Solar® Turbines

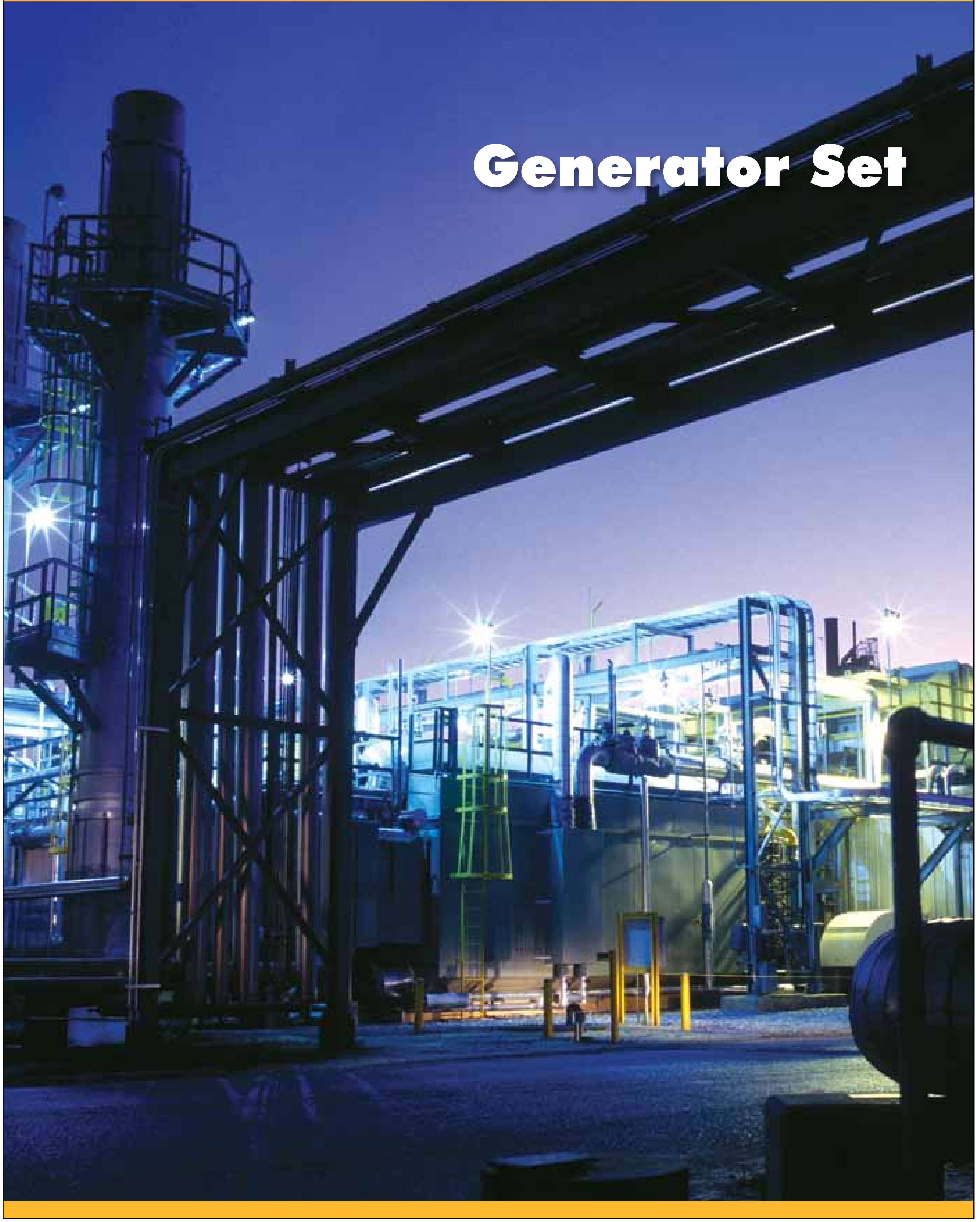
A Caterpillar Company

TAURUS 60

Turbomachinery Package Specification

Oil & Gas and Power Generation Applications

Generator Set



TURBOMACHINERY PACKAGE SPECIFICATION

Taurus™ 60 Generator Set

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TPS60GS/309

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1 Introduction

1.1 General Description

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

The *Taurus* 60 generator set represents 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 specifications for the *Taurus* 60 generator set. Presented within this booklet are basic package configurations, ancillary descriptions, installation requirements, and a list of customer support services available at the time of publication. Please note that changes in equipment, service descriptions, and specifications may occur without prior notice.

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2 Taurus 60 Gas Turbine Generator Set

2.1 General Description

The *Taurus 60* gas turbine generator set (Figure 1) is a completely integrated and fully operational package equipped with the accessories and auxiliary systems required for operation. In addition to the standard package features, a wide array of optional equipment is available to meet the customer's installation and operation requirements. Designed specifically for industrial service, the *Taurus 60* gas turbine generator set is a compact, lightweight unit requiring minimal floor space for installation. Proven packaging designs greatly reduce installation costs, time, materials, and labor.

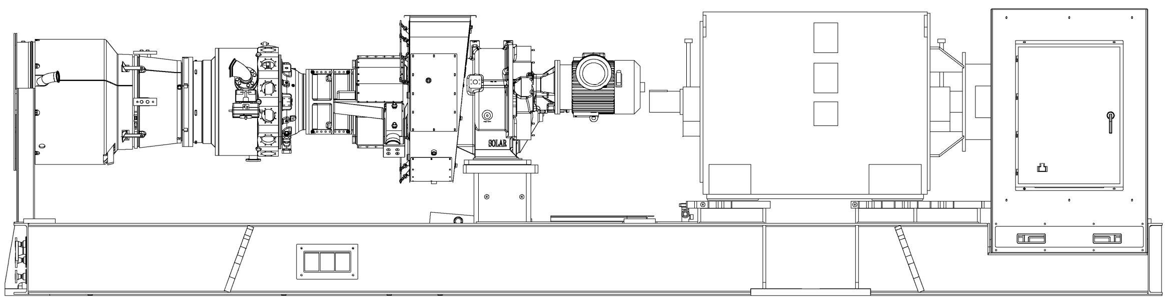

Figure 1. Typical Taurus 60 Gas Turbine Generator Set

2.2 Package Description

The *Taurus 60* 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 heavy-steel base frame referred to as the skid. The skid is a structural steel assembly with beam sections and cross members welded together to form a rigid foundation. Drip pans are included to collect any potential liquid leakage. Package connection points for fuel, lube oil, air, and water are located on the outer edge of the skid.

Electrical connections are made in 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 spark-proof 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 *Taurus 60* gas turbine generator set include:

- Gas turbine
- Reduction-drive gearbox
- Generator
- Start system
- Fuel system
- Lubricating oil system

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- Turbotronic 4 Control System
- Onskid electrical wiring
- Skid with drip pans
- Piping and manifolds

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, 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 *Taurus 60* 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 edge of the skid.

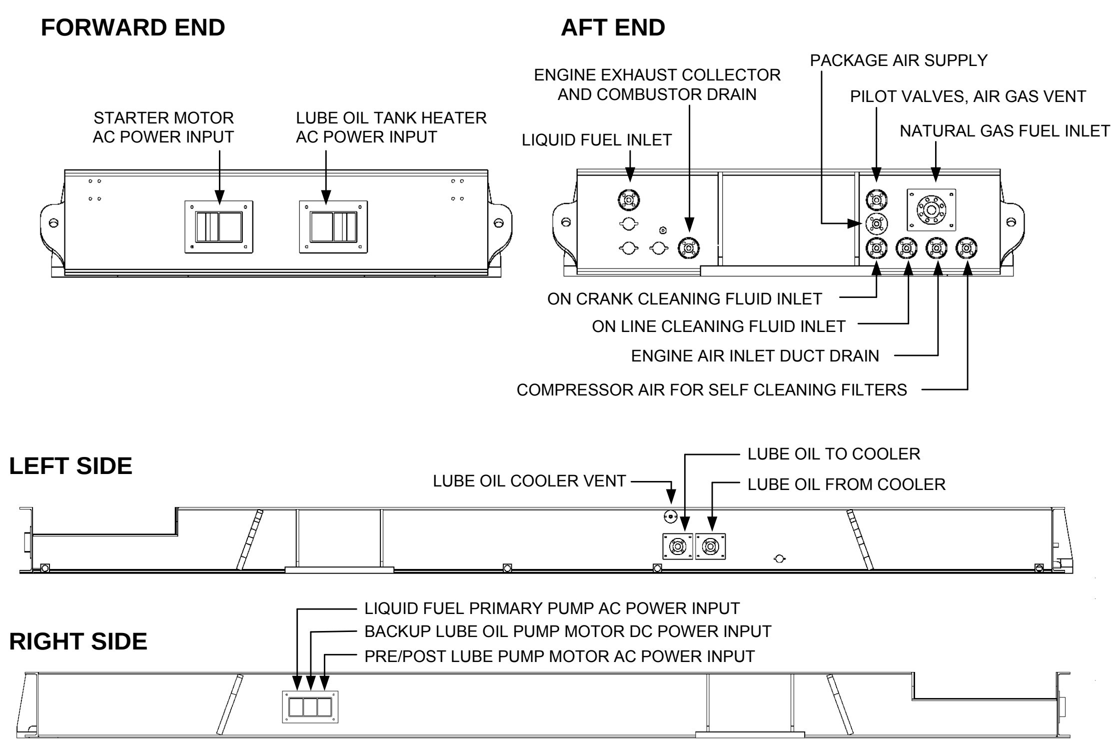

Figure 2. Typical Taurus 60 Service Connections

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Table 1. Package Specifications

Dimensions	
Approximate Package Measurements	
Height, Enclosed	3.16 m (10 ft 4.5 in.)
Width (base only)	2.59 m (8 ft 6in.)
Width at Lift Points	2.72 m (8 ft 11 in.)
Length	9.83 m (32 ft 3 in.)
Approximate Package Weights	
Gearbox	1491 kg (3287 lb)
AC Start Motor Assembly	467 kg (1030 lb)
Generator (Typical Open Drip Proof)	17 545 kg (38,680 lb)
Gas Turbine Assembly	2300 kg (5070 lb), **See Note a**
Total Dry Weight	37 921 kg (83,600 lb), **See Note b**
Lube Oil	1161 kg (2560 lb)
Total Wet Weight	39 0535 kg (87,160 lb)
Piping and Tubing Thickness	
Piping ≥ 76.2 mm (3 in.) Nominal Pipe Size (NPS)	Schedule 40 (Unless Otherwise Specified)
Piping ≤ 50.8 mm (2 in.) NPS	Schedule 80 (Unless Otherwise Specified)
Tubing 6.35 mm (0.25 in.) NTS	1.2446 mm (0.049 in.) Minimum Wall Thickness
Tubing 9.53 mm (.375 in.) NTS	1.2446 mm (0.049 in.) Minimum Wall Thickness
Tubing 12.7 mm (0.500 in.) NTS	1.651 mm (0.065 in.) Minimum Wall Thickness
Tubing 19.05 mm (0.75 in.) NTS	1.651 mm (0.065 in.) Minimum Wall Thickness
Tubing 25.40 mm (1.00 in.) NTS	2.108 mm (0.083 in.) Minimum Wall Thickness
Tubing 31.75 mm (1.25 in.) NTS	2.768 mm (0.109 in.) Minimum Wall Thickness
Construction Materials	
Piping, Manifolds, and Tubing ≤ 10.2 cm (4 in.)	316L Stainless Steel (Unless Otherwise Specified), **See Note c**
Piping Interface Connections	316L Stainless Steel (Unless Otherwise Specified) **See Note c**
Flange Assembly Hardware	316L Stainless Steel
Pipe Support Brackets	316 L Stainless Steel
Pipe Flexible Couplings	Carbon Steel
Tubing Dual Ferrule Compression Fittings	316L Stainless Steel
Lube Oil Vent Flame Arrestor with Weatherhood	Carbon Steel
Electrical System Certifications	
NEC	Class 1, Group D, Division 2
CENELEC	Zone 2, Group II
CE, ATEX	Zone 2, Group II
Three-Phase Package Motors	
Optional Motor Voltage Ratings	380, 400, or 415 VAC, 50 Hz 460 VAC, 60 Hz
Single-Phase Battery Charger	
Optional Battery Charger Voltage Ratings, CE	220, 230, or 240 VAC, 50 Hz or 60 Hz
Optional Battery Charger Voltage Ratings, NEC	220, 230, 240, 380, 400, 415, 440, 460 or 480 VAC, 50 Hz or 60 Hz
Single-Phase Lighting And Space Heater Voltage	
Optional Package Lighting and Space Heater Voltage Ratings	120, 220, 230, or 240 VAC, 50 Hz or 60 Hz

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Ingress Protection (IP) Ratings	
Onskid Junction Boxes	IP56 to IP66
Control Console	IP50
Battery Charger, NEC	IP30
Battery Charger, CE	IP30

Solar's Applicable Engineering Specifications	
ES 9-56	Fusion Welding
ES 1593	Guidelines for NEC Compliance of Solar Product Lines: Class I, Group D, Division 1 and Division 2
ES 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cable Installed In Class 1, Division 2 Hazardous Areas
ES 1762	Standards and Practices for The Design and Installation of Cable Channels and Armored Cable Installed In Zone 2, Group IIA Hazardous Areas
Solar's Applicable Product Information Letters	
PIL 127	Product Certification

Notes:

(a) Includes mount and air inlet and exhaust collectors.

(b) Excludes enclosure ventilation, enclosure supported ancillary equipment, and lube oil.

