1 TECHNICAL DESCRIPTION - GAS TURBINE GENERATOR PACKAGE

1.2 GAS TURBINE PACKAGE

Baseframe
The gas turbine package major components are installed on a heavy-steel baseframe, also referred to throughout this document as the "skid". The skid is a structural steel assembly with beam sections and cross members welded together to form a rigid foundation. Machined mounting surfaces on the skid facilitate major component alignment. Drip pans are welded within the base to collect any potential liquid spills.

Gas Turbine Package Orientation:
Throughout this proposal, all references to package orientation (left, right, clockwise, counter clockwise, etc.) are based on standing at the "aft" end of the package looking forward. The "aft" end of the package is always the same end as the turbine engine exhaust.

Service Connections
The gas turbine package is supplied with self-contained systems for starting, fuel, lube oil, and control Package electrical connections are made in on-skid junction boxes via skid gland plates. Service connection points for fuel, lube oil, air, and water are conveniently located on the outer edge of the skid.

Electrical Ratings
Unless otherwise noted, package motors and heaters are rated for:

- 380 VAC / 50 Hz / 3 Phase

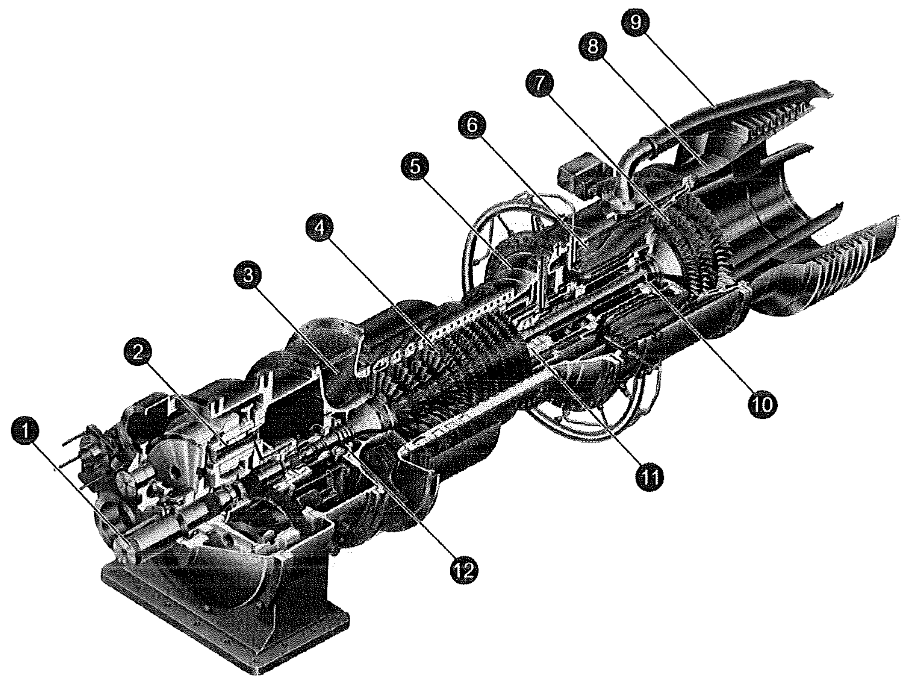
Unless otherwise noted, single phase package loads (such as lighting, space heater loads, etc) and the off-skid battery charger are rated for:

- 220 VAC / 50/60 Hz

Instrument Tagging/Labeling. Instrument tagging is not provided

1.3 GAS TURBINE ENGINE

The *SoLoNOx* Taurus 60 is a self-contained, completely integrated prime mover of a single shaft, axial flow design. Its design embraces Solar's fundamental engineering principles of long life and low maintenance.



