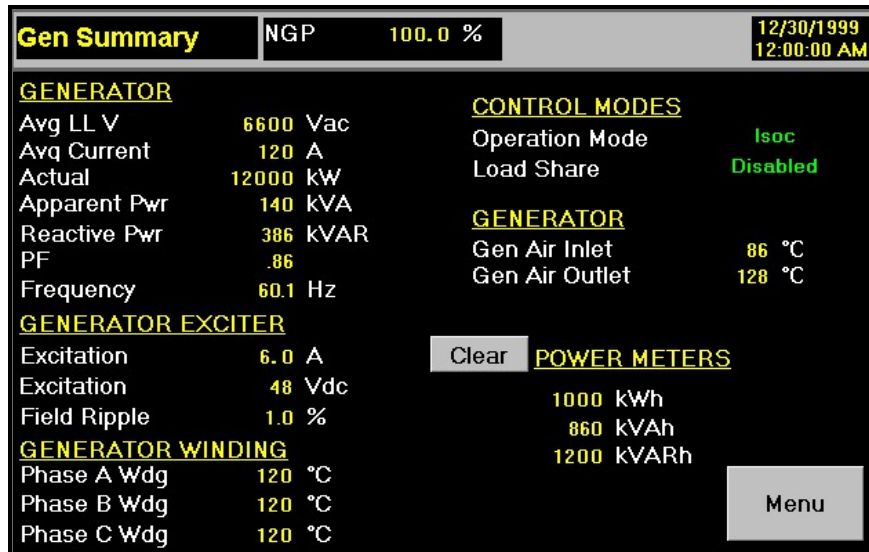


Figure 18. Typical TT4000S Generator Summary Screen

### 9.5.2 TT4000S Display Screens

The TT4000S displays a comparable set of screens to the full TT4000 except that the data are in numerical form and graphics are limited (Figures 17 and 18).

### 9.5.3 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 is 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.

#### 9.5.4 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.

#### 9.5.5 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.

#### 9.5.6 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

#### 9.5.7 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

#### 9.5.8 Engineering Units

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

	Metric 1	Metric 2	Metric 3	English
<b>Pressure</b>	kPa	bar	kg/cm <sup>3</sup>	psig
<b>Temperature</b>	°C	°C	°C	°F

**Table 7. Turbotronic 4 Control System Specifications**

<b>Control System Components</b>	
Control Processor	Allen-Bradley ControlLogix controller
Input/Output Modules	Allen-Bradley Flex I/O modules
Generator Control	Allen-Bradley/Basler Electric Combination Generator Control Module
Vibration Monitoring System	Bently Nevada 1701 FieldMonitor
Internal Control System Network	ControlNet 1.5
Human Machine Interface (HMI)	Solar's TT4000 Display & Monitoring System
Fire & Gas Monitoring System (Enclosed Packages)	Det-Tronics Eagle Quantum Premier System
<b>Temperature &amp; Vibration Monitoring</b>	
Gas Turbine	Refer to Section 3
Gearbox	Refer to Section 4
Generator	Refer to Section 5
<b>Offskid Control Console Dimensions</b>	
One-Bay Control Console	
Height	2286 mm (90 in.)
Width	914 mm (36 in.)
Depth	800 mm (31.5 in.)
Approximate Weight	570 kg (1250 lb)
Two-Bay Control Console	
Height	2286 mm (90 in.)
Width	1448 mm (57 in.)
Depth	800 mm (31.5 in.)
Approximate Weight	680 kg (1500 lb)
<b>Supervisory Interface Modules</b>	
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

<b>Package End Devices</b>	
Transmitters	4-20 mA
Switches	0-24VDC
Thermocouples	Type N
Resistance Temperature Devices (RTDs)	100 ohm Platinum
Proximiters	3300XL
<b>Solar's Applicable Engineering Specifications</b>	
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 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cables Installed In Class 1, Division 2 Hazardous Areas



## 10 Generator Control and Monitoring

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### 10.1 General Description

For generator control and monitoring, the *Turbotronic 4* control system incorporates a Rockwell Automation/Allen-Bradley combination generator control module (CGCM). The CGCM provides generator control, protection, and monitoring. Three excitation control modes are available:

- Automatic voltage regulation (AVR) - A constant generator output voltage is maintained
- Power factor (PF) control - A constant power factor is maintained when operating in parallel with a large power source
- Reactive power control - A constant reactive load is maintained when operating in parallel with a large power source

The following excitation control features are available:

- Under frequency limiting
- Over and under excitation limiting
- Reactive droop compensation
- Cross-current compensation
- Line-drop compensation

Protection features for the driver and driven equipment include:

- Field current limit
- Generator overcurrent
- Generator overvoltage
- Generator undervoltage
- Loss of excitation current
- Loss of operating power
- Loss of sensing
- Over excitation voltage
- Overfrequency
- Underfrequency
- Phase rotation error
- Reverse power
- Reverse volt amp reactive (VAR)
- Exciter (rotating) diode monitor

The protection features provided typically do not meet the requirements of power utility companies for the general protection of power distribution systems. This can only be done through the use of appropriately certified protective relay components with settings approved by qualified personnel based on a comprehensive analysis of the complete system.