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

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3 Taurus 60 Gas Turbine

3.1 General Description

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

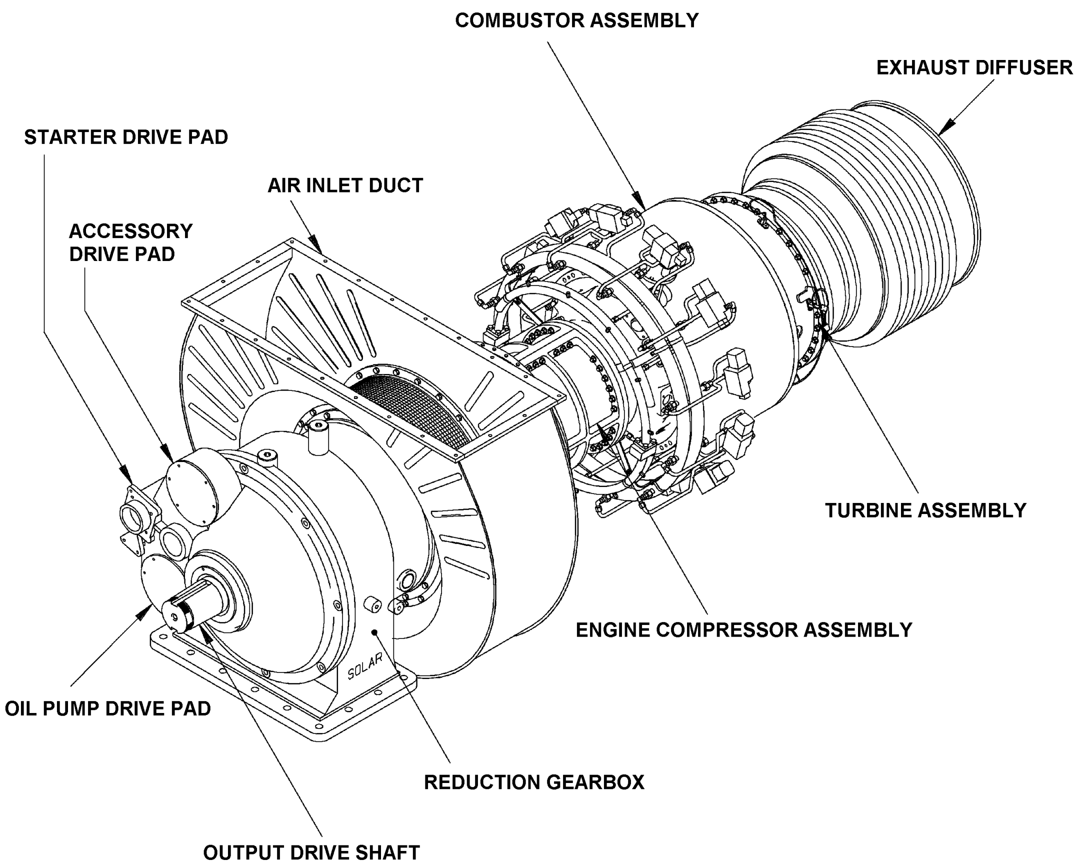

Figure 3. Typical Taurus 60 Single-Shaft Gas Turbine

3.1.1 Principles of Operation

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

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

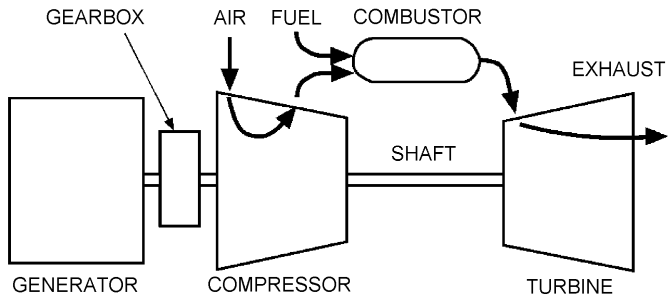

Figure 4. Typical Combustion Process

3.1.2 SoLoNOx Combustion System (Optional)

In addition to Solar's conventional combustion system, Solar's proprietary *SoLoNOx* dry emissions system reduces pollution by limiting the formation of nitrogen 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 2. Taurus 60-7901 Gas Turbine Specifications

Compressor	
Type	Axial Flow
Number of Stages	12
Compression Ratio	12.2:1
Flow (Nominal)	21.6 kg/sec (47.6 lb/sec)
Combustion Chamber	
Type	Annular
Ignition	Torch
Number of Fuel Injectors	Conventional Combustion: 12 *SoLoNox* Combustion: 12
Power Turbine	
Type	Reaction
Number of Stages	3
Speed	14 944 rpm (50 Hz) 14 951 rpm (60 Hz)
Bearings	
Radial	3 Tilt Pad with Proximity Probes
Thrust, Active	1 Tilt Pad with Resistance Temperature Device Probes
Thrust, Inactive	1 Fixed Tapered Land

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Construction Materials	
Compressor Case	Nodular Iron
Combustor Case	Carbon Steel
Exhaust Diffuser	Stainless Steel
Accessory Gear Housing	Ductile Iron
Protective Coatings	
Compressor Rotor and Stator Blades	Inorganic Aluminum
Nozzles, First and Second Stage	Precious Metal Diffusion Aluminide
Blades, First and Second Stage	Precious Metal Diffusion Aluminide
Approximate Weight	
Gas Turbine Assembly	2300 kg (5070 lb), **See Note a**
Performance	
Output Power	5670 kW (7603 hp), **See Note a**
Heat Rate	11 427 kJ/ kW-hr (10 832 Btu/ kW-hr)
Exhaust Flow	78 385 kg/hr (172,809 lb/hr)
Exhaust Temperature	510°C (950°F)
Vibration Monitoring	
Turbine Bearing #1	Displacement Probes, X and Y axis
Turbine Bearing #2	Displacement Probes, X and Y axis
Turbine Bearing #3	Displacement Probes, X and Y axis
Turbine Rotor Shaft	Displacement Probe, Axial Position
Turbine Rotor Shaft	Keyphasor
Temperature Monitoring	
Turbine T5	6 Thermocouples
Turbine Air Inlet	Resistance Temperature Device (RTD)
Turbine Lube Oil Header	RTD
Turbine Lube Oil Tank	RTD
Turbine Gas Producer Thrust Bearing	RTD (1 connected and 1 spare)
Turbine #2 and #3 Bearing Drain	RTD

Notes:

(a) Includes air inlet and exhaust collectors.

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

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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 spark-proof 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. The gears can be serviced without removing the main case.

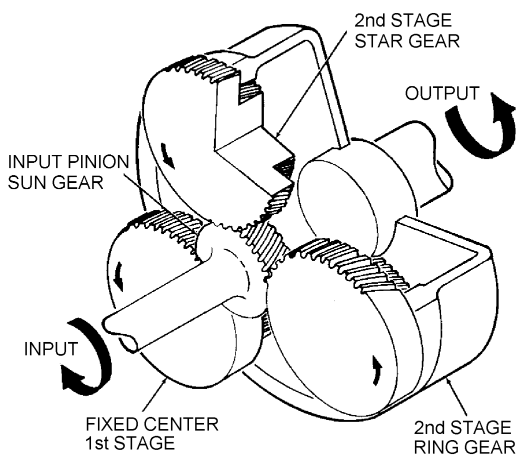

Figure 5. Typical Star Compound Epicyclic Gearbox

Table 3. Reduction-Drive Gearbox Specifications

Approximate Weight	
Gearbox	1491 kg (3287 lb)
Output Speed	
50 Hz Service	1500 rpm
60 Hz Service	1800 rpm
Inspection and Overhaul Intervals	
Major Inspection Interval	30,000 hours
Overhaul Interval	100,000 hours
Compliance	
American Petroleum Institute (API)	613 Compliant With Exceptions, Refer to Solar's Standard List of Exceptions
Ratings	
American Gear Manufacturers Association (AGMA)	In Excess of 1.10 for Generator Applications and 10.0 Under Full-Load Short-Circuit Conditions
Vibration Monitoring	
Gearbox	Acceleration Probe

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5 Generator and Associated Equipment

5.1 General Description

For maximum flexibility, the *Taurus 60* 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.

Five generator enclosure types are available to suit a variety of environmental conditions and cooling requirements:

- Open drip proof (ODP, Figure 6)
- Closed air circuit air cooled (CACA)
- Closed air circuit water-to-air cooled (CACW)
- Totally enclosed air-to-air cooled (TEAAC)
- Totally enclosed water-to-air cooled (TEWAC)

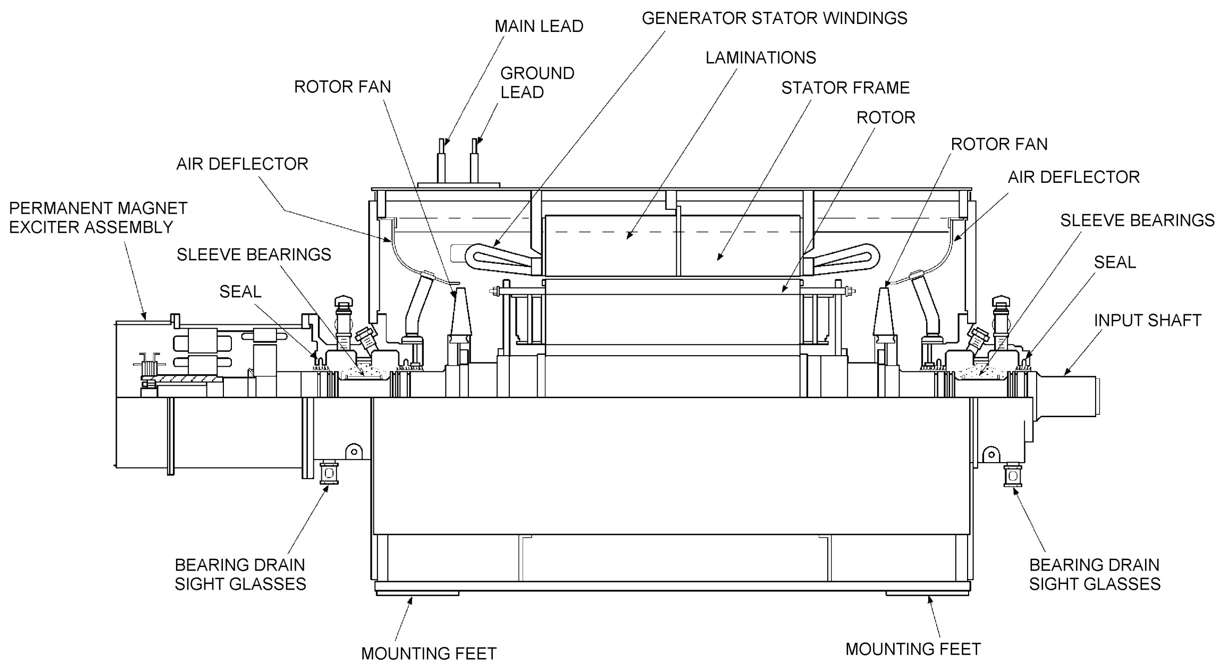

Figure 6. Typical Open Drip-Proof Generator with Permanent Magnet Exciter System

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.

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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, laminated 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, which 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 permanent magnet generator (PMG) pilot exciter. The exciter is mounted directly

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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 combined generator control module (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 4. Generator and Associated Equipment Specifications

Approximate Weight	
Generator (Typical Open Drip Proof)	17 545 kg (38,660 lb)
Construction Types	
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
Generator	
Optional Voltage Ratings	3300, 4160, 5500, 6600, 6900, 11000, 12470, 13200, or 13800 VAC, **See Note a**
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	NEMA Class B, **See Note 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
Space Heater	
Voltage	110 or 220 VAC
Frequency	50 or 60 Hz
Phase	1 Phase
Temperature Monitoring	
Generator Driven End Bearing	RTD (1 connected and 1 spare)
Generator Exciter End Bearing	RTD (1 connected and 1 spare)
Generator Windings (3 phases)	RTD (1 connected and 1 spare per phase)

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Vibration Monitoring	
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.

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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.

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 a standard frame size and is constructed to be explosion proof and flameproof. The motor includes an integral over-temperature protection thermostat connected to the *Turbotronic* 4 control system for hazardous area motor certification and protection. Separate cable/conduit entry points are provided for power connections, thermal protection wiring, and the space heater wiring. Starting power is transferred to the gas turbine via the reduction-drive gearbox and over-running clutch and shaft assemblies.

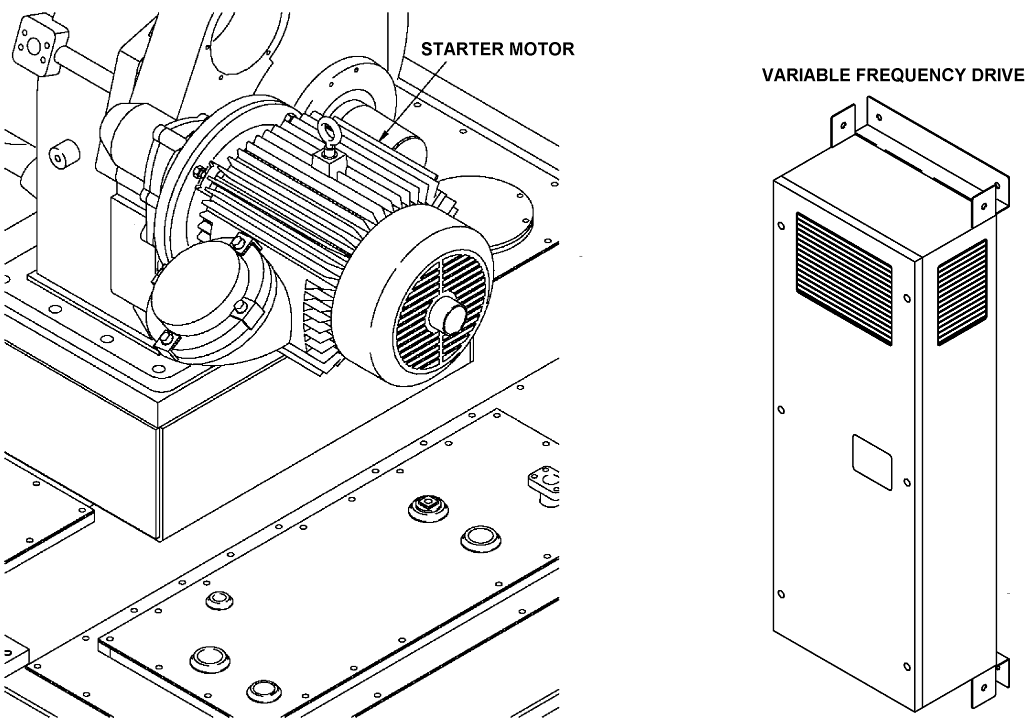

Figure 7. Direct-Drive AC Starter Motor and Variable Speed Drive

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6.2.2 Variable Frequency Drive

The variable frequency drive (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 three consecutive starts with a four-minute purge time on each start. (Refer top Product Information Letter 149). 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 motor. A start contactor is not required for VFD operation. A customer-furnished fused disconnect at the VFD input is recommended. Optional motor space heater wiring is available.