1	*Coupling*	*7*	*Three-stage turbine*
2	*Gearbox*	*8*	*Turbine exhaust diffuser*
3	*Air inlet*	*9*	*Bleed valve duct*
4	*Compressor stages*	*10*	*#3 tilt-pad journal bearing*
5	*Compressor diffuser*	*11*	*#2 tilt-pad journal and thrust bearing*
6	*Combustor, comprising of an annular combustion chamber and fuel injectors*	*12*	*#1 tilt-pad journal bearing*

Taurus 60 SoLoNOx Gas Turbine Specifications:

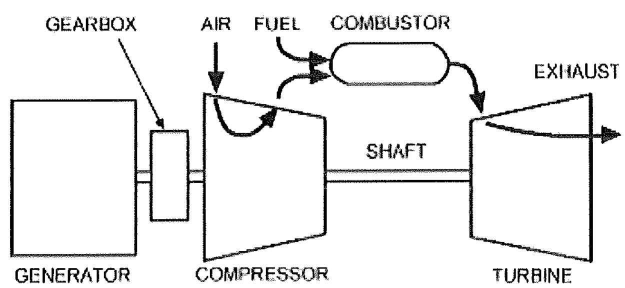
Compressor	
Type:	Axial
Number of Stages:	12
Compression Ratio:	12.2:1
Combustion Chamber	
Type:	Annular; *SoLoNOx*
Ignition:	Torch
Number of Fuel Injectors:	12
Turbine	
Type:	Reaction, Axial Flow
Number of Stages:	3

Principles of Operation

The continuous power cycle and rotary motion of the gas turbine provides several advantages over other types of engines. These advantages include:

- Low weight
- Relatively vibration-free operation
- Fewer moving parts (and correspondingly fewer wear points)
- Higher quality AC power

Air is drawn into the air inlet of the gas turbine and is compressed by the multi-stage axial-flow compressor. The compressed air is directed into the combustion chamber at a steady flow. Fuel is injected into the pressurized air within the annular combustion chamber. During the gas turbine start cycle, this fuel/air mixture is ignited and continuous burning is maintained as long as there is adequate flow of pressurized air and fuel. The hot, pressurized gas from the combustion chamber expands through and drives the turbine section of the engine, dropping in pressure and temperature as it exits the turbine. Thus, the energy of the fuel is transformed into the kinetic rotational power of the turbine output shaft.



The turbine shaft is mechanically attached to both the compressor and turbine sections of the gas turbine to form a "solid" or "single" shaft configuration. This feature enhances speed stability and response under both constant and varying load conditions.

For stoichiometric combustion, the gas turbine requires approximately one-fourth of the total air it compresses. The excess air is used to cool the combustion chamber and mixes with the combustion products to reduce the gas temperature at the inlet to the first turbine stage. The cooling air also keeps surface metal temperatures in the combustion chamber and turbine sections at required design levels to ensure long component lives.

The *SoLoNOx* combustion system utilizes Solar's proprietary lean-premixed dry emissions system to reduce the formation of criteria pollutant combustion products such as nitrogen oxides (NOx) and carbon monoxide (CO) by limiting peak flame temperature during combustion.

Air Inlet Orientation

The standard gas turbine air inlet flange terminates in the "up" (0°) position.

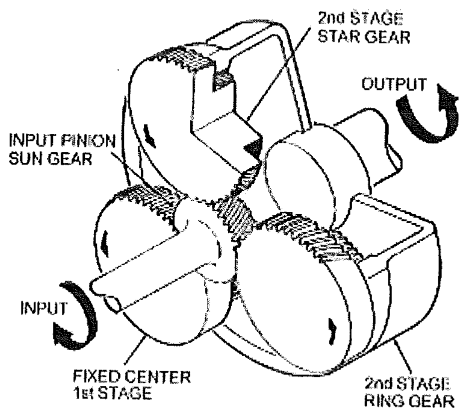
Exhaust Outlet Orientation

The gas turbine exhaust outlet flange terminates axially from the aft end of the turbine package.

1.4 SPEED REDUCTION GEARBOX

The reduction-drive gearbox 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 designed to provide 99% reliability between major inspections and overhauls. The gears can be serviced without removing the main case.