## 10.2 Generator Control

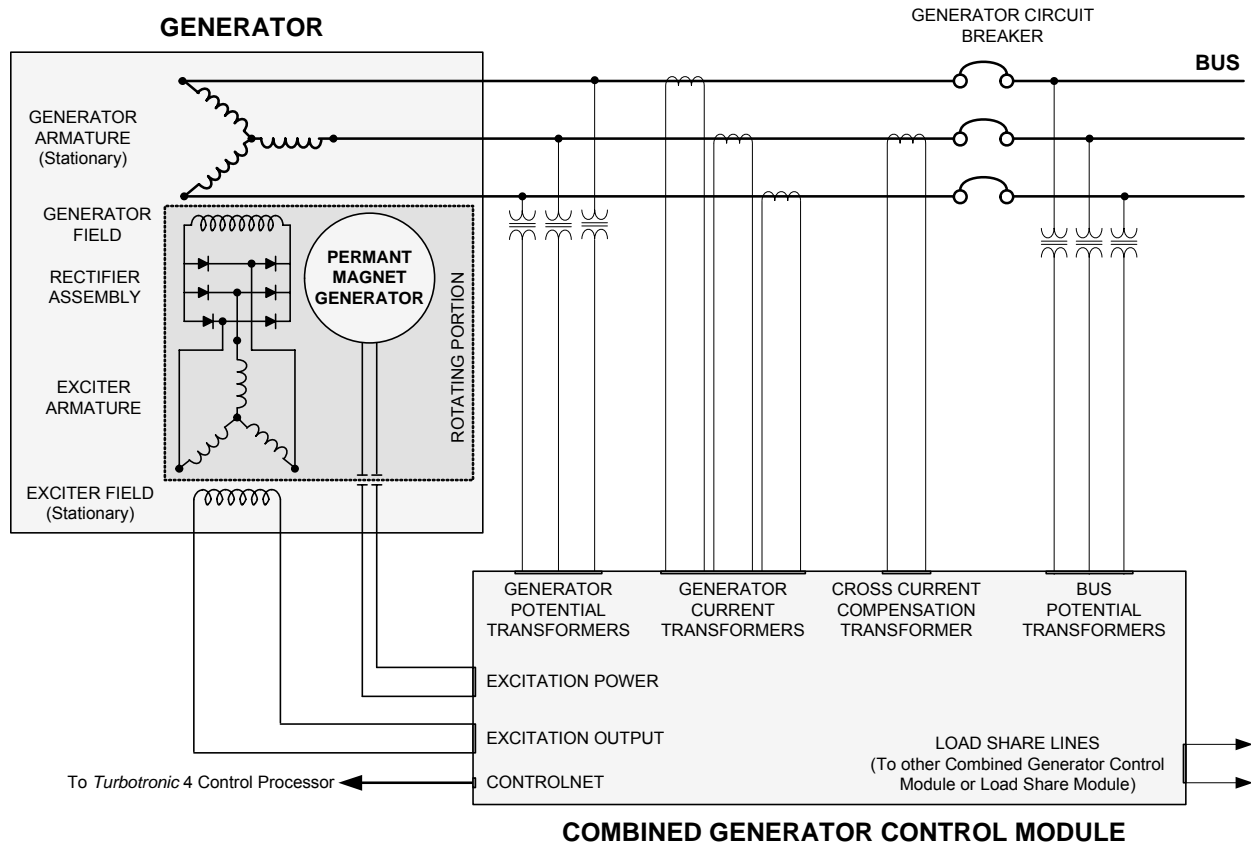
### 10.2.1 Functional Description

The *Turbotronic 4* control system working in conjunction with the generator’s excitation system provides control, monitoring, and protection of the generator and its output. The key components are:

- Permanent magnet generator (PMG)
- Rotating armature-type AC exciter
- Full-wave rectifier assembly
- CGCM

Figure 19 provides a simplified layout of these components. The exciter armature is mounted on the main generator rotor and generates an AC voltage as it revolves in the magnetic flux produced by the stationary field. The stationary field is wound on salient poles supported by the stator core or frame. The PMG consists of permanent magnets on the generator rotor and a stationary armature, also supported by the generator frame.

The rotating rectifier assembly rectifies the exciter armature AC output to DC. In turn, the DC power is applied to the main generator rotating field windings. The complete exciter is enclosed and protected by a removable cover. When the rotor operates at synchronous speed, the PMG provides power to the CGCM. The CGCM provides the appropriate exciter field current to control the exciter armature output, which is rectified to provide DC power to the main generator rotating field winding.



**Figure 19. Typical Generator, Exciter, and Generator Control Module Arrangement**

During initial turbine generator acceleration, the excitation power is switched off. At approximately 80% speed, the PMG output is connected to the excitation power contacts and voltage begins to build. The CGCM then provides controlled exciter field current at a level to maintain the generator terminal voltage at a predetermined value established by the operator. A potential transformer (usually supplied with the switchgear) provides a voltage level signal to the CGCM. By sensing the generator output voltage and controlling the power to the brushless exciter, the CGCM automatically maintains the generator output voltage at a constant level at all load conditions.

Since the PMG output power is independent of the main generator line voltage and current levels, there is no need for additional auxiliary equipment to provide power to the CGCM during transient conditions. The PMG provides sufficient generator terminal voltage during conditions of high generator line current to allow for selective tripping during a short-circuit condition. Current, potential, and cross current transformers required for input to the CGCM are not included. A cross-current compensating circuit is included to accommodate reactive load sharing between multiple turbine generators operating in parallel. Instrumentation transformers are usually supplied with the switchgear.

### 10.2.2 Control Modes

In addition to voltage regulation, the following generator control modes are also available:

- Speed/Load Control
  - Isochronous (Isoch) Speed Control
  - Droop Speed Control
  - Kilowatt Import Control
- Reactive Compensation
  - Droop Voltage Control
- Power Factor Control
- Reactive Load Volt Amp Reactive Control
  - Differential Cross Current Control

### 10.2.3 Breaker Synchronization

The control system provides automatic generator breaker synchronization control when paralleling to the bus. Automatic synchronization can be initiated by the operator or by a remote signal received from a supervisory control system. If manual synchronization is required, an optional generator metering panel must be included. Synchronization control is provided by the CGCM.

### 10.2.4 Auto Start and Synchronizing System

When the generator set is in standby mode, the control system will automatically start the generator set, accelerate the engine to loading speed, and synchronize the generator breaker to the bus upon receipt of a supervisory command. If the control system detects a hot bus, it will synchronize the generator to the bus and close the breaker. If the control system detects a dead bus, it will close the generator breaker without synchronization.

### 10.2.5 Kilowatt Import Control

The kW import control system controls the real load (kW) when the generator set is in parallel with a large power source. When kW import control is enabled, the control system monitors the load imported from the utility and adjusts the turbine generator set fuel flow to maintain a preset amount of imported power. When it is not desirable to export power to the utility, kW import control is normally selected. While in parallel with a

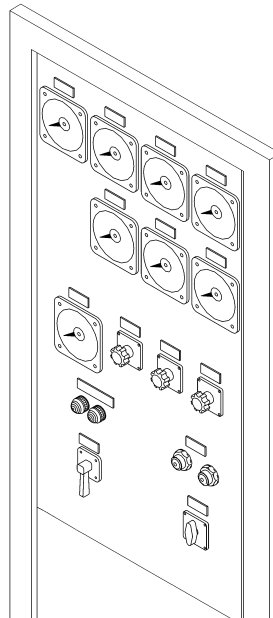
large power source, protection against excessive kW load is provided by turbine T5 temperature control.

### 10.2.6 Generator Metering Panel (Optional)

Mounted on the front of an optional control console, the generator metering panel (Figure 20) provides meters to monitor generator output and switches to manually adjust generator voltage and to synchronize the generator breaker to the bus. The metering panel typically includes the following analog meters, lights, and switches:

- AC ammeter
- Frequency meter
- KW/kVAr meter
- AC voltmeter
- Power factor meter
- Synchroscope
- Exciter field ammeter
- Exciter field voltmeter
- Manual synchronizing lights
- Manual synchronizing switch
- Generator breaker Open/Close switch
- Generator breaker Open/Close status lights
- Automatic synchronization switch (optional)
- Automatic synchronization fail light (optional)
- Generator line-to-line voltmeter select switch
- Kilowatt (kW) and kilovolt amp reactive (kVAr) power meter select switch
- Generator phase current ammeter select switch

All data indicated by the metering panel is also indicated on the video display terminal.



**Figure 20. Typical Generator Metering Panel****10.2.7 Generator Vibration and Temperature Monitoring**

X and Y proximity probes are mounted in the generator exciter and driven-end bearings. These probes are monitored continuously by the control system. Alarm and shutdown levels are set to protect the generator from excessive vibration levels

Resistance temperature devices (RTDs) are mounted in the generator exciter and driven end bearings. Two RTDs are also imbedded in each of the three stator-winding phases. One RTD is connected to the control system and the other is provided as a spare. Alarm and shutdown levels are set to protect the generator from excessive temperature levels.

**10.2.8 Redundant Combined Generator Control Module (Optional)**

A second CGCM can be provided to function as a hot backup to the primary CGCM. The system is configured for automatic transfer to the second CGCM in the event the primary CGCM fails. All control, protection, and monitoring features of the primary CGCM are duplicated in the second CGCM. Control can also be manually transferred between the CGCMs.