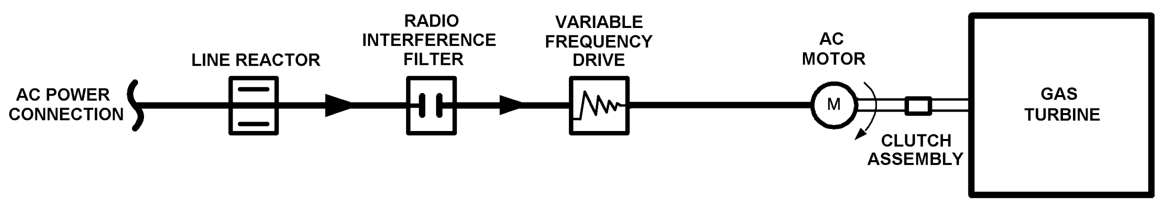

Figure 8. Typical Direct-Drive AC Start System

Table 5. Start System Specifications

Variable Frequency Drive	
Optional Voltage Input Ranges	380 to 460 VAC, (48 to 62 Hz) 500 to 600 VAC, (48 to 62 Hz), **See Note a**
Minimum Input Current	
380 to 460 VAC Input	255 amps
500 to 600 VAC Input	140 amps
Voltage Output Range	0 to 380 VAC, (0 to 575 Hz)
Maximum Line Distribution Capacity	1000 kVa
Maximum Fault Current Capacity	30 000 amps, **See Note b**
Maximum Breakaway Amperage	390 amps
Maximum Breakaway Torque	918 N-m (677 ft-lb)
Power Factor	0.96
Efficiency	98%
Operating Temperature	0 to 50°C (32 to 122°F)
Heat Rejection	
380 to 460 VAC Input	2513 watts
500 to 600 VAC Input	2290 watts
Input Fuse Rating	293 amp
Approximate Measurements	
Height	850 mm (33.46 in.)
Width	403.9 mm (15.9 in.)
Depth	275.5 mm (10.85 in.)
Approximate Weight	71.44 kg (157.5 lb)
VFD Enclosure Rating	NEMA 1, IP20

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Starter Motor	
Motor Type	Squirrel-cage Induction
Motor Voltage Rating	380 AC, (3.5 - 120 Hz)
Power	93 kW (125 hp)
Operating Speed	0 to 4800 rpm
Maximum Breakaway Amperage	1885 amps max.
Maximum Breakaway Torque	732 N-m (540 ft-lb)
Operating Temperature	-25 to 60°C (-13 to 140°F)
Space Heater Voltages	220 to 240 VAC, 50 Hz 110 to 120 VAC, 60 Hz
Approximate Measurements	
Length	80.8 cm (31.8 in.)
Diameter	49.5 cm (19.5 in.)
Approximate Weight	467.2 kg (1030 lb)
Power Wiring	
VFD to Starter Motor Power Cable Length	37.5 m (123 ft), **See Note c**

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

Notes:

(a) If the customer-furnished input voltage is greater than 600 VAC ±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.

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7 Fuel System

7.1 General Description

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

- Gas Fuel – Conventional Combustion
- Gas Fuel – *SoLoNOx* Combustion
- Gas and Liquid (Dual Fuel) – Conventional Combustion
- Gas and Liquid (Dual Fuel) – *SoLoNOx* Combustion

Figure 9 provides a simplified schematic of the configurations.

7.1.1 Conventional Combustion System

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

7.1.2 *SoLoNOx* Combustion System

The *SoLoNOx* combustion system uses special fuel injectors with main and pilot fuel ports. The fuel injected through these ports is controlled during starting and steady-state operation to maintain stable combustion and minimize the formation of nitrogen oxide (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.

7.2 Gas Fuel System

For conventional combustion, the gas fuel system includes:

- Skid edge gas fuel filter
- Supply pressure transmitter
- Pilot air operated primary gas fuel shutoff valve
- Pilot air operated secondary gas fuel shutoff valve
- Pilot air operated gas vent valve
- Electrically operated fuel control valve
- Torch with shutoff valve and pressure regulators
- Main fuel manifold
- Fuel injectors

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

- Fuel pilot control valve
- Fuel pilot manifold

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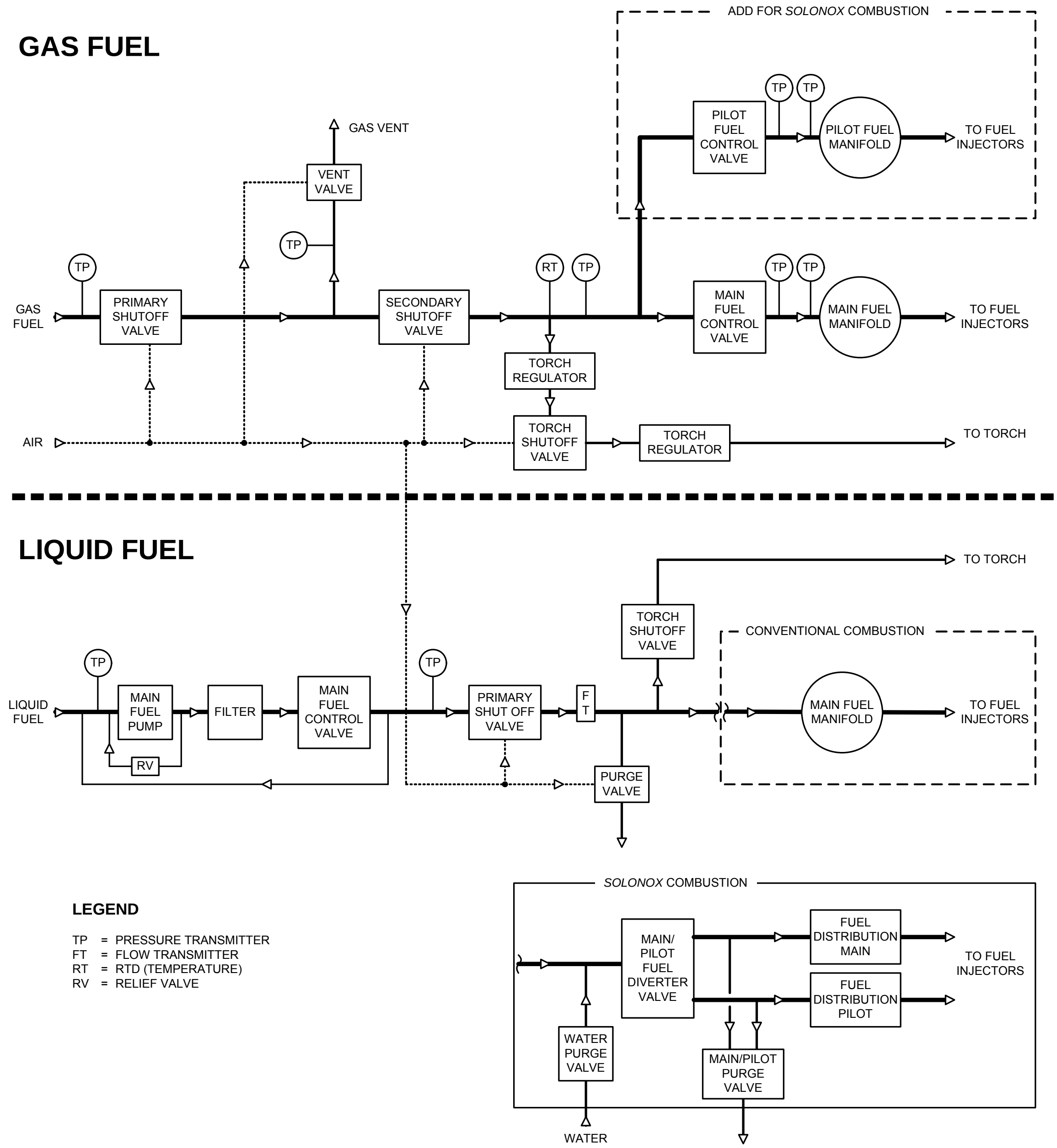

Figure 9. Simplified Dual Fuel System Schematic

7.2.1 Component Operation

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

The gas fuel control valve and, when applicable, the *SoLoNOx* fuel pilot control valve, are powered by integrated DC motor-driven actuators. Integrated actuator electronics provide precise closed-loop valve control based on position command inputs versus position feedback outputs. Both valves are fast acting and provide fuel metering for light-off,

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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.

7.3 Dual Fuel System

The dual fuel system uses special fuel injectors that handle both gas and liquid fuels. This system consists of the gas fuel system (described above) and the liquid fuel system (described below).

7.4 Liquid Fuel System

The liquid fuel system requires an external air source to atomize fuel during the start sequence and a customer-furnished purge tank. After starter dropout speed is attained, the external atomizing air source is de-energized and the turbine compressor discharge pressure (Pcd) provides atomizing air.

For conventional combustion, the liquid fuel system includes:

- AC motor-driven main fuel pump
- Main fuel pump relief valve
- Simplex high pressure fuel filter
- Liquid fuel control valve
- Pilot air-operated main liquid fuel shutoff, purge, and torch shutoff valves
- Electrically operated liquid fuel valve
- Main fuel manifold
- Liquid fuel injector assemblies
- Main pump suction pressure transmitter
- Main pump discharge pressure transmitter

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

- Liquid fuel main/pilot distribution valve
- Main/pilot purge valve
- Main fuel distribution system
- Pilot fuel distribution system

7.4.1 Component Operation

The main liquid fuel control valve and, when applicable, the *SoLoNOx* optional liquid fuel main/pilot distribution valve are powered by integrated DC motor-driven actuators. Integrated valve electronics provide precise closed-loop valve control based on position command inputs versus position feedback outputs. The actuators require minimum power under full load and provide excellent black-start capability. The 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.

7.4.2 Offskid Liquid Fuel Boost System (Optional)

The fuel boost system includes an AC motor-driven pump with a suction strainer to boost the fuel pressure at the skid edge to the pressure required for the application. It is supplied pre-assembled on a skidded frame shipped separately for installation by the purchaser. The motor starter, interconnect piping, and wiring are not included.

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7.4.3 Liquid Fuel Quality

High quality fuel is essential to the successful long-term operation of the gas turbine. The standard package includes an offskid liquid fuel monitor system. As an alternative, customers may select on offskid liquid fuel filter/coalescer system. A description of both systems follows.

Offskid Liquid Fuel Monitor System

A liquid fuel monitor system is provided for use with an external liquid fuel filter system. The monitor system is designed to detect water and/or solid contamination and contains dual particle filter elements that must be replaced if the contamination reaches the alarm level. The system includes a transfer valve and is supplied pre-assembled on a skidded frame shipped separately for installation by the purchaser. Pressure at the fuel monitor connection must be regulated according to the Package Utility List. Note that the monitor system is not a fuel filter and cannot be used as such.

Offskid Liquid Fuel Filter/Coalescer System

The fuel filter contains dual solid particle removal elements with a transfer valve and a simplex coalescer element with an automatic drain for continuous water removal. The filter system is pre-assembled on a skidded frame shipped separately for installation by the purchaser and includes a transmitter to monitor the active filter pressure drop. The filter elements must be replaced when the contamination reaches the alarm level. The pressure at the fuel filter connection must be regulated according to the Package Utility List.

7.5 Fuel Transfers

With a dual fuel system, the gas turbine may be started on gas or liquid fuel. When a liquid fuel start is initiated, the control system checks the liquid fuel pressure. If the liquid fuel pressure is below the minimum acceptable pressure, the control system aborts the liquid fuel start and automatically selects a gas fuel start. When gas producer speed (Ngp) is greater than 90%, a fuel transfer can be initiated. Fuel transfers can be initiated manually by the operator or automatically by the control system.

7.5.1 Manual Liquid Fuel to Gas Fuel Transfer

When a manual liquid fuel to gas fuel transfer is initiated, the control system checks the gas fuel pressure to verify the pressure is within operating limits. The control system then performs a gas fuel valve check to ensure proper operation of all gas fuel valves. Should the gas fuel valve check fail, an alarm is generated by the control system, the fuel transfer stops, and the turbine continues to operate on liquid fuel.

Once the gas fuel valve check has been completed, the control system gradually begins to supply gas fuel to the turbine. During the fuel transfer, the liquid fuel system and the gas fuel system will both be active. As gas fuel delivery increases, the control system gradually begins to decrease liquid fuel delivery and operation on gas fuel begins. Once the liquid fuel control valve is completely closed, operation on gas fuel is indicated.

7.5.2 Manual Gas Fuel to Liquid Fuel Transfer

When a manual gas fuel to liquid fuel transfer is initiated, the control system checks the liquid fuel pressure to verify the pressure is within operating limits. If liquid fuel pressure is below the minimum limit, the control system does not permit a transfer to liquid fuel and an alarm is generated by the control system to alert the operator that liquid fuel pressure is low. Once the minimum liquid fuel pressure has been verified, the control system gradually begins to deliver liquid fuel to the gas turbine.

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During the fuel transfer, the gas fuel system and the liquid fuel system are both active. As liquid fuel delivery increases, the control system gradually begins to decrease gas fuel delivery and operation on liquid fuel begins. Once the gas fuel valves are completely closed, operation on liquid fuel is indicated.

7.5.3 Automatic Gas Fuel to Liquid Fuel Transfer

If gas fuel pressure decreases below the minimum pressure limit at Ngp speeds greater than 90%, the control system initiates an automatic fuel transfer to liquid fuel. The automatic transfer sequence is the same as the manual transfer sequence except status indications denote that gas fuel operation is selected but liquid fuel is active.

Table 6. Fuel System Specifications

Gas Fuel System	
Acceptable Gas Fuels, **See Note (a)**	Natural Gas, Propane
Fuel Quality	Refer to Solar's Engineering Specification ES 9-98
Optional Fuel System Types	Conventional Combustion or *SoLoNOx* Combustion
Compliance	National Association of Corrosion Engineers (NACE) Compliant
Minimum/Maximum Gas Fuel Supply Pressure	1379 to 2068 kPag (200 to 300 psig), **See Note (b)**
Minimum Flow Rate	2201 kg/hr (4853 lbm/hr), **See Note (c)**
Minimum/Maximum Fuel Supply Temperature	-40° to 93°C (-40° to 200°F), **See Note (d)**
Primary Gas Fuel Shutoff Valve	Pneumatically Actuated Spring-Closed Ball Valve
Secondary Gas Fuel Shutoff Valve	Pneumatically Actuated Vane Type Valve
Gas Fuel Control Valve and *SoLoNOx* Fuel Pilot Control Valve (If Applicable)	
Actuator Voltage	120 VDC
Valve Discrete Signals	24 VDC
Valve Analog Signals	4 to 20 mA
Maximum Operating Pressure	3447 kPag (500 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
Liquid Fuel System	
Acceptable Liquid Fuels, **See Note (a)**	Light Distillate Fuels Including: Fuel oil Grades 1 and 2, Diesel Grades 1 and 2 JP-5 or JP-8, Commercial Grade Kerosene
Fuel Quality	Refer to Solar's Engineering Specification ES 9-98
Optional Fuel System Types	Conventional Combustion or SoLoNOx Combustion
Compliance	National Association of Corrosion Engineers (NACE)
Liquid Fuel System (cont.)	
Main Liquid Fuel Control Valve	
Actuator Voltage	24 VDC
Valve Discrete Signals	24 VDC
Valve Analog Signals	4 to 20 mA
Maximum Operating Pressure	10 432 kPa (1500 psig)
Maximum Operating Temperature	93°C (200°F)
Response Time	Less Than 120 msec From 10-to-90% Stroke
Valve Body	Aluminum (Standard) Stainless Steel (Optional)