The gearbox is mounted to the oil tank on the baseframe, and the gas turbine is bolted directly to the gearbox and includes accessory pads to accommodate the start motor, and lubricating oil pump. The gas turbine and gearbox are coupled by means of a splined interconnecting drive shaft, eliminating the need for field alignment.

The gearbox and generator are connected by means of a flexible (disc, gear, etc.), shear-type coupling enclosed in a spark-proof coupling guard. Jacking points are provided to facilitate alignment of the gas turbine and gearbox/generator combination. This close-coupled arrangement allows precision alignment, facilitated by jacking bolts.

One (1) set of alignment tooling is provided, per sales order, to align the reduction gearbox output shaft with the generator input shaft.

Reduction-Drive Gearbox Specifications

Inspection and Overhaul Intervals	
Major Inspection Interval	30,000 hours
Overhaul Interval	100,000 hours
Ratings	
American Gear Manufacturers Association (AGMA)	In Excess of 1.10 for Generator Applications
Vibration Monitoring	
Gearbox	Accelerometer

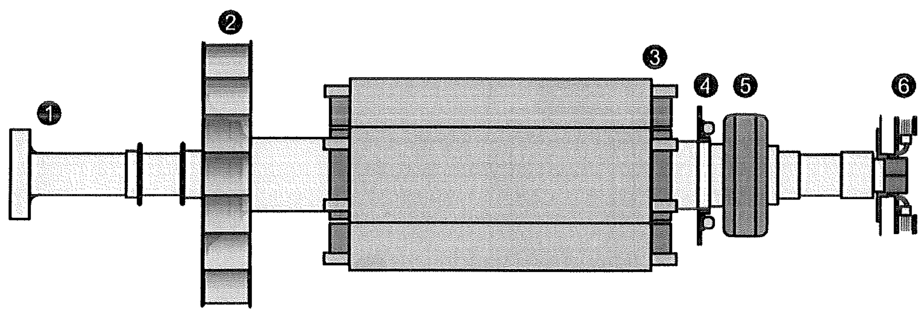
1.5 GENERATOR GENERAL DESCRIPTION

Generator construction
The synchronous generator transforms mechanical energy into electrical energy. The alternating current is generated with a brushless generator. The generator is rated to match the gas turbine power over the ambient temperature range and is nominally rated at 40°C inlet air temperature.
The generator is installed on the base frame on mounting blocks. The shaft of the generator is coupled to the low speed shaft of the gearbox.
The generator is composed of the following main items.

Frame
The box-type stator frame is made of welded steel.

Stator
The stator consists of a stator core and a stator winding:
The stator core is a magnetic circuit made by stacking of low-loss silicon steel lamellae. Each lamella is coated on both sides with insulating painting to reduce eddy current losses.
The stator winding for medium voltage (MV) is made of a flat copper wire, which is enamelled and wrapped with a fibre tape