**Table 8. Generator Specifications**

<b>Voltage Regulation</b>	
Voltage Regulator	Solid State
Phase Sensing	Three Phase (Standard) Single Phase Sensing (Optional)
Voltage Adjustment Range	±10% With a Voltage Resolution of 0.1%
Steady-State Voltage Regulation	0.25% From No Load to Rated kVA
Reactive Load Sharing	Within 5% of Nameplate Rating
Cross-Current Compensation	Optional
Voltage Drift	See Note (a)
<b>Generator Breaker Synchronization</b>	
Generator Voltage	To Close Breaker, Generator Voltage Must be Within ± 1.0 Percent of Bus Voltage
Generator Phase	To Close Breaker, Generator Phase Must be Within ± 10 Degrees of Bus Phase
Generator Frequency	To Close Breaker, Generator Frequency Must Be Within ± 0.01 Hz of bus frequency
Generator Ready to Load	Twenty seconds after generator set attains 90 percent speed

**Notes:**

- (a) The change in voltage will not exceed 1.0% over a 30-minute period when the generator is operating at rated voltage, power factor of 0.8 to 1.0, and with a constant load between no load and full rated load.

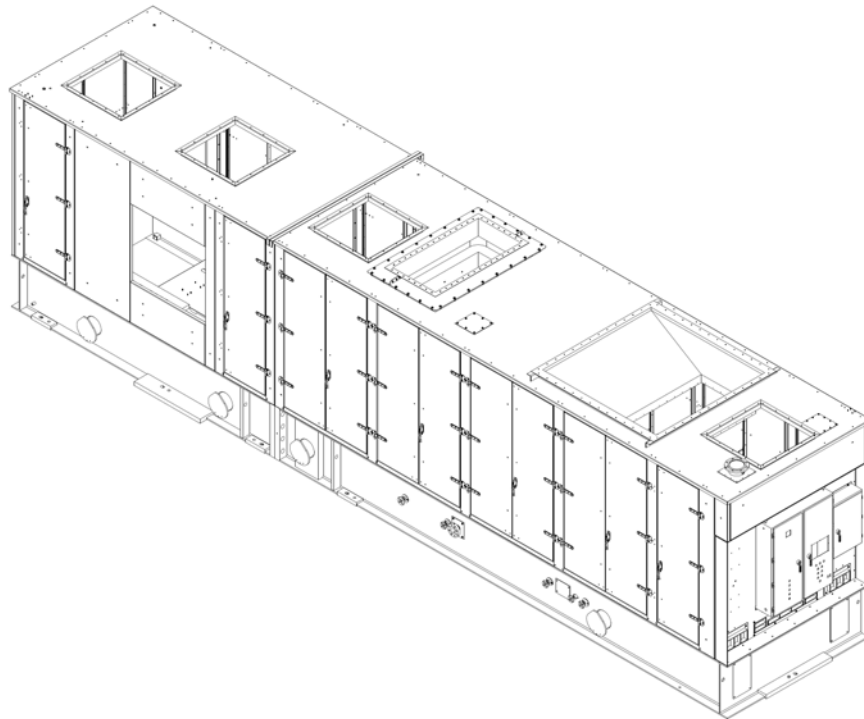
# 11 Enclosure

## 11.1 General Description

A driver-only or complete package enclosure can be provided as required. The enclosure housing (Figure 21) 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



**Figure 21. Typical Complete Package Enclosure**

## **11.2 Standard Features**

### **11.2.1 Inlet and Exhaust Ventilation Silencers**

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

### **11.2.2 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.

### **11.2.3 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.

### **11.2.4 Pressurization System**

The ventilation airflow through the enclosure can be controlled to provide either positive or negative pressure relative to the outside pressure. Hazardous area classifications and the applicable codes and regulations will determine the pressurization requirements for specific projects.

### **11.2.5 Lighting**

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

### **11.2.6 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."

## **11.3 Optional Features**

### **11.3.1 Enclosure Configuration**

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

### **11.3.2 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.

### 11.3.3 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.

### 11.3.4 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.

### 11.3.5 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.

### 11.3.6 Marinization

Increased stiffening of enclosure structural components and additional flexibility of enclosure and flexible joints between the gas turbine and enclosure can be provided.

### 11.3.7 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.

### 11.3.8 Fire and Gas System

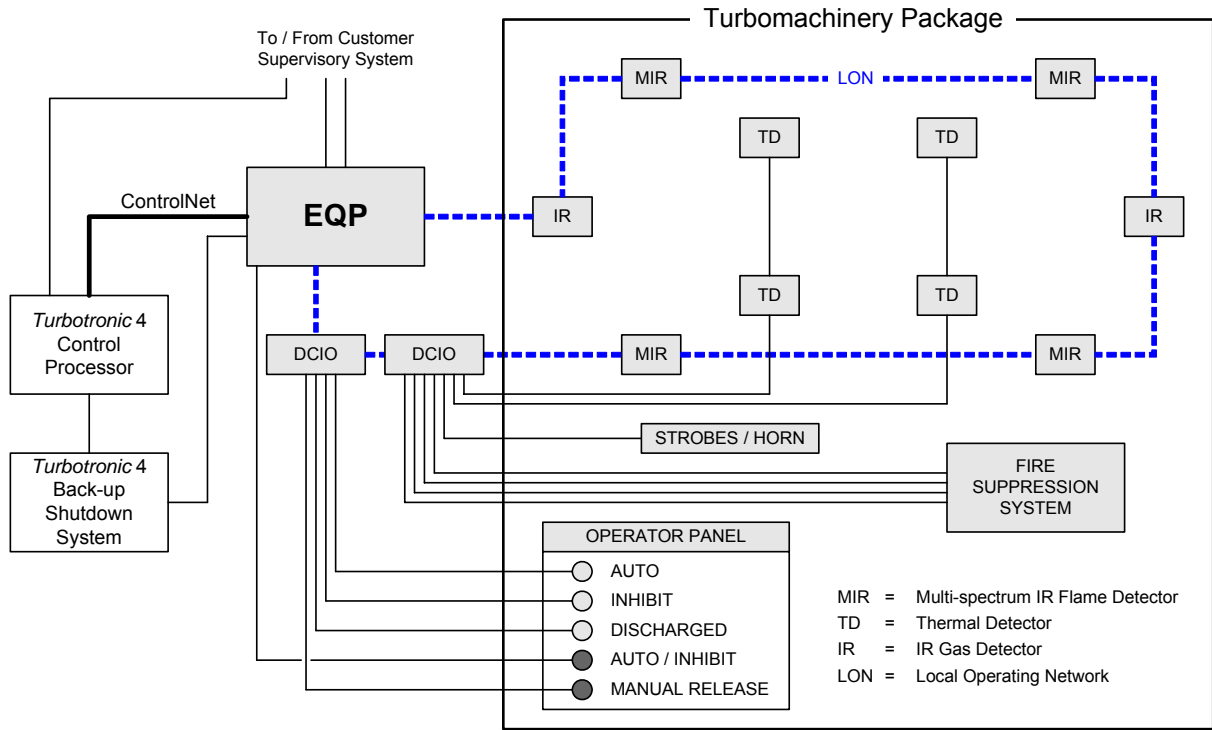
Enclosed packages must include a fire and gas control system. The typical fire and gas system shown in Figure 22 provides gas monitoring, fire detection, and extinguishing agent release using an advanced distributed architecture to monitor gas, heat, and optical flame detectors. The system communicates 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 multi-spectrum IR (MIR) flame 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. The number of detectors may vary depending on the enclosure configuration.

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<sub>2</sub> 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.