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Liquid Fuel Main/Pilot Distribution Valve (*SoLoNOx* Units Only)	
Actuator Voltage	24 VDC
Valve Discrete Signals	24 VDC
Valve Analog Signals	4 to 20 mA
Maximum Operating Pressure	10 342 kPa (1500 psig)
Maximum Operating Temperature	93°C (200°F)
Response Time	Less Than 120 msec From 10-to-90% Stroke
Valve Body	Aluminum (Standard) Stainless Steel (Optional)
High Pressure Simplex Fuel Filter	25 Micron
Customer-Furnished Pilot Air System (Gas Fuel Units Only)	
Fluid	Clean-Dry Air
Air Quality	**See Note (e)**
Minimum/Maximum Regulated Pressure Range	689 to 1379 kPag (100 to 200 psig)
Pilot Air Filter	3 micron
Customer-Furnished Start-up Air Assist (Atomizing Air) System (Liquid Fuel Units Only)	
Air Quality	**See Note (e)**
Minimum/Maximum Regulated Supply Pressure	689 to 1379 kPag (100 to 200 psig)
Maximum Flow Demand Rate	4.67 nm^3/min (165 scfm)
Start Cycle Air Assist Duration	3 minutes, 20 seconds
Liquid Fuel Pump (Liquid Fuel Units Only)	
Optional Motor Voltage Ratings	380, 400, and 415 VAC (50 Hz) 460 VAC (60 Hz)
Flow	28.8 L/min (7.6 gpm) With 60 Hz Motor 34.8 L/min (9.2 gpm) With 50 Hz Motor
Speed and Pressure	2000 rpm at 1380 kPag (200 psig)
Minimum/Maximum Liquid Fuel Supply Pressure, With Boost Pump	6m (20 ft) Wet Lift to 172 kPag (25 psig)
Minimum/Maximum Liquid Fuel Supply Pressure, Without Boost Pump	241 to 345 kPag (35 to 50 psig)
Min./Max. Liquid Fuel Supply Temperature	**See Notes (d) and (f)**
Offskid Liquid Fuel Boost Pump (Liquid Fuel Units Only)	
Required Supply Pressure (With Customer-Furnished Liquid Fuel Boost Pump)	241 to 345 kPag (35 to 50 psig)
Optional AC Motor Voltage Ratings	380, 400, and 415 VAC (50 Hz): 460 VAC (60 Hz)
Optional DC Motor Voltage Rating	120 VDC
Supply Pressure (With Solar-Furnished AC or DC Liquid Fuel Boost Pump)	9 m (20 ft) wet lift to 172 kPag (25 psig)
Flow (With AC or DC Solar-Furnished Liquid Fuel Boost Pump)	57 L/min at 172 kPag (15 gpm at 25 psig)
Min./Max. Liquid Fuel Supply Temperature	**See Notes (d) and (f)**
Suction Strainer	75 micron
Off-Skid Liquid Fuel Filters	
Fuel/Monitor Skid	10 Micron, Duplex Filters
Fuel/Coalescer Skid	3 Micron, Duplex Filters
Construction Materials	
Piping, Manifolds, and Tubing	316L Stainless Steel

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

Notes:

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

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

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

(d) Minimum liquid fuel temperature must be -1.1°C (30°F), or 12 centistokes maximum viscosity, or 11.1°C (20°F) above pour point, or 5.6°C (10°F) above cloud point, whichever is greatest.

(e) The particle size in the air stream should not exceed 10µ. Since it is impractical to remove 100% of all particles larger than 10µ, this is defined as ß10 > 100, or 99% efficient. Oil or hydrocarbon content should not exceed 1 ppm. The dew point at line pressure shall be at least 5.6°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.

(f) Maximum liquid fuel temperature must be 71.1°C (160°F) or 1 centistoke minimum viscosity, whichever is lower.

(g) If the customer-furnished input voltage is greater than 600 VAC ±5%, a step-down transformer is recommended.

(h) 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.

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8 Lubrication System

8.1 Lubrication System

The lubrication system (Figure 10) circulates oil under pressure to the gas turbine and driven equipment. Lube oil is supplied from the lube oil tank located in the driver frame. Oil temperature is maintained at optimal levels by a thermostatic control valve, oil tank heater, and optional oil cooler.

The lubrication system incorporates the following components:

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

Optional features include:

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

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 the reduction-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 oil pressure during the package start sequence and after package shutdown to protect 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

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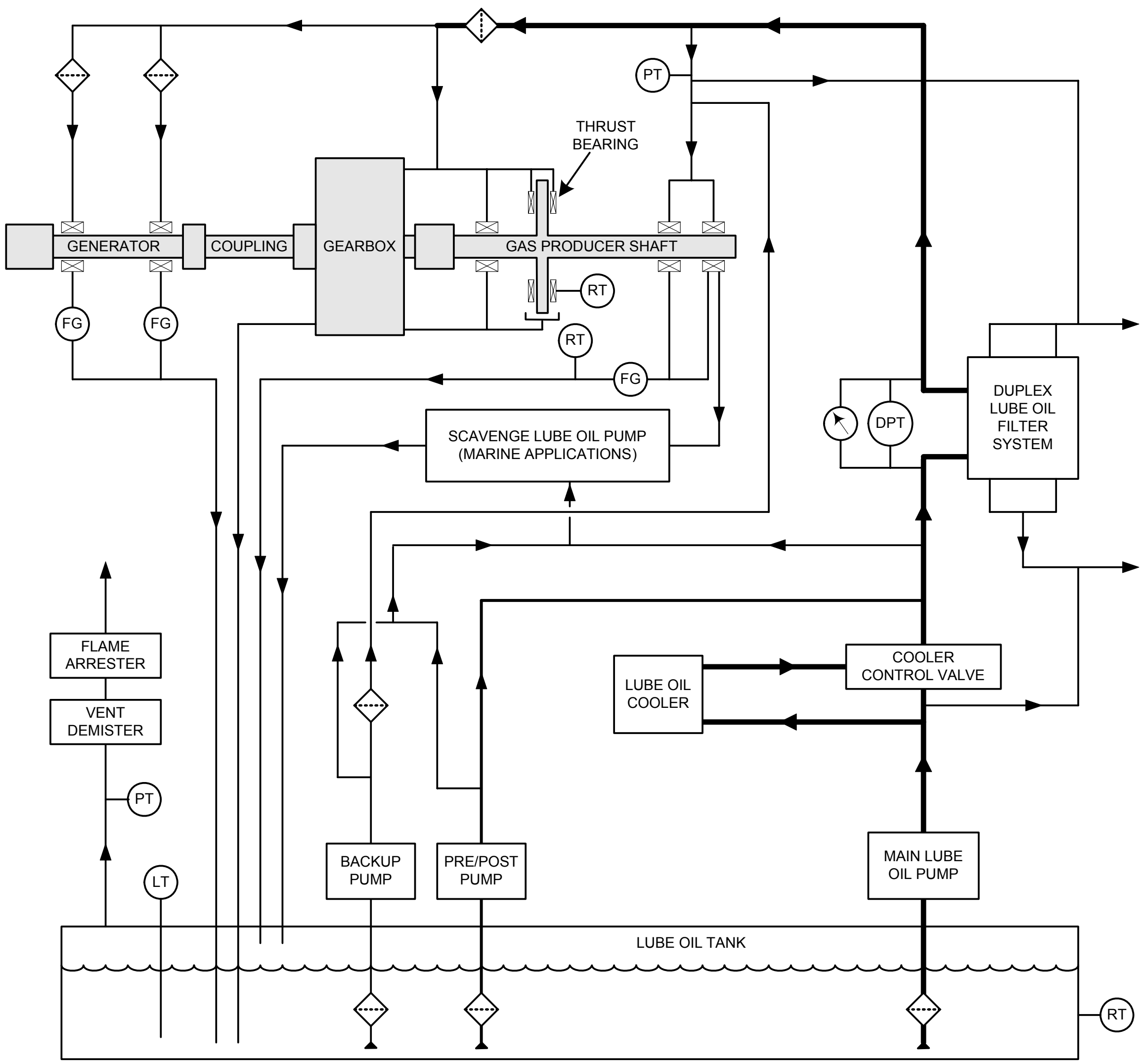
fire, control system failure, emergency stop, or if a turbine over speed is detected by the backup system.

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.



LEGEND

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

Figure 10. Typical Lube Oil System

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8.1.6 Lube Oil Vent Coalescer

An offskid lube oil vent separator is provided to remove oil vapor from the lube oil tank vent airflow. The separator 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 separator is loose shipped for offskid installation by others.

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 either a 13.8°C or 22.2°C (25°F or 40°F) approach temperature. The cooler is loose shipped for installation by others. When the cooler is supplied for installation on the package enclosure, the interconnect piping is provided. When it is provided on a skid for offskid installation, the interconnect piping is not included.

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 7. Lubrication System Specifications

Main Lube Oil Pump	
Pump Type	Engine-Driven Rotary Screw
Flow	530 lpm (140 gpm) at 2030 rpm
Discharge Pressure	1379 kPag (200 psig), **See Note (a)**
Pre/Post Lube Oil Pump	
Pump Type	AC Motor-Driven Hydraulic/Gear Pump
Optional Motor Voltage Ratings	380, 400 & 415 VAC, 50 Hz 460 VAC, 60 Hz
Motor, Power	1.5 kW (2 hp)
Backup Lube Oil Pump	
Pump Type	DC Motor-Driven Hydraulic/Gear Pump
Motor Voltage Rating	120 VDC
Motor, Power	1.1 kW (1.5 hp)
Scavenge Lube Oil Pump (Marine Applications Only)	
Primary Pump	
Pump Type – AC Motor Driven Centrifugal	
Optional Motor Voltage Rating	380 VAC, 400 VAC and 415 VAC (50 H_z) 460 VAC and 575 VAC (60 H_z)
Motor, Power	0.375 kW (0.5 hp)
Backup Pump	
Pump Type – DC Motor Driven Centrifugal	
Motor Voltage Rating	120 VDC
Motor, Power	0.25 kW (0.33 hp)

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Lube Oil Cooler (Single Fan, Direct Drive)	
Lube Cooler Oil Volume	36 L (9.5 gal)
Design Heat Load	183 kW (623,731 Btu/hr)
Design Oil Flow Rate	401 lpm (106 gpm) at 150^{o} F
Air Flow Rate	768 nm^{3}/min (14,488 scfm), **See Note (b)**
Maximum Ambient Temperature	43°C (110°F)
Maximum Design Lube Oil Cooler Outlet Temperature	65.6°C (150°F)
Maximum Lube Oil Cooler Design Pressure Drop	138 kPag (20 psig), **See Note (c)**
Minimum Lube Oil Cooler Design Pressure	1379 kPag (200 psig)
Optional Motor Voltage Ratings	50 Hz: 380, 400 & 415 VAC; 60 Hz: 460 VAC
Optional Motor, Power	3.7 kW (5 hp)
Lube Oil Tank Immersion Heater, See Notes (d) and (e)	
Optional Voltage Ratings	50 Hz: 380, 400 & 415 VAC; 60 Hz: 460 VAC
Power	3-Phase VAC, 4.5 kW
Lube Oil Duplex Filters	
Type	Self-Supporting Pedestal
Duplex Filters	10 Micron
Certification	ASME, Section VIII, Division 1
Lube Oil Vent Separator	
Type	Air/Oil Mist Eliminator
Maximum Working Temperature	66°C (150°F)
Orientation	Vertical
Performance	100% removal of all droplets greater than 3 microns and 99.5% removal of all droplets less than 3 microns. Pressure drop across element, when saturated with collected liquid but free of undissolved solids, shall be 4” H_2O maximum at 130 ACFM air flow.
Certification	ASME Quality, No Stamp
Approximate Dimensions (Height x Diameter)	182.9 cm x 30.5 cm (72 in. x 12 in.)
Approximate Weight	168 kg (370 lb)
Lube Oil Vent Flame Arrestor	
Orientation	Vertical, **See Note (f)**
Approximate Dimensions (Height x Diameter)	26 cm x 55 cm (10.24 in. x 21.56 in.)
Approximate Weight	26 kg (58 lb)
Lube Oil	
Viscosity Grade ISO VG 32 (C32)	Use When Ambient Temperature is <43°C (110°F)
Viscosity Grade ISO VG 46 (C46)	Use When Ambient Temperature is >43°C (110°F)
Pour Point	Must Be At Least 6°C (11°F) Below The Lowest Ambient Temperature)
Lube Oil Tank Capacity	1514 L (400 gal), **See Note (h)**
Weight	1161 kg (2560 lb)
Construction Materials	
Piping, Manifolds, and Tubing	316L Stainless Steel
Lube Oil Tank and Tank Covers	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Main Lube Oil Duplex Filter Housing	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Lube Oil Vent Separator	Carbon Steel
Lube Oil Vent Flame Arrestor	Carbon Steel (Standard) 316L Stainless Steel (Optional)

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

Notes:

(a) A pressure control valve regulates main lube oil supply pressure to 379 kPag (55 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 onskid oil cooler loop including supply and return lines shall not exceed 40 psid (276 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 within 4.6 m (15 ft) of 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).

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9 Turbotronic 4 Control System

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 11) 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 12).

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)

* Included with standard offskid configuration, optional with onskid configuration

Figure 13 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.

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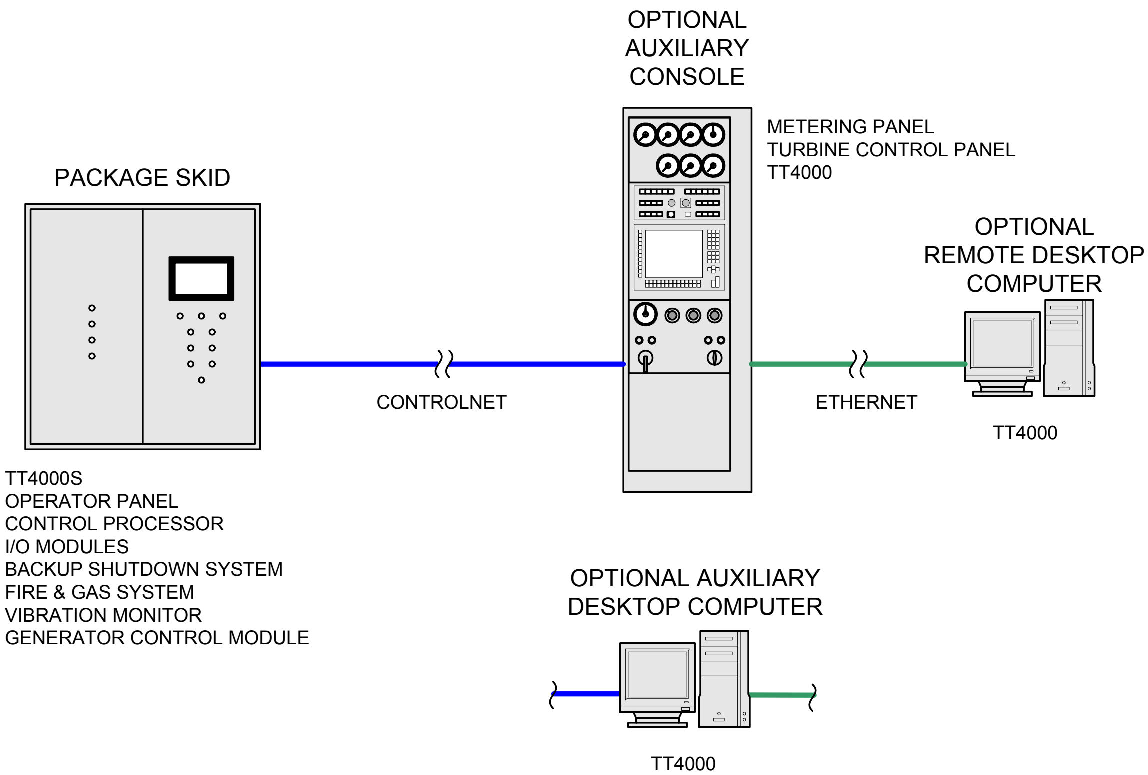

Figure 11. Typical Onskid Control System

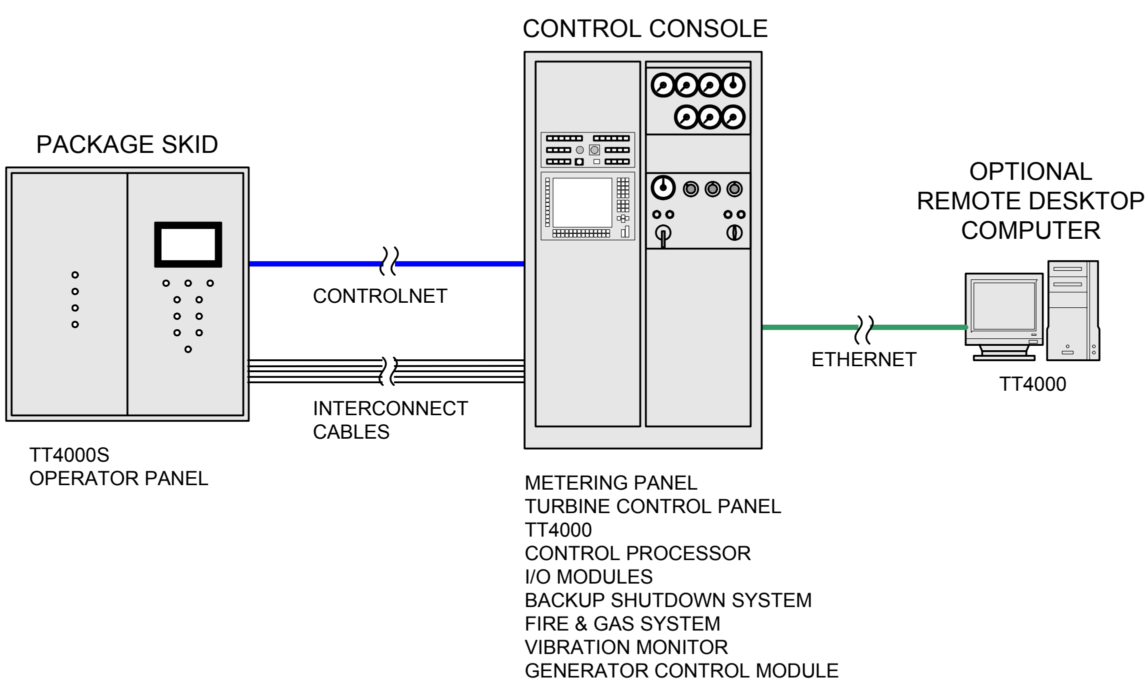

Figure 12. Typical Offskid Control System

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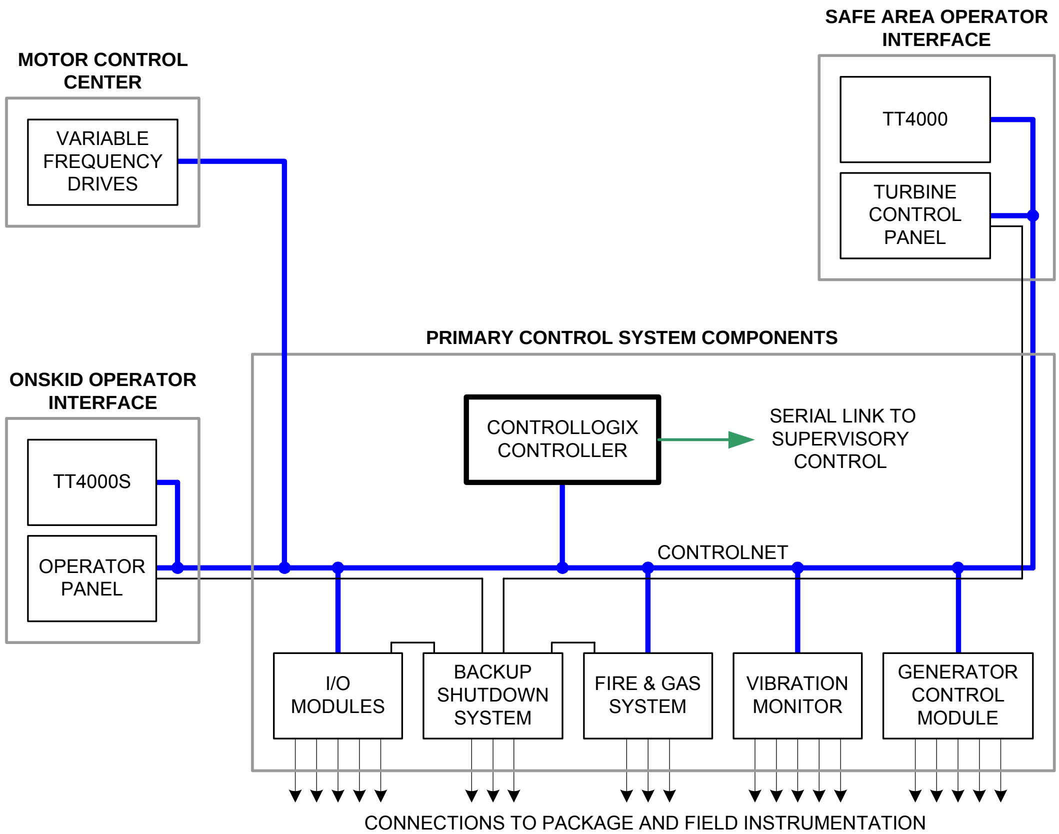

Figure 13. Turbotronic 4 System Architecture

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.

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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 combustible gas and/or fire inside the enclosure based on inputs from gas, thermal, and optical flame detectors. If fire is detected, the system releases an extinguishing agent into the enclosure. If a fire or an unacceptable gas level is detected, the system instructs the *Turbotronic* control processor to initiate a package shutdown. The system is also wired directly to the backup shutdown system. See Enclosure Section 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.

9.3.9 Interconnect Cables – Offskid Control Systems

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

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.

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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). Six thermocouples are used and the values averaged. If one thermocouple has a value that deviates from the average by more than a preset amount, an alarm is generated by the control system. If two thermocouples deviate, the package is shut down.

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

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

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until the malfunction is reset. Lockout stops result from serious malfunctions that require corrective action before the system can be restarted. Nonlockout stops result from an operational disruption or abnormal condition and can be reset when conditions return to normal.

In all cases, after the package has come to a complete stop and the rundown timer has timed out, the control system initiates and supervises a post-lube cycle to protect the gas turbine and driven equipment bearings from thermal damage. If the shutdown is the result of fire being detected, 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 14)
- Generator Summary (generator operating data)
- Temperature Summary (all monitored temperature values)
- Vibration Summary (all monitored vibration values)
- Alarm Summary
- First Out Alarms
- Discrete Event Log
- Strip Chart Display (real time data, Figure 15)
- Historical Data Display (strip chart format)
- Program Constants

Optional Display Screens:

- Gas Turbine Performance

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

Figure 14. Typical TT4000 Operation Summary Display Screen

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Figure 15. Typical TT4000 Strip Chart Display

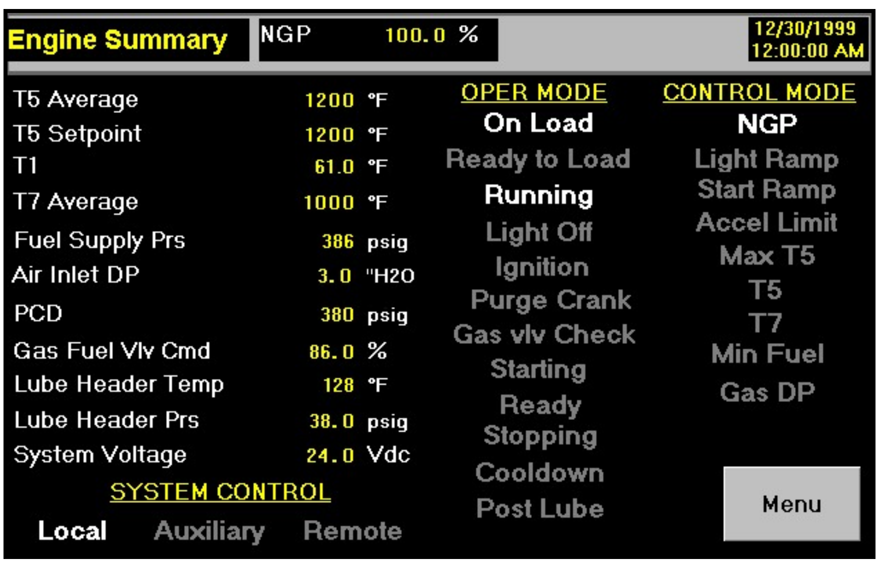

Figure 16. Typical TT4000S Engine Summary Screen

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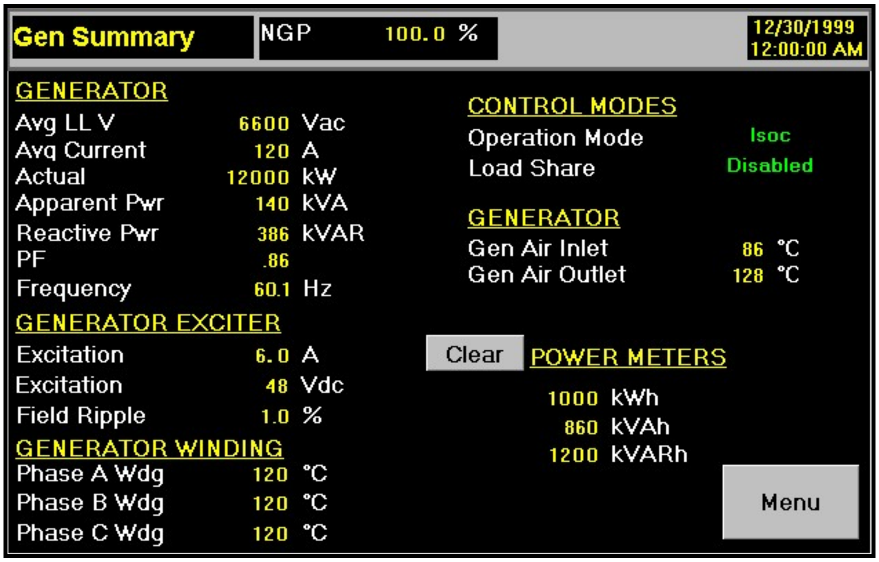

Figure 17. Typical TT4000S Generator Summary Screen

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 16 and 17).

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.

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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:

1. Software, instruction manual, interface card and connecting cable.
2. 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
Pressure	kPa	bar	kg/cm^3	psig
Temperature	°C	°C	°C	°F

Table 8. Turbotronic 4 Control System Specifications

Control System Components	
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
Temperature & Vibration Monitoring	
Gas Turbine	Refer to Section 3
Gearbox	Refer to Section 4
Generator	Refer to Section 5

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Offskid Control Console Dimensions	
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	720 kg (1580 lb)
Supervisory Interface Modules	
ControlNet 1.5	
Cables	RG-6U Coaxial
Maximum Cable Length	1000 m (3280 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: 1219 m (4000 ft)
Transmission Protocol	Subset of Modbus RTU Protocol
Package End Devices	
Transmitters	4-20 mA
Switches	0-24VDC
Thermocouples	Type K
Resistance Temperature Devices (RTDs)	100 ohm Platinum
Proximitors	3300XL

Solar's Applicable Engineering Specifications	
ES 9-56	Fusion Welding
ES 1593	Guidelines for NEC Compliance of Solar Product Lines: Class I, Group D, Division 1 and Division 2
ES 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cables Installed In Class 1, Division 2 Hazardous Areas

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10 Generator Control and Monitoring

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.

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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
- Combined generator control module (CGCM)

Figure 18 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.

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

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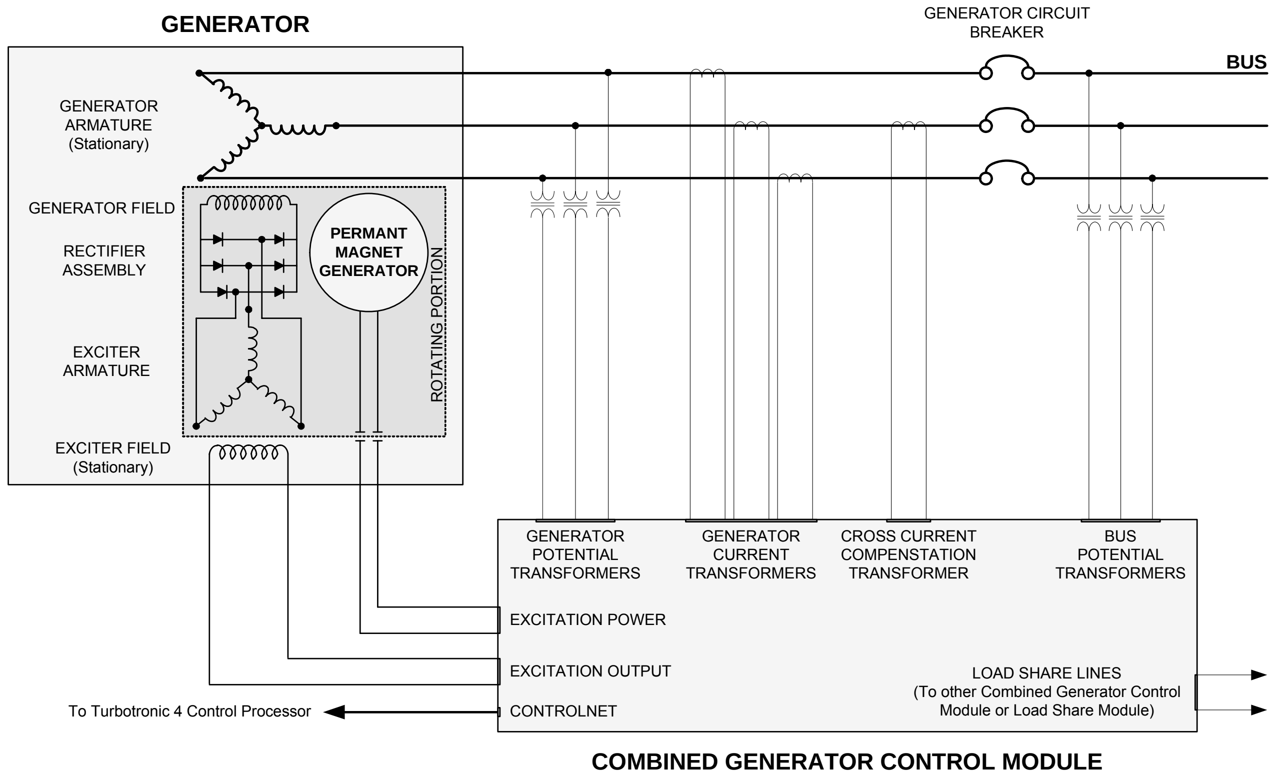

Figure 18. Typical Generator, Exciter, and Control Module Arrangement

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.