**Figure 22. Typical Fire and Gas System**

**11.3.9 CO<sub>2</sub> Fire Suppression System**

The enclosure can be equipped with a CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> fire suppression cylinder cabinets (Figure 23). On receipt of this signal, the solenoid actuated control heads activate the CO<sub>2</sub> cylinders, releasing CO<sub>2</sub> into the enclosure. CO<sub>2</sub> pressure actuates the pressure trip operated dampers that close all vent openings. CO<sub>2</sub> release control heads are also provided with manual release levers.

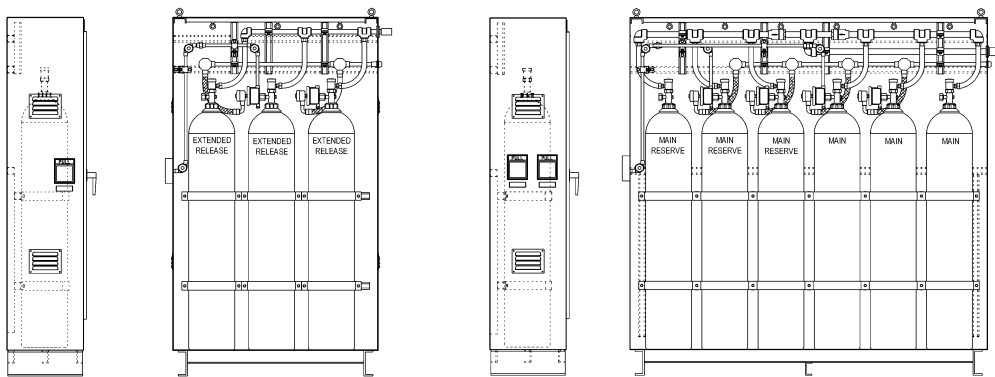
**11.3.10 Water Mist Fire Suppression System**

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 24) consists of two high-pressure nitrogen cylinders used as a propellant and five water bottles.

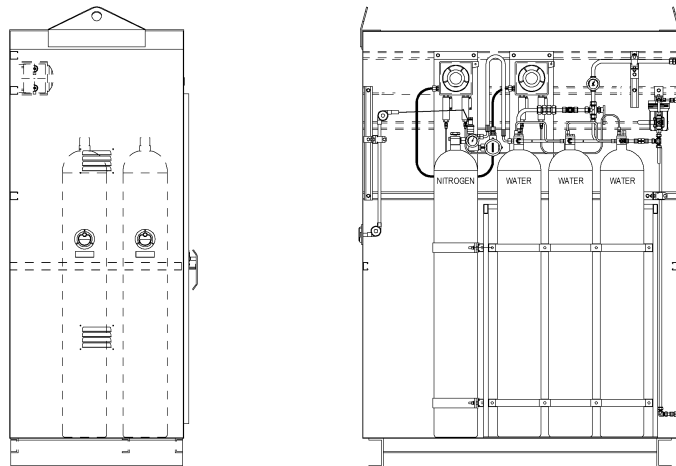
On detection of a fire by the optional fire and gas detection system, the fire control panel activates the fire suppression system release solenoids located on the water mist suppression skid. On receipt of this signal, the solenoid actuated control heads activate the discharge valves on the water cylinders, 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.

**11.3.11 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 23. Typical CO<sub>2</sub> Fire Suppression Cylinders and Cabinets**



**Figure 24. Typical Water Mist Fire Suppression Cylinders and Cabinet**

**Table 9. Enclosure Specifications**

<b>Enclosure</b>	
Optional Ventilation Fan Motor Voltage Ratings	380 VAC, 400 VAC, and 415 VAC (50 Hz) 460 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	<b>See Note (a)</b>
Enclosure Roof Load	244 kg/m <sup>2</sup> (50 lb/ft <sup>2</sup> )
Enclosure Wind Load	193 kph (120 mph)
Approximate Measurements	
Height	4 m (13 ft), Does Not Include Ventilation Ducting
Width	7 m (23 ft), With Enclosure Doors Open and Engine Removal Hoist Attached
Length	15 m (49 ft)
Approximate Weights	
Gas Turbine Enclosure	8618 kg (19,000 lb)
Generator Enclosure	5670 kg (12,500 lb)
<b>Fire Suppression System Compliance</b>	
CO <sub>2</sub> 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
<b>Water Mist Fire Suppression System</b>	
Minimum Operating Temperature	4°C (40°F), Optional Heater Available
<b>CO<sub>2</sub> Fire Cylinder Cabinets</b>	
Fire Cylinder Cabinet, Main	
Height	198 cm (78 in.)
Width	214 cm (84 in.)
Depth	46 cm (18 in.)
Approximate Cabinet Weight	429 kg (946 lb), Without Cylinders
Approximate Cylinder Weight	45 kg (100 lb)
Fire Cylinder Cabinet, Extended Release	
Height	198 cm (78 in.)
Width	122 cm (48 in.)
Depth	46 cm (18 in.)
Approximate Cabinet Weight	269 kg (592 lb), Without Cylinders
Approximate Cylinder Weight	45 kg (100 lb)
<b>Water Mist Fire Cylinder Cabinet</b>	
Fire Cylinder Cabinet	
Height	226 cm (89 in.)
Width	165 cm (65 in.)
Depth	91 cm (36 in.)
Approximate Cabinet Weight	1297 kg (2859 lb), Without Cylinders
Approximate Cylinder Weight	1697 kg (3741 lb)
<b>Construction Materials</b>	
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)

<b>Solar's Applicable Engineering Specifications</b>	
ES 1593	Guidelines for NEC Compliance of <i>Solar</i> 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)
<b>Solar's Applicable Product Information Letters</b>	
PIL 054	OSHA Noise Requirements
PIL 058	Package Sound Levels
PIL 150	Fire and Gas Detection and Control System