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10.2.6 Generator Metering Panel (Optional)

Mounted on the front of an optional control console, the generator metering panel (Figure 19) 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.

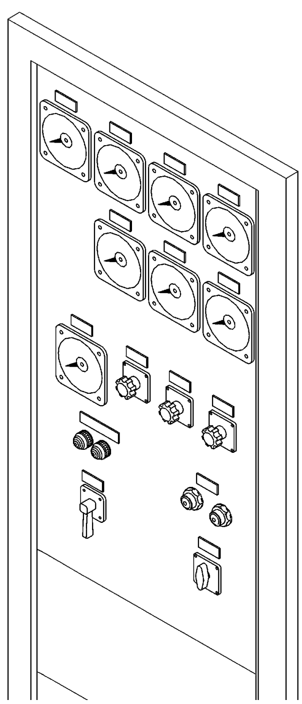

Figure 19. Typical Generator Metering Panel

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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 be 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 9. Generator Specifications

Voltage Regulation	
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	Included
Voltage Drift	**See Note a**
Generator Breaker Synchronization	
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.

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11 Enclosure

11.1 General Description

A driver-only or complete package enclosure can be provided as required. The enclosure housing (Figure 20) is a completely self-contained, weatherproof, insulated, and sound-attenuated system. The enclosure is mounted on the package skid.

The sides of the enclosure consist mostly of doors supported by narrow panels to allow for access to major components. The engine can be removed from either side of the package after the doors and narrow panels are removed in that area. All maintenance enclosure doors include a stainless steel 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 factory assembled on the package skid prior to shipment. 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
- IP34 ingress protection rating

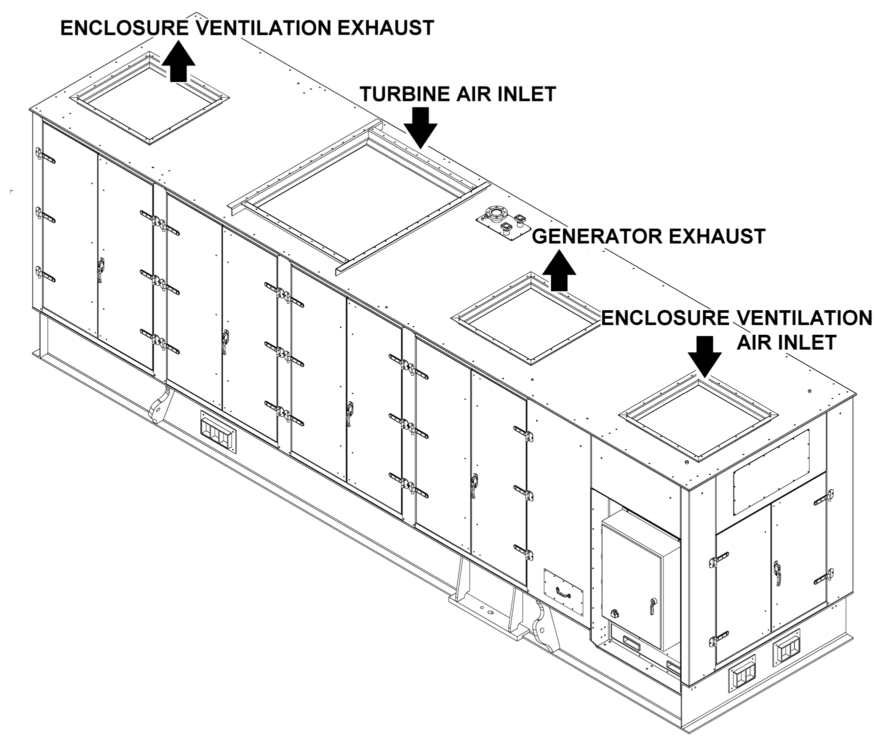

Figure 20. Typical Enclosure

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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 Pressurization System

The driver section of the enclosure has a positive pressure to prevent the entry of potentially hazardous external atmospheres through the enclosure seams. If provided, the driven section of the enclosure has a positive pressure to prevent the entry of potentially hazardous external atmospheres. A differential pressure switch is provided to indicate an alarm when low enclosure pressure is detected.

11.2.4 Lighting

Fluorescent Lighting is provided to illuminate the enclosure interior. Lighting On/Off switches are provided on the enclosure exterior.

11.2.5 Equipment Handling Kit

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

- One internal movable trolley rail located over the gas turbine for gas turbine maintenance and removal
- For land-based applications, one lightweight clamp-on aluminum beam is supplied to support starter removal
- For marine applications, one internal movable trolley rail located over the gearbox for package component maintenance and removal

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."

11.2.7 Fire and Gas System

Enclosed packages must include a fire and gas control system. The typical fire and gas system shown in Figure 21 provides gas monitoring, fire detection, and extinguishing agent release using an advanced distributed architecture to monitor gas, heat, and optical flame detectors. The system communicates with the *Turbotronic* 4 control system to initiate a shutdown if a fire or a high gas level is detected. On the package exterior,

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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_2 or water mist suppression system can also be activated manually by switches mounted on the gas turbine enclosure or at the suppression skid. If a fire is detected, the fire detectors transmit an electrical signal to the fire system control panel to activate the fire alarm and suppression system.

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

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.

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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 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.

11.3.7 CO_2 Fire Suppression System

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

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

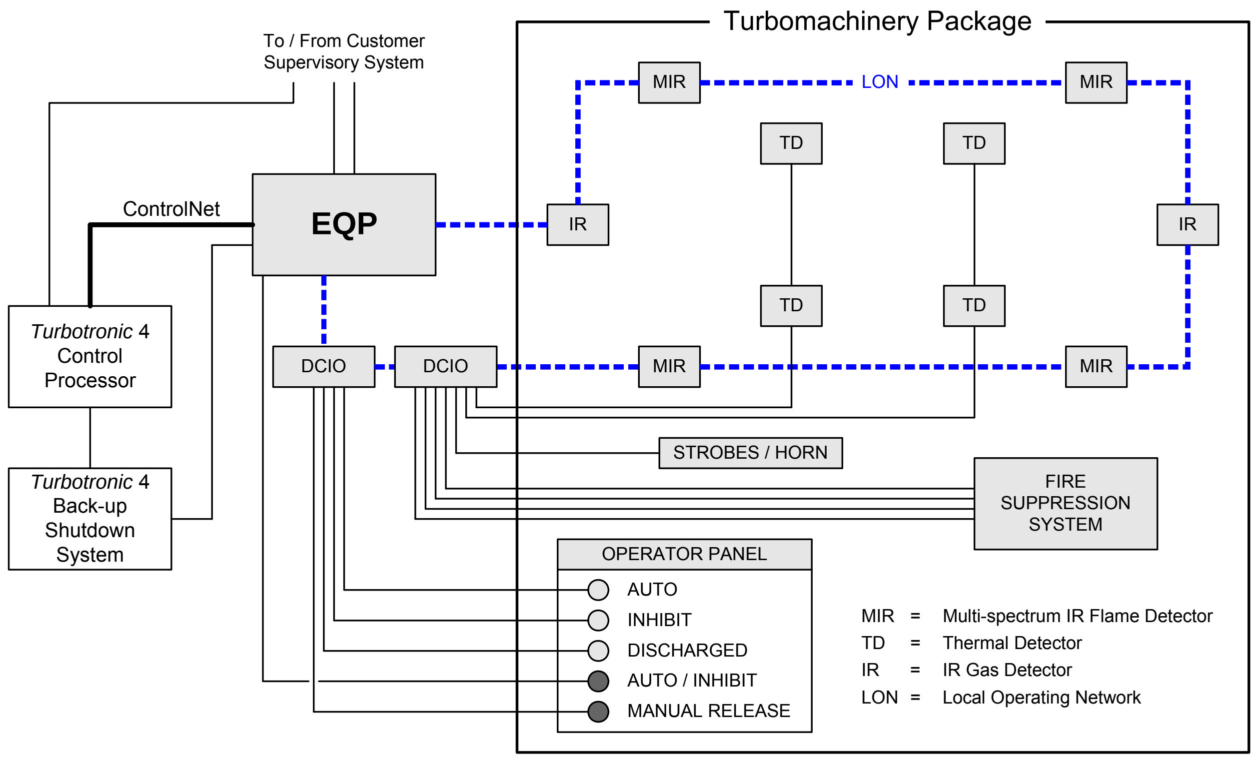

Figure 21. Typical Fire and Gas System

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11.3.8 Water Mist Fire Suppression System

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

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

11.3.9 Fire Cylinder Cabinets

The extinguishing agent cylinders are usually supplied mounted on a rack. For outdoor installations weatherproof cabinets are available as an option. The cabinets are equipped with service doors. The manual pull levers are routed by cable to the exterior wall of the cabinet.

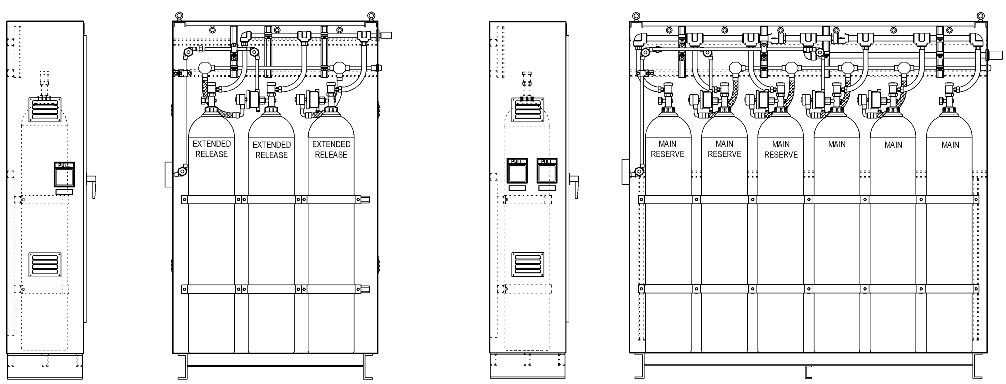

Figure 22. Typical CO_2 Fire Suppression Cylinder Cabinets

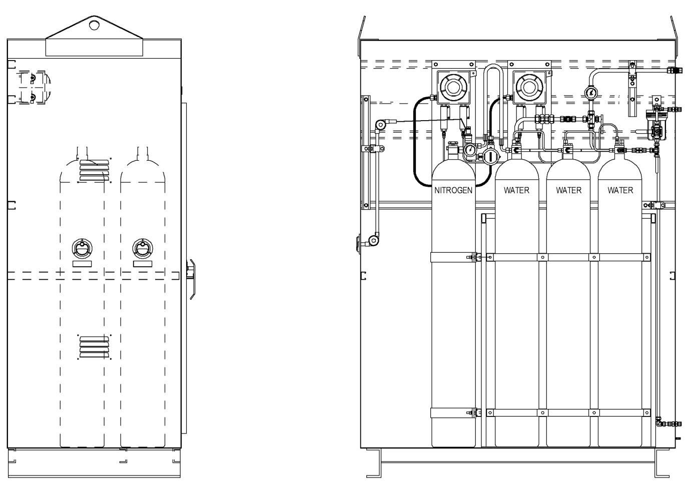

Figure 23. Typical Water Mist Fire Suppression Cylinder Cabinet

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Table 10. Enclosure Specifications

Enclosure	
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	**See Note (a)**
Enclosure Roof Load	**See Note (b)**
Enclosure Wind Load	193 kph (120 mph)
Approximate Measurements	
Height	3.16 m (10.4 ft), Does Not Include Ventilation Ducting
Width	2.65 m (8.7 ft)
Width (with Enclosure Doors Open and Engine Removal Hoist Attached)	6.24 m (20.5 ft)
Length	9.83 m (32.25 ft)
Approximate Weights	
Driver Only Enclosure	2967 kg (6540 lb)
Full Enclosure	4437 kg (9760 lb)
Fire Suppression System Compliance, See Note (c)	
CO_2 Fire Suppression System	U.S. National Fire Protection Association (NFPA) 12 United States Coast Guard (USCG) CFR 46
Water Mist Fire Suppression System	U.S. NFPA Code 750 USCG CFR 46
Water Mist Fire Suppression System	
Minimum Operating Temperature	4°C (40°F)
CO_2 Fire Cylinder Cabinets (Optional)	
Fire Cylinder Cabinet, Main	
Height	213 cm (78.0 in.)
Width	153 cm (60.06 in.)
Depth	45 cm (17.5 in.)
Approximate Cabinet Weight	416 kg (916 lb), Without Cylinders
Approximate Cylinder Weight	447 kg (986 lb)
Water Mist Fire Cylinder Rack	
Fire Cylinder Rack	
Height	228.6 cm (90.0 in.)
Width	132 cm (52.0 in.)
Depth	30.5 cm (12.0 in.)
Approximate Cabinet Weight	600 kg (1323 lb), Without Cylinders
Approximate Cylinder Weight	200 kg (441 lb)
Water Mist Cabinet	
Height	241.3 cm (95.0 in.)
Width	165.25 cm (65.06 in.)
Depth	59.7 cm (23.5 in.)
Approximate Cabinet Weight	870 kg (1918 lb)
Approximate Cylinder Weight	200 kg (441 lb)
Construction Materials	
Enclosure Housing	Carbon Steel
Enclosure Door Hardware	316L Stainless Steel
Fire Cylinder Cabinets	Carbon Steel
Dust and Moisture Protection System	Carbon Steel

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Solar's Applicable Engineering Specifications	
ES 1593	Guidelines for NEC Compliance of Solar Product Lines: Class I, Group D, 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)
ES2379	Offshore Motion Requirements for Oil & Gas Package Designs

Solar's Applicable Product Information Letters	
PIL 054	OSHA Noise Requirements
PIL 058	Package Sound Levels
PIL 150	Fire and Gas Detection and Control System

Notes:

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

(b) Standard packages are designed to withstand loads in accordance with Solar ES2379, Offshore Motion Requirements for Oil & Gas Package Designs. Designs that deviate from the standard should be evaluated for adequate structural integrity for the respective operational conditions.

(c) **Applies to NFPA 12 only**. The complete system required for fire detection and suppression consists of a number of elements, not all of which are in Solar's scope of supply. The design, installation and regulatory approvals for the complete fire system are the responsibility of the owner and must comply with all the requirements and regulations for the geographic area in which it will be installed and operated. When properly installed and tested, the completed system will meet the requirements of the U.S. National Fire Protection Association (NFPA) Code 12.

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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 24 shows typical *Centaur* 40 air inlet systems and support structures.

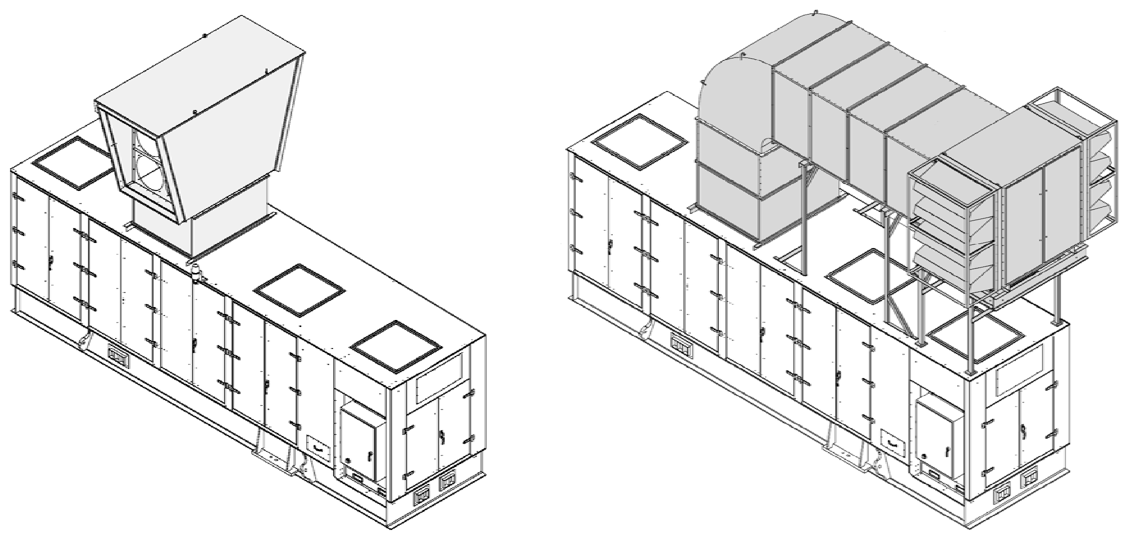

Figure 24. Typical Air Inlet Systems and Support Structures

12.1.1 Prefilter and Barrier Inlet Air Filter

The prefilter / barrier inlet air filter system is suitable for moderate environments. This system features vertical moisture eliminators, prefilter elements, and high efficiency barrier filters. Access doors are provided in the filter housing for servicing. A weather hood and insect screens are available as options. The system is available in two versions (Figure 24): the one on the left has a bottom outlet and mounts directly on the inlet silencer without the need for additional ducting; the one on the right has a outlet and requires ducting and a support frame.

12.1.2 Self-Cleaning Barrier Type Air Filter

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

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

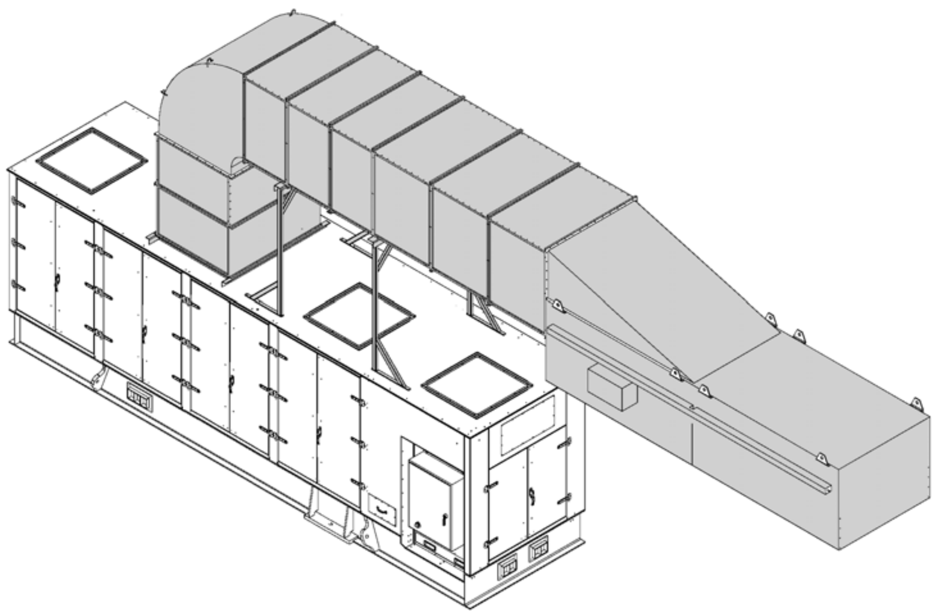

Figure 25. Typical Self-Cleaning Barrier Air Inlet System (Support Structure Not Shown)

12.1.3 Marine / Offshore-High Velocity Type Air Filter

The marine and offshore high velocity type air filter system (Figure 26) is suitable for use in many offshore applications. This system provides removal of salt, water, and particulates. This system consists of:

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

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

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

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

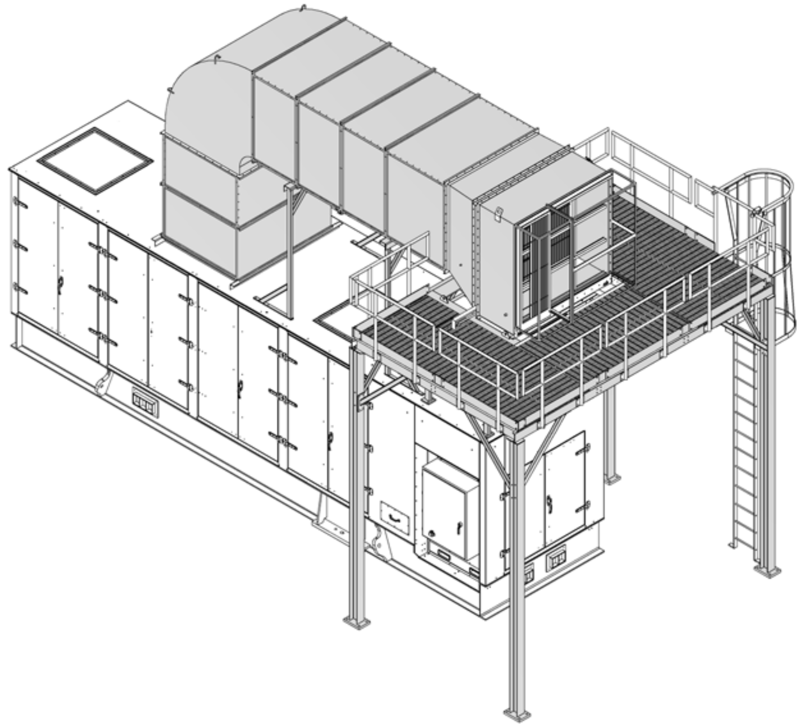

Figure 26. Typical High Velocity Air Inlet System and Support Structure

12.1.4 Offshore / Coastal Medium Velocity Type Air Filter

The offshore and coastal medium velocity type air filter system (Figure XX) is suitable for use in offshore and coastal (up to 10 miles inland) applications. This system provides high efficiency removal of salt, water, and particulates. This filter is recommended in extreme conditions (reference ES 9-98) or when higher efficiencies and / or availability is desired. This system consists of:

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

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

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

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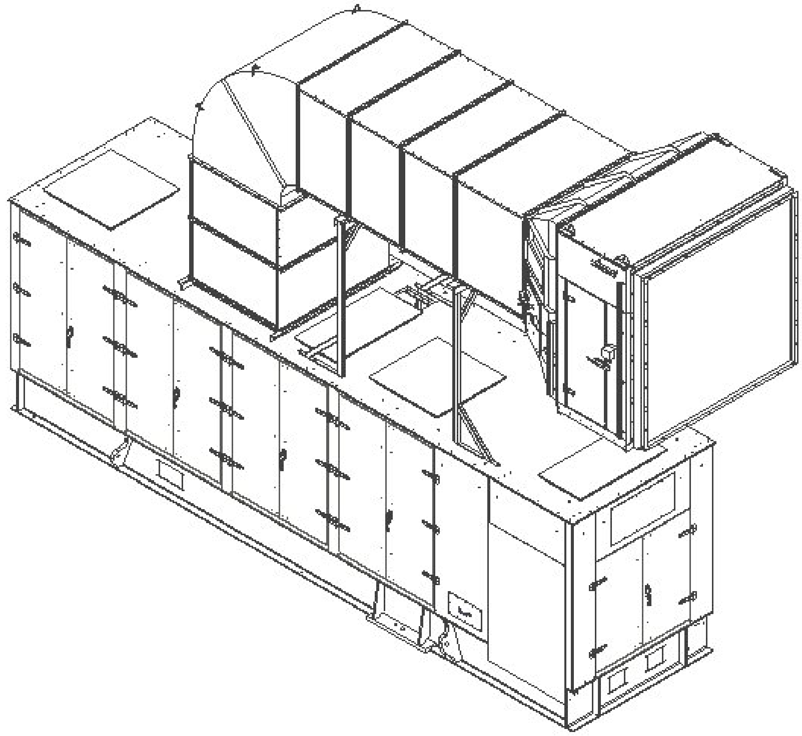

Figure 27. Typical Offshore / Coastal Medium Velocity Filter Air Inlet

12.1.5 Insect Screens

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

12.1.6 Air Inlet Gas Detection

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

12.1.7 Air Inlet Silencer

Air inlet silencers can be incorporated into the air inlet ducting to reduce noise levels. Typical installations include one or more air inlet silencers.

12.1.8 Air Inlet Ducting and Support

A 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.

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Table 11. Air Inlet System Specifications

Air Inlet System	
Pressure Drop	Less Than 102 mm (4 in.) of Water With A Clean Air Filter
Ducting Loads	Loads Exceeding 91 kg (200 lb) Should Not Be Applied In Any Direction
Prefilter and Barrier Inlet Air Filter	
Air Flow	14.7 m3/s (31,200 cfm)
Approximate Measurements	
Height	229 cm (90.0 in.)
Width	225 cm (88.6 in.)
Length	167 cm (65.8 in.)
Weight	996 kg (2197 lb)
Pressure Drop	
Clean	44 mm (1.75 in.) water
Fouled	127 mm (5 in.) water
Self-Cleaning Barrier Type Air Filter	
Fluid	Clean-Dry Air
Air Quality	See Note (a)
Minimum/Maximum Regulated Pressure Range	552 to 758 kPag (80 to 100 psig)
Intermittent Flow Rate (Est.)	0.25 nm3/min (9 scfm)
Pressure Drop	
Clean	25 mm (1.0 in.) water
Fouled	76 mm (3.0 in.) water
Air Flow	14.7 m3/s (31,200 cfm)
Approximate Measurements	
Height	234 cm (92.0 in.)
Width	188 cm (74.0 in.)
Length	1384 cm (545.0 in.)
Weight	2500 kg (5500 lb) with filter elements
Marine / Offshore High Velocity Type Air Filter	
Pressure Drop (Clean), HVL	38 mm (1.5 in.) water
Pressure Drop (Clean), HVX	46 mm (1.8 in.) water
Air Flow	14.7 cms (31,200 cfm)
Approximate Measurements	
Height	206 cm (81.1 in.)
Width	198 cm (78.1 in.)
Length	153 cm (60.4 in.)
Weight	739 kg (1630 lb) with filter elements
Offshore / Coastal Medium Velocity Type Air Filter	
Pressure Drop (Clean) - 3 stage	28 mm (1.1 in.) water
Pressure Drop (Clean) - 4 stage	48 mm (1.9 in.) water
Air Flow	14.7 cms (31,200 cfm)
Approximate Measurements	
Height	280 cm (110.3 in.)
Width	280 cm (110.3 in.)
Length	312 cm (122.7 in.)
Weight	2056 kg (4532 lb) with filter elements (4 stage)

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Construction Materials	
Prefilter/Barrier	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Insect Screen (Optional)	316L Stainless Steel
Self Cleaning Barriers	Carbon Steel (Standard) 316L Stainless Steel (Optional)
Marine / Offshore High Velocity Air Cleaner	316L Stainless Steel
Offshore / Coastal Medium Velocity Type Air Filter	316L Stainless Steel (Standard) Carbon Steel (Optional for mild coastal environments)
Air Inlet Silencer	Carbon Steel (Standard); 316L Stainless Steel (Optional)
Air Inlet Ducting	Carbon Steel (Standard); 316L Stainless Steel (Optional)
Solar's Applicable Product Information Letters	
PIL 054	OSHA Noise Requirements
PIL 178	Salt Ingress Protection for Gas Turbines

Notes:

(a) The particle size in the compressed air stream should not exceed 10µ. Since it is impractical to remove 100% of all particles larger than 10µ, this is defined as ß10 > 100, or 99% efficient. Oil or hydrocarbon content should not exceed 1 ppm. The dew point at line pressure shall be at least 5.6°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.

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13 Exhaust System

13.1 General Description

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

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

13.1.1 Exhaust Silencer

The exhaust silencer is connected to the gas turbine exhaust by ducting and a cylindrical bellows. A rain protection stack is available as an option. This system and optional rain protection stack are available in carbon or stainless steel. Figure 27 shows a typical *Taurus* 60 generator set with an axial exhaust silencer.

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.