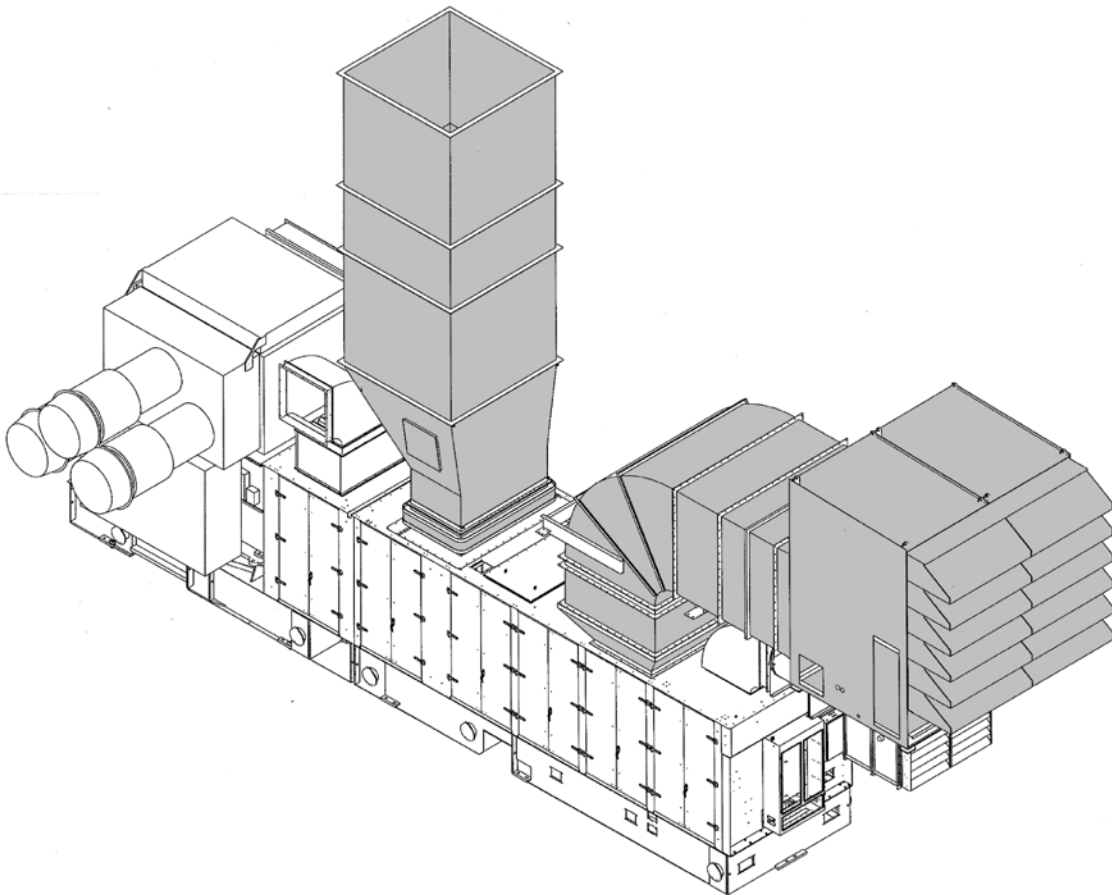
**Notes:**

- (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.

## 12 Air Inlet System

### 12.1 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 25 shows typical *Titan 250* air inlet and exhaust systems.



**Figure 25. Typical Titan 250 Turbine Air Inlet and Exhaust Systems**

#### 12.1.1 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, direct-contact prefilter elements, and high efficiency barrier filter elements. Access doors are provided in the filter housing for servicing. A weather hood and insect screens are available as options.

### 12.1.2 Insect Screens

Optional insect screens can be installed on each side of the air inlet filters (except for self-cleaning filters). This option is used with the air filter when large numbers of insects are present. The insect screen design reduces 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 insect screens should be removed and stored due to a potential for ice or snow to clog the screens.

### 12.1.3 Self-Cleaning Barrier Type Air Filter (Updraft Type)

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 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. Access to change filter elements from below must be provided. Standard features include:

- Support leg kit
- Dual differential pressure alarm and shutdown switch
- Filter elements
- Differential pressure gauge
- Electrical connections prewired to a common junction box

### 12.1.4 Marine-Type

The marine-type air filter system is suitable for use in coastal, offshore, and tropical locations. This system provides high efficiency removal of salt, water, and particulates. This system consists of:

- First stage marine vane separator/moisture eliminator
- Second stage prefilter
- Third stage high efficiency 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:

- High performance drainage system
- Transition outlet flange
- Lifting lugs
- Instrumentation panel
- Differential pressure gauge
- Electrical connections prewired to a common junction box
- High differential pressure alarm and shutdown switches

### 12.1.5 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..

### 12.1.6 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 10. Air Inlet System Specifications**

<b>Air Inlet System</b>	
Pressure Drop	Less Than 102 mm (4 in.) H <sub>2</sub> O with a Clean Air Filter
Ducting Loads	Should Not Be Applied In Any Direction
<b>Prefilter and Barrier Inlet Air Filter</b>	
Pressure Drop	
Clean	44 mm (1.75 in.) water
Fouled	127 mm (5 in.) water
<b>Self-Cleaning Barrier Type Air Filter</b>	
Fluid	Clean-Dry Air
Air Quality	<b>See Note (a)</b>
Minimum/Maximum Regulated Pressure Range	552 to 758 kPag (80 to 100 psig)
Intermittent Flow Rate	0.5 nm <sup>3</sup> /min (18 scfm)
Pressure Drop (Clean)	25 mm (1.0 in.) water
<b>Marine-Type Air Filter</b>	
Pressure Drop (Clean)	53 mm (2.1 in.) water
<b>Construction Materials</b>	
Prefilter/Barrier	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Insect Screen	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Self Cleaning Barriers	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Marine-Type Air Filter	316L Stainless Steel (Standard)
Air Inlet Silencer	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Air Inlet Ducting	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Air Inlet Support Structure	Carbon Steel (Standard)
<b>Applicable Product Information Letters</b>	
Solar's Product Information Letter PIL 054	OSHA Noise Requirements
Solar's Product Information Letter PIL 178	Salt Ingress Protection for Gas Turbines

**Notes:**

- (a) The particle size in the air stream should not exceed 10µm. Since it is impractical to remove 100% of all particles larger than 10µm, this is defined as β<sub>10</sub> > 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.

## 13 Exhaust System

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### 13.1 General Description

The exhaust system (Figure 25) typically consists of all components installed downstream of the engine exhaust bellows expansion joint, including silencers 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. A poorly designed exhaust system can cause loss of power capability and impose severe mechanical strains on the gas turbine. 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.

When exhaust silencing is required, provisions must be made to adequately mount and support the equipment and limit the exhaust silencer pressure loss.

#### 13.1.1 Exhaust Silencer

Solar can provide a silencer with support structure and ducting suitable for connection to the radial exhaust of the *Titan 250* generator set. Brackets are available for mounting the silencer in a vertical or horizontal position.

### 13.2 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 11. Exhaust System Specifications**

<b>Exhaust System</b>	
Temperature Class	T2
Total System Pressure Loss	Should Not Exceed 152 mm (6 In.) of Water
Exhaust Temperature	465°C (865°F)
Nominal System Back Pressure	203 mm (8 in.) of water, <b>See Note (a)</b>
<b>Construction Materials</b>	
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)
<b>Solar's Applicable Engineering Specifications</b>	
ES 1632	Exhaust Silencers for <i>Solar</i> Turbine Engines

**Notes:**

- (a) Higher backpressures can be accommodated. The exhaust backpressure should be less than 25.4 mm (1 in.) water column during gas turbine starting.

## 14 Accessory Equipment

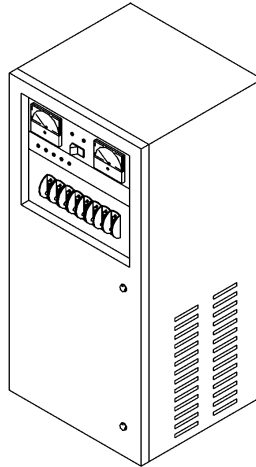
### 14.1 DC Power Supply and Battery Charger System

This system provides 120 VDC power for the following devices:

- The electric actuators that drive the fuel valves, bleed valve and variable guide vanes.
- The 120 to 24 volt DC-to-DC converter in the control system that provides the 24 VDC control power.
- The DC backup lube oil pump and DC back-up engine turning gear motors.
- The DC backup lube oil scavenging pump motor (when applicable for offshore installations).