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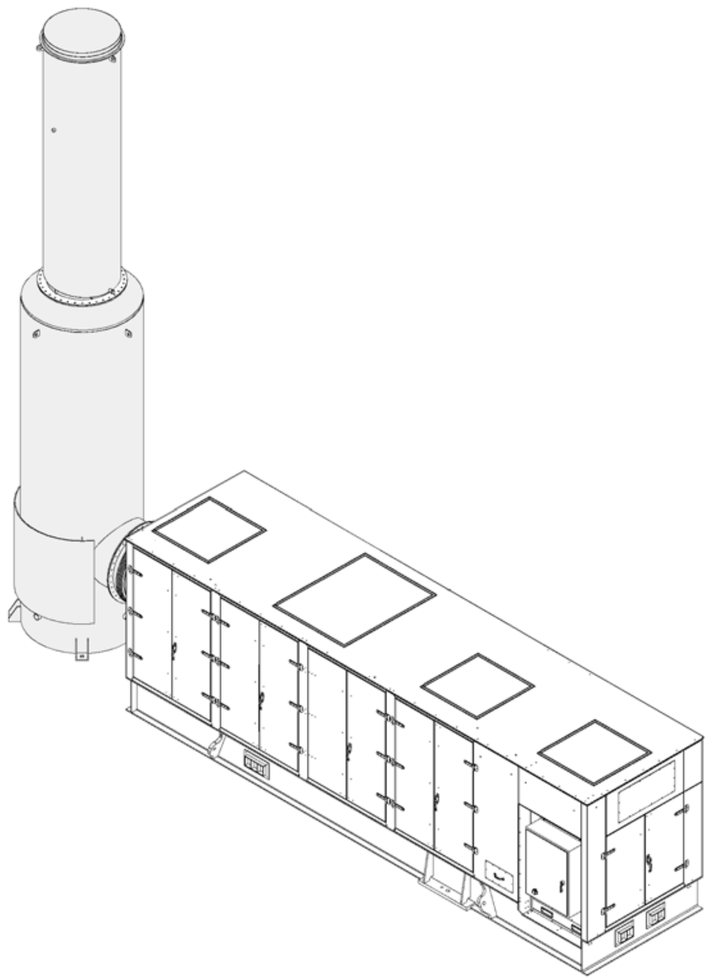

Figure 28. Typical Taurus 60 Generator Set System Exhaust

Table 12. Exhaust System Specifications

Exhaust System	
Temperature Class	T2
Exhaust Temperature	482°C (900°F)
Nominal System Back Pressure	203 mm (8 in.) of water, **See Note a**
Construction Materials	
Exhaust Silencers	Carbon Steel 316L Stainless Steel (Optional)
Exhaust Ducting	Carbon Steel 316L Stainless Steel (Optional)
Exhaust Bellows Expansion Joint	Carbon Steel 316L Stainless Steel (Optional)

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.

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14 Accessory Equipment

14.1 Battery Charger System

The battery charger system consists of a battery charger (Figure 28) and batteries to provide 120 VDC emergency power to the control console, fuel valve, bleed valve and variable guide vane actuators, and the DC backup lube oil pump. The control console 120 to 24 volt DC-to-DC converter provides 24 VDC power for the control system. The battery charger system is designed for indoor installation in a nonhazardous area. Battery options include:

- Valve Regulated Lead Acid
- Nickel Cadmium

14.1.1 Valve Regulated Lead Acid

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

14.1.2 Nickel Cadmium

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

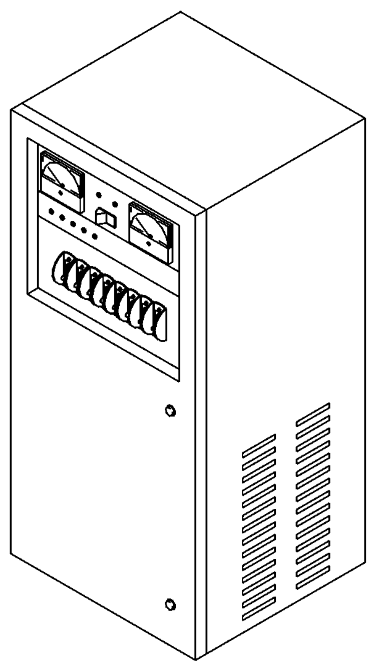

Figure 29. Typical Battery Charger

14.2 Turbine Cleaning System

The optional turbine compressor cleaning system (Figure 29) 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

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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.

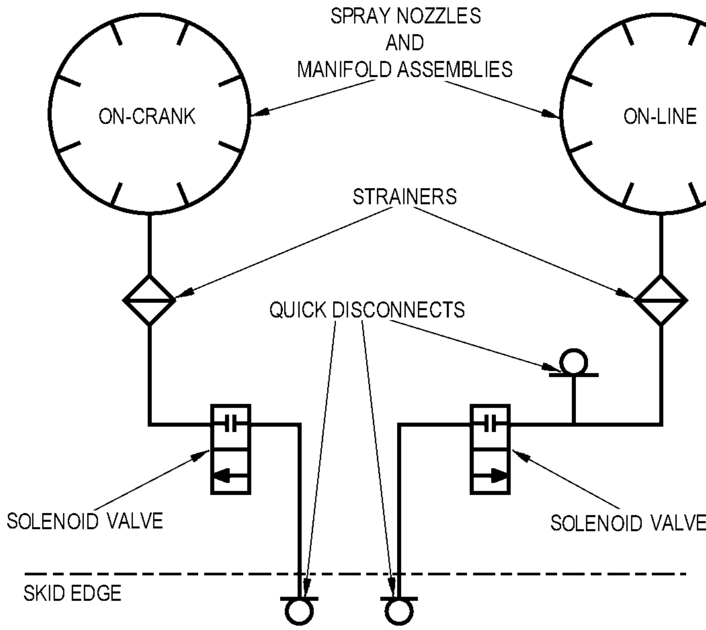

Figure 30. Turbine Cleaning System

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 (Optional)

A portable offskid cleaning tank (Figure 30) 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.

14.2.4 Package Lifting Kit (Optional)

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

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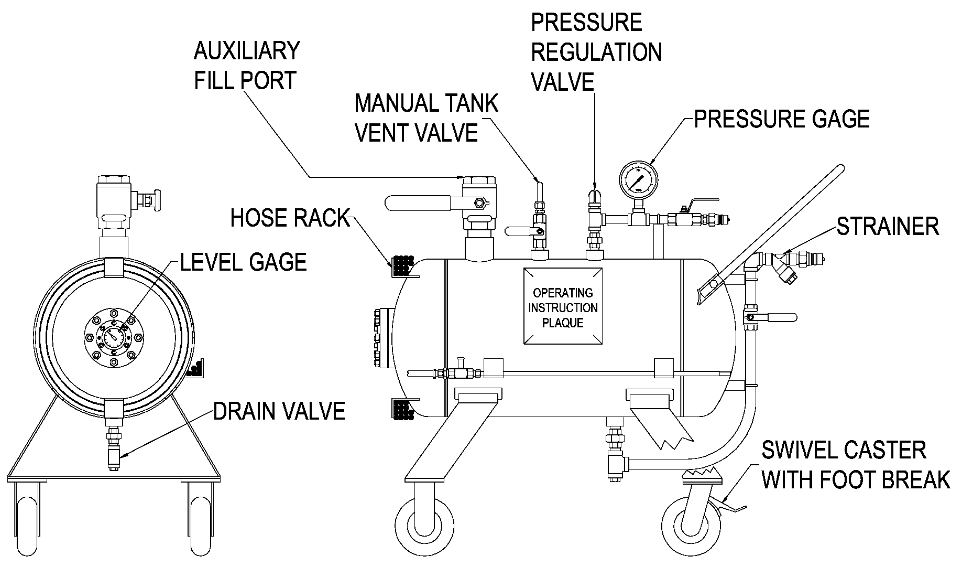

Figure 31. Turbine Cleaning Cart

Table 13. Accessory Equipment Specifications

Battery Charger System	
Charger Type	Wall Mounted, Bottom Entry, IP30
Supply Voltage	240, 380, and 480 VAC, 50 or 60 Hz.
Output	Single Phase, 120 VDC, 20 amps
Operating Temperature	-10 to 50°C (14 to 122°F)
Approximate Measurements	
Height	90.2 cm (35.5 in.)
Width	40.4 cm (15.9 in.)
Depth	39.7 cm (15.63 in.)
Weight	63.5 kg (140 lb)
Ampere Hours	
Valve Regulated, Sealed Gas-Recombination Lead Acid	10 AMPERE - HOUR
Nickel Cadmium	10 AMPERE - HOUR
Turbine Cleaning System	
Water/Solvent Supply Pressure	85 to 100 psig (586 to 689 kPag)
Water/Solvent Supply Min. Temperature	Ambient: Above +4°C (+39°F)
On-Line Water/Solvent Flow Rate	2.3 – 4.5 L/min (0.6 – 1.2 gpm)
On-Line Propulsion Air Flow Rate	0.026 nm^3/min (0.98 SCFM)
Package On-Line Triple Stage Strainer	300/200/100 Micron
On-Crank Water/Solvent Flow Rate	9.1 – 12.9 L/min (2.4 – 3.4 gpm)
On-Crank Propulsion Air Flow Rate	0.080 nm^3/min (3.0 SCFM)
Package On-Crank Triple Stage Strainer	300/200/100 Micron
External Air Supply	Clean Filtered Air
Air Supply Pressure	586 to 690 kPag (85 to 100 psig)

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Turbine Cleaning Cart	
Capacity	98 L (26 gal)
Tank Discharge Strainer	100 Micron
External Air Supply	Clean Filtered Air
Air Supply Pressure	586 to 690 kPag (85 to 100 psig)
Approximate Measurements	
Height	102 cm (40.2 in.)
Width	55 cm (21.7 in.)
Length	121.6 cm (47.87 in.)
Approximate Weight	86 kg (190 lb)
Tank Material	316L Stainless Steel
Certification	American Society of Mechanical Engineers (ASME) or Pressure Equipment Directive (PED)
Electrical Certifications	
CSA	LR 77954

Solar's Applicable Engineering Specifications	
ES 9-62	Ingestive Cleaning Solar Gas Turbine Engines
ES 9-98	Fuel, Air, and Water (or Steam) for Solar Gas Turbine Engines
ES 2416	Battery Supply Systems

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15 Marinization

15.1 General Description

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

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

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

15.1.1 Gimbals (Optional)

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

15.1.2 Anti-Vibration Mounts (Optional)

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

15.1.3 Internal Package Modifications

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

15.1.4 Inclinometers

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

15.1.5 Certification

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

- Det Norske Veritas (DNV)
- Bureau Veritas (BV)

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

15.1.6 Deck Deflection Limits

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

15.1.7 Angular Displacement and Acceleration

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

15.1.8 Main and Auxiliary Service

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

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16 Quality Assurance and Testing

16.1 Quality Assurance

Solar is an Industry Standards Organization (ISO) 9000 company with ISO 9001:2000 and 9002 certification. Several *Solar* gas turbine models and manufacturing processes have been "type" certified. In recognition of Solar's commitment to quality, Solar has received Manufacturing Resource Planning (MRP) II Class A certification and the Malcolm Baldrige National Quality Award. Solar has developed a comprehensive set of 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 applied to parts manufactured both in and outside of Solar.

16.2 Testing

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

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

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- 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

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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 higher percentage of the gas fuel and/or lube oil system piping and manifolds.

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17 Preservation, Installation, and Documentation

17.1 General Description

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

17.2 Preservation

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

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

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

17.2.1 Long-Term Preservation

Long-term preservation is required if:

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

17.2.2 Short-Term Preservation

Short-term preservation may be acceptable if:

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

17.3 Site Requirements

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

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~~17.~~4 Mechanical Installation

17.4.1 TPIM-1000

Solar's document TPIM-1000 "Package Installation Guidelines – Generator Sets" outlines the responsibilities of the Customer and Solar regarding installation of the package. It provides guidelines for the installation of the standard package design and the interface with the turbine driven generator.

17.4.2 Mounting

Correct mounting of the gas turbine package is vital to successful package installation and requires adequate preparation by the user. The site pad thickness is governed by soil condition and the weight of the gas turbine package, air inlet system, and exhaust system. Mounting pad locations and 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.

17.4.3 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.

17.4.4 Lube Oil Cooler(s)

The lube oil cooler(s) can be mounted on an ancillary support frame on top of the enclosed package or located offskid. The interconnect piping is not part of Solar's standard scope.

17.4.5 Gas Turbine Air Inlet System

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

17.4.6 Gas Turbine Exhaust System

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

17.5 Documentation

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

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17.5.1 Torsional Analysis Report (Optional)

A torsional analysis can be performed on the entire drive train to determine if there are any significant torsional resonance conditions within ±10% of the operating speed range. If a resonance condition (interference) is found, then a fatigue analysis is performed to confirm the resonance will not cause fatigue failure in the shafting.

17.5.2 Lateral Analysis Report (Optional)

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

Table 14. Preservation, Installation, and Documentation Specifications

Mechanical Installation Requirements	
Mounting	
Space Between Units In Multiple-Unit Installations	A Minimum of 2.4 m (8 ft)
Lube Oil Cooler(s)	
Top of The Lube Oil Cooler(s)	Not Be More Than 9.1 m (30 ft) Above The Bottom of The Package Frame, **See Note a**
Total oil volume of "Outgoing and Return" Lines	1282 L (340 gal)
Total Combined Pressure Drop of The Supply and Return Lines and Lube Oil Cooler(s)	Should Not Exceed 345 kPag (50 psig)
Start, Fuel, Lube, Air/Drain System Schematics	
Compliance	American National Standards Institute (ANSI) Y32.10
Solar's Applicable Engineering Specifications	
ES 9-4	Interpretation of Drawing Requirements
ES 9-76	Traceability Requirements Critical Parts, Engine and Related Systems
ES 9-414	Leveling and Installing of Package Bases
ES 2231	Standards and Practices for The Design and Installation of Cable Channels and TC Rated Cables Installed In Class 1, Division 2 Hazardous Areas
Solar's Applicable Product Information Letters	
PIL 097	Package Preservation and Preparation for Shipment
PIL 181	Package Tie-down Options
PIL 184	Order Fulfillment and Documentation for Oil and Gas Projects
Solar's Applicable Guidelines	
TPIM-1000	Package Installation Guidelines – Generator Sets

Notes:

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

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18 Certification

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 (ENTELA)

(CSA and UL also develop and promulgate standards).

The NEC establishes classification of hazardous sites in terms of Classes, Divisions, Zones, and material Groups. Class I covers locations where flammable gases may be present in quantities sufficient to ignite. Division 1 covers situations where flammable gases may be present as part of a process, while Division 2 covers locations where flammable gas is less likely to be present. 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. (ENTELA), when certifying to Canadian standards
- Underwriters Laboratories Inc. (UL), when certifying to Canadian standards

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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 also has a program to obtain "type certification" for standard turbomachinery packages for ATEX and PED directives.

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

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

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.

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18.5 International Electrotechnical Commission Safety Assessment

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

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.

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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

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

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19 Support Services

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

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

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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.

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Appendix 1 - Conversion Chart

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

To Convert From Old Metric	**To S.I. Metric**	**Multiply By**
Atm	kPa	101.325
Bar	kPa	100.0
cm	mm	10
cm Hg	kPa	1.3332
cm H_2O	kPa	0.09807
kcal/h	W	1.16279
kg/cm^2	kPa	98.0665
Nm^3/h	Nm^3/min	0.0167

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Appendix 2 - List of Abbreviations

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

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

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

* "Standard" = 60°F, 14.7 psia
** "Normal" = 0°C, 1.01325 x 10^5 Pascals
*** "Standard" = 15°C, 760 mm Hg

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