The system includes a 3-phase charger (Figure 26) and a set of batteries configured for 120VDC output, mounted on a freestanding rack. The batteries are sized to provide sufficient power to allow the package to shut down and cool down in an orderly manner in the event of loss of external AC power. The system is designed for indoor installation in a nonhazardous area. The batteries are shipped fully charged and ready for use. Two battery types are available:

- Valve-regulated, sealed gas-recombination, lead-acid
- Nickel Cadmium



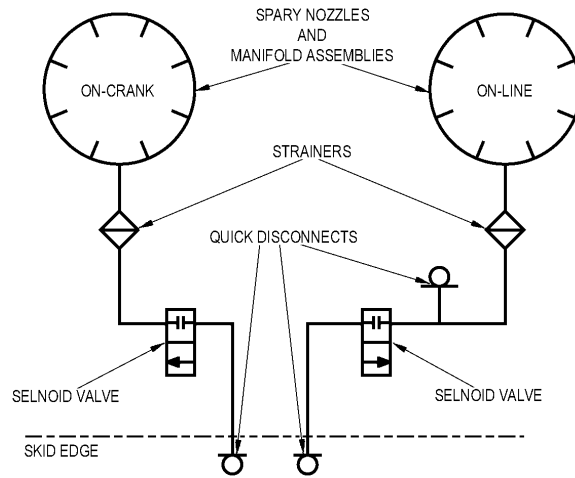
**Figure 26. Typical Battery Charger**

### 14.2 Turbine Cleaning System

The optional turbine compressor cleaning system (Figure 27) 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 27. Turbine Cleaning System**

**14.2.1 On-Crank Cleaning System**

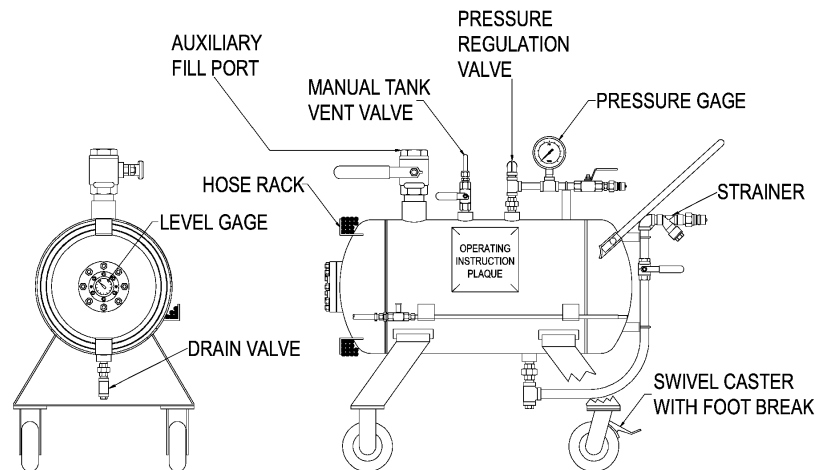
The on-crank cleaning system only operates at gas turbine cranking speed with the fuel system and ignition system deactivated. The gas turbine cranking and cleaning solution activation can be initiated from the control console or turbine control junction box.

**14.2.2 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.

**14.2.3 Turbine Cleaning Cart**

A portable offskid cleaning tank (Figure 28) 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.



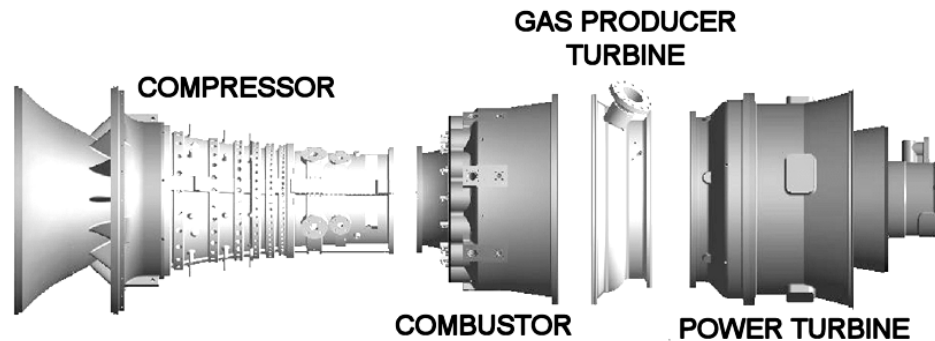
**Figure 28. Turbine Cleaning Cart**

### 14.3 Package Lifting Kit

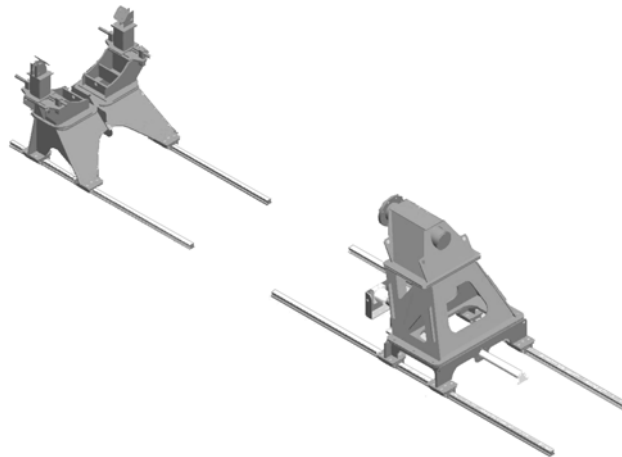
A package lifting kit can be shipped separately that contains slings, spreader bars, and assorted hardware to facilitate separate lifting of the driver and driven equipment modules with or without an export crate.

### 14.4 Engine Removal Equipment

The Titan 250 package is equipped with an innovative system to remove the gas turbine as a complete entity or in sections (Figure 29). The compressor, combustor, gas producer turbine and the power turbine can be separated axially using fixtures that attach to longitudinal rails (Figure 30). The rails are an integral part of the package frame. When service is scheduled, the fixtures are mounted on the rails and attached to the turbine. A screw-thread mechanism is then used to separate the sections. This arrangement allows easy access to the different sections of the engine for in-situ service. It also allows the individual sections, or the entire engine, to be removed laterally using a separate external rail-based handling system.



**Figure 29. Separation of Engine Sections**



**Figure 30. Rails and Fixtures for Axial Separation of Engine Sections**

**Table 12. Accessory Equipment Specifications**

<b>120 VDC Battery and Charger System</b>	
Charger Type	Floor Mount
Supply Voltage	380, 400, or 415 VAC, 50 Hz, 3 phase 460 VAC 60 Hz, 3 phase
Operating Temperature	-10 to 50°C (14 to 122°F)
Approximate Measurements (Charger)	
Height	1.21 m (47.5 in.)
Width	0.98 m (38.5 in.)
Depth	0.65 m (25.5 in.)
Approximate Measurements (Lead Acid Batteries)	
Height	1.78 m (5.8 ft)
Width	3.05 m (10.0 ft)
Depth	0.76 m (2.5 ft)
Approximate Measurements (NiCd Batteries)	
Height	1.65 m (5.4 ft)
Width	4.83 m (15.8 ft)
Depth	1.02 m (3.3 ft)
<b>Turbine Cleaning System</b>	
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 <sup>3</sup> /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 <sup>3</sup> /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)
<b>Turbine Cleaning Cart</b>	
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)
<b>Electrical Certifications</b>	
CSA	LR 77954
<b>Solar's Applicable Engineering Specifications</b>	
ES 9-62	Ingestive Cleaning Solar Gas Turbine Engines
ES 2416	DC Supply Systems

## 15 Marinization

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### 15.1 General Description

The *Titan 250* generator sets 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.

#### 15.1.1 Package Sub-base

As a standard, the *Titan 250* package is suitable for three-point mounting. In severe cases, a substructure may be required to provide additional package rigidity to protect equipment and to maintain proper alignment of the driver and driven equipment.

#### 15.1.2 Gimbals

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.

#### 15.1.3 Anti-Vibration Mounts

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.

#### 15.1.4 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.

#### 15.1.5 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.

#### 15.1.6 Flexible Ducting

Flexible ducting can be provided for the turbine air inlet duct, turbine exhaust duct, and, enclosure ventilation duct.

### 15.1.7 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)

### 15.1.8 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. Table 13, 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.

### 15.1.9 Angular Displacement and Acceleration

Table 15, Marinization Specifications, 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.

### 15.1.10 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 met.

**Table 13. Marinization Specifications**

Supporting Deck Deflection Limits					
Hogging and Sagging		0.3833 mm/m (0.0046 in/ft)			
Deck Twist		0.0198°/m (0.006°/ft)			
Angular Displacement and Acceleration Limits					
		Basic Duty	Moderate Duty	Severe Duty	
				Parallel	Perpendicular
Maximum Permissible Angular Displacements					
Dynamic:	Pitch / Period	2° / 13 sec	7.5° / 9 sec	10° / 9 sec	7.5° / 9 sec
	Roll / Period	2° / 13 sec	7.5° / 13 sec	22.5° / 13 sec	10° / 13 sec
Static:	Trim	2°	5°	5°	5°
	List	2°	5°	15°	5°
Maximum Permissible Accelerations					
Operating:		± 0.1 g	± 0.5 g	± 1.0 g	± 1.0 g
Survival:		± 0.5 g	± 1.0 g	± 1.5 g	± 1.5 g

## 16 Quality Assurance and Testing

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### 16.1 Quality Assurance

Solar is an International Organization for Standards (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 specifications 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 apply to parts manufactured both in and outside of Solar.

### 16.2 Testing

Factory testing is in accordance with Solar's engine 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.

#### 16.2.1 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.

#### 16.2.2 Generator Package Acceptance Testing

The basic package assembly, which includes the gas turbine, reduction-drive gearbox, generator, package-mounted accessories, and control console, are tested as a complete system to ensure proper integration and function in accordance with Solar's package test specifications. Results are recorded and maintained by Solar. The acceptance test 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 with a unity power factor of 1.0
- Turbine and generator temperature measurement
- Variable guide vane adjustment
- Generator and engine tuning
- Fuel transfers (for dual fuel units)
- Load/speed transient testing
- Malfunction and safety devices testing
- AC metering and control circuitry testing (if AC metering is supplied), calibration of AC metering circuits is performed by bench testing

The package is usually tested with the generator. When this is not practical due to schedule availability or test cell limitations, the package may be tested with a slave generator. Prior to shipment, the contract generator will be mounted and aligned on the package. Items excluded from standard package testing are inlet and exhaust systems, ancillary equipment such as filters, silencers, ducting, battery systems, oil coolers, ancillary skid, switchgear, and any customer-furnished hardware.

### 16.2.3 Generator Testing

The generator is tested in accordance with the Institute of Electrical and Electronic Engineers (IEEE) standard specifications and Solar's specifications at the manufacturer's plant. These tests satisfy both Solar and National Electrical Manufacturers Association (NEMA) requirements. Supplier testing is performed under periodic quality control review by Solar to ensure conformity.

### 16.2.4 Acceptance Test Data

Acceptance test data are reviewed and approved by Test Engineering, Quality 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 generator set. 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.
- Voltage and frequency transients – strip chart traces are provided that show voltage and frequency deviations during load transitions.
- Operating values – a chart that includes the following operating parameters at each step load from no load to full load:
  - Lubricating oil pressure, temperature, and flow
  - Package temperatures
  - Generator power
  - Generator voltage, amperage, and frequency
  - Engine compressor discharge pressure
  - Package vibration levels

### 16.2.5 Additional Testing

As an option, additional testing can include a four hour full-load test using gas and/or liquid fuel, factory emissions testing, and field performance testing.

### **16.2.6 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
- Generator, including rotor balancing and standard generator testing

### **16.2.7 Customer Participation**

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

### **16.2.8 Weld Radiography**

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

## 17 Preservation, Installation, and Documentation

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### 17.1 General Description

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

### 17.2 Preservation

Long term and short term preservation can be provided for the engine and package. The type of preservation required depends upon 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

Long-term preservation is required if:

- Equipment will be stored in an unimproved storage area for greater than 90 days 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

Short-term preservation is required if:

- Equipment will be stored in an improved storage area for less than 90 days 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

### 17.3 Site Requirements

*Solar's* gas turbine generator sets require minimal site preparation. The *Titan 250* generator set 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.

### 17.4 Mechanical Installation Requirements

#### 17.4.1 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 weights 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.

#### 17.4.2 Alignment Tooling

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

#### 17.4.3 Lube Oil Cooler(s)

The lube oil cooler(s) is/are not integral with the package and must be located and installed separately.

#### 17.4.4 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.

#### 17.4.5 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.

### 17.5 Documentation

Four copies of the Operation and Maintenance Instruction (OMI) manuals and Quality Control (QC) data books are provided on CD-ROM. Additional copies and alternative formats can be ordered at additional cost. Project specific drawings are provided in electronic format and include:

- Electrical schematic
- Wiring diagram
- Electrical interface/Interconnect diagram
- *Turbotronic* software documentation
- Cause and effect drawing
- Mechanical interface drawing
- Start, Fuel, Lube, Air/Drain, and Enclosure system schematics

Solar's Product Information Letter 184 "Documentation for New Equipment" provides a complete list of all the documentation supplied on a typical project.

#### 17.5.1 Quality Control Data Book

The QC data book typically includes the following:

- Inspection and test plan (ITP)
  - Describes the quality assurance requirements for each product on a project basis.
  - Lists the primary controlling and verifying documents, codes and standards used to define the quality requirements, and identifies inspection points.
- Package certified test report

- Generator acceptance test report
- American Society of Mechanical Engineers (ASME) data reports, as applicable
- Solar's Certificate of Compliance

If specified on the final project ITP, the QC data book may also include the following documents at additional cost and increased delivery time:

- Engine rotor balance record
- Engine casing leak test record
- Documentation from suppliers of major package components such as oil coolers, oil filters, gearboxes and driven equipment
- Optional electrical device list when applicable
- Third-Party Certificates and Declarations of Conformity when applicable

#### 17.5.2 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  $\pm 10\%$  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.

#### 17.5.3 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.

#### 17.5.4 Operation and Maintenance Instruction Manual

The Operation and Maintenance Instruction Manual (OMI) provides descriptive and instructional data for operating and servicing the turbomachinery package. General, functional, and component descriptions of the turbine engine and associated package systems with supporting illustrations are included in four volumes:

- **Systems Operator's Guide** - Intended for the equipment operator, the systems operator's guide provides familiarization with controls and indicators, operating procedures, and safety precautions to ensure safe equipment operation.
- **Maintenance Instructions** - Intended for maintenance and field service personnel, the maintenance instructions include preventive and corrective procedures, including periodic inspection requirements, alignment procedures, cleaning procedures, removal and installation procedures, adjustment procedures, and tolerances.
- **Supplementary Data** - Provided in the form of supplier manuals and data sheets, the supplementary data provides descriptions of components and assemblies not covered or fully discussed in the Maintenance Instructions volume. Due to copyright restrictions, supplementary data from suppliers is available in English only.
- **Illustrated Parts List** - Provides part numbers, part names, quantities, reference designators, and illustrations for locating and ordering parts.
- **Language** - The OMI is provided in English. Other languages are available as an option.

The OMI manual typically includes the following features:

- Electronic viewing of data in a Windows environment
- All volumes of the manual set on one CD-ROM
- Search feature including full text search for supplier data

- Graphics in a separate window for simultaneous viewing of text with associated illustration
- PDF version for printing

**17.5.5 Service Parts List**

Identifies operational service parts and tooling. Once engineering has been finalized and manufacturing bills are available, Solar's Service Parts department creates a detailed listing of service parts from the actual equipment manufacturing bills of material.

**Table 14. Preservation, Installation, and Documentation Specifications**

<b>Mechanical Installation Requirements</b>	
Mounting	
Space Between Units In Multiple-Unit Installations	A Minimum of 2.5 m (8 ft)
Lube Oil Cooler(s)	
Top of The Lube Oil Cooler(s)	Not Be More Than 9 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)
<b>Start, Fuel, Lube, Air/Drain System Schematics</b>	
Compliance	American National Standards Institute (ANSI) Y32.10
<b>Solar's Applicable Engineering Specifications</b>	
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
<b>Solar's Applicable Product Information Letters</b>	
PIL 184	Documentation for New Equipment
PIL 097	Package Preservation and Preparation for Shipment

**Notes:**

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

## 18 Certification

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### 18.1 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

### 18.2 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 (ENTECLA)

(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. Generator packages are designed for use in Class I, Division 2 hazardous locations.

### 18.3 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. (ENTECLA), when certifying to Canadian standards
- Underwriters Laboratories Inc. (UL), when certifying to Canadian standards

## 18.4 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

### 18.4.1 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 has received from DNV "type certification" for standard turbomachinery packages for ATEX and PED directives. As a result, Solar self-certifies for CE Mark requirements on standard packages. 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.

### 18.4.2 Solar Compliance

International Electrotechnical Commission (IEC) / Electrotechnical Standardization (CENELEC) (60079-10) categorizes hazardous areas in terms of Zones shown in Table 15.

**Table 15. 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, generator sets can only be certified for Zone 2 due to the hot surface temperature of the gas turbine.



## 18.5 International Electrotechnical Commission Safety Assessment

International Electrotechnical Commission (IEC) 61508 is an international standard that describes a standardized approach to Assess 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.

## 18.6 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.

### 18.6.1 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.

### 18.6.2 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.

### 18.6.3 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).

### 18.6.4 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.

## 18.7 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 16. Certification Specifications**

<b>Solar's Applicable Engineering Specifications</b>	
ES 1593	Guidelines for NEC Compliance of Solar Product Lines: Class I, Group D, Division 1 and Division 2
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
<b>Solar's Applicable Product Information Letters</b>	
PIL 127	Product Certification

## 19 Support Services

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### 19.1 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

### 19.2 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 11,500 units in 90 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.

### **19.3 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.

### **19.4 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](http://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 <sup>3</sup>	39.3694	kcal/nm <sup>3</sup>	9.382
cfm	m <sup>3</sup> /min	0.028317	m <sup>3</sup> /min	0.028317
cfm	m <sup>3</sup> /s	0.00047195	m <sup>3</sup> /s	0.00047195
cu ft	m <sup>3</sup>	0.028317	m <sup>3</sup>	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 <sub>r</sub> /lb <sub>m</sub>	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 <sub>2</sub> O	kPa	0.2488	cm H <sub>2</sub> O	2.540
kcal	kJ	4.1868		
lb	kg	0.4536	kg	0.4536
lb/cu ft	kg/m <sup>3</sup>	16.0185	kg/m <sup>3</sup>	16.0185
lb <sub>f</sub> -in.	Nm	0.1129848		
MMSCFD	Nm <sup>3</sup> /min	18.62	Nm <sup>3</sup> /h	1117
mph	km/h	1.6093	km/h	1.6093
psi	kPa	6.8948	kg/cm <sup>2</sup>	0.070
psia	kPa (a)	6.8948	bars Abs	0.068948
psig	KPa (g)	6.8948	Ata	0.070
scfm	Nm <sup>3</sup> /min	0.0268	Nm <sup>3</sup> /h	1.61
sq in.	mm <sup>2</sup>	645.16	cm <sup>2</sup>	6.4516
sq ft	m <sup>2</sup>	0.0929	m <sup>2</sup>	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 <sub>2</sub> O	kPa	0.09807		
kcal/h	W	1.16279		
kg/cm <sup>2</sup>	kPa	98.0665		
Nm <sup>3</sup> /h	Nm <sup>3</sup> /min	0.0167		

## List of Abbreviations

Abbreviations	
ABS <sub>1</sub>	American Bureau of Shipping
ABS <sub>2</sub>	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 <sup>2</sup>	Square Centimeter
cm <sup>3</sup>	Cubic Centimeter
CO	Carbon Monoxide
CO <sub>2</sub>	Carbon Dioxide
CSA	Canadian Standards Association
CT	Compliant Tower
Cu ft	Cubic Feet
°C	Degrees Celsius
dBA	Decibels (Acoustic)
DNV	Det Norske Veritas
ENTECLA	Entela Incorporated
ES	Engineering Specification
EU	European Union
FM	Factory Mutual
FP	Fixed Platform
fps <sub>1</sub>	Feet Per Second
FPS <sub>2</sub>	Floating Production Systems
FPSO	Floating Production, Storage and Offloading
ft-lb	Foot-Pound
ft-lb <sub>f</sub> /lb <sub>m</sub>	Foot-Pound Force/Pound Mass
ft/s	Feet/Second
°F	Degrees Fahrenheit
gal.	Gallon
hp	Horsepower

<b>Abbreviations (Cont.)</b>	
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 <sub>2</sub> O	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 <sup>2</sup>	Square Meter
m <sup>3</sup>	Cubic Meter
m <sup>3</sup> /min	Cubic Meters/Minute
N	Newton
N/m <sup>2</sup>	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 <sup>3</sup> /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

<b>Abbreviations (Cont'd)</b>	
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 <sup>3</sup> /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 <sup>5</sup> Pascals
***	"Standard" = 15°C, 760 mm Hg



## List of Solar's Engineering Specifications

Solar's Engineering Specifications	
ES 9-4	Interpretation of Drawing Requirements
ES 9-56	Fusion Welding
ES 9-62	Ingestive Cleaning Solar Gas Turbine Engines
ES 9-76	Traceability Requirements Critical Parts, Engine and Related Systems
ES 9-98	Fuel, Air, and Water (or Steam) for Solar Gas Turbine Engines
ES 9-224	Lubricating Oils for Use In 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 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
ES 2416	DC Supply Systems

**Note:**

Engineering specifications can be made available upon request in accordance with Caterpillar and Solar Turbines Incorporated confidentially guidelines.

## List of Solar's Product Information Letters

Solar's Product Information Letters	
PIL 012-OG	Customer Drawings - Oil and Gas
PIL 054	OSHA Noise Requirements
PIL 058	Package Sound Levels
PIL 097	Package Preservation and Preparation for Shipment
PIL 127	Product Certification
PIL 148	LPG and NGL Fuels
PIL 149	Direct-drive AC Start Systems
PIL 150	Direct-drive AC Start Systems
PIL 161	Lube Oil System Cleanliness
PIL 162	Recommendations for the Sourcing, Handling, Storage and Treatment of Fuels for Solar Gas Turbines
PIL 176	Siloxanes in Gas Fuel
PIL 178	Salt Ingress Protection for Gas Turbines