Rotor



Rotor

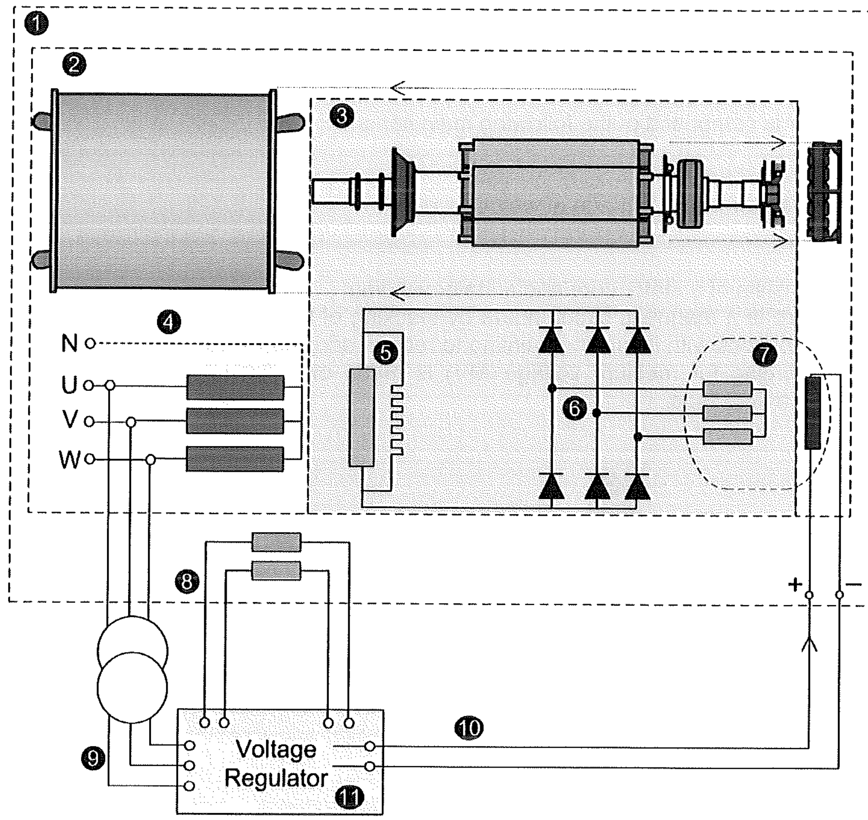
1: Rotor shaft	*4: Rotating resistors*
2: Cooling fan	*5: Exciter armature*
3: Polar wheel	*6: Rotating diode bridge*

The rotor is a polar wheel (3) with rotor winding, rotor shaft (1) and surrounding equipment. The polar wheel consists of a minimum of four salient poles. The poles are made of steel lamellae stacks.
The rotor winding is made of a flat copper wire. The rotor shaft is equipped with the following components: Cooling fan (2), Rotating resistors (4), Exciter armature (5), Rotating diode bridge (6).
The complete rotor assembly is balanced. The rotor assembly is designed to operate below the first critical speed with a minimum safety margin and can withstand 20% overspeed for two minutes without damage.

Impregnation

All windings incorporated in stator, rotor and exciter parts are impregnated by a vacuum and pressure impregnation (VPI) process.

Exciter



Schematic diagram of the excitation system

1: Generator
2: Static parts (yellow background)
3: Rotating parts (blue background)
4: Stator winding
5: Main field
6: Rotating diode bridge
7: Exciter
8: AREP
9: Voltage measurement
10: Excitation current
11: Voltage regulator (CGCM)

The shaft driven exciter (7) has a stationary field and a rotating armature. The armature has a three-phase rotating diode bridge (6) which rectifies the AC output of the exciter into DC for the main field (5). The diodes are protected against overvoltage by resistors. The exciter works according to the Auxiliary Winding Regulation Excitation Principle (AREP) with a permanent magnet insert (PMI).

The constant power to the voltage regulator is provided from two independent auxiliary windings incorporated within the main stator windings (4):

The power output of the first auxiliary winding is proportional to the stator output voltage (shunt characteristic).

The power output of the second auxiliary winding relates to the stator current output (compound characteristic – booster effect).
A permanent magnet insert is embedded in the exciter field to ensure automatic build-up of the voltage due to residual magnetism.

Bearings
Sleeve bearings are installed on the drive end (DE) and on the non-drive end (NDE) side of the generator. The bearings are lubricated by the lube oil system. The bearing shells are internally insulated from the housings.

Terminals
The main terminal box of the generator is located on the top of the machine containing mains and neutral terminals. The star point is made internally within the generator terminal box. The three line side terminals consist of copper plates mounted on post insulators. The voltage and current transformers for control, measurement and protection devices of the generator are also located within this box.

Ventilation
A characteristic aspect of the synchronous machine is a self-ventilation system. A fan draws ambient air into the generator at the non-drive end opening and through the stator. The air is expelled through the drive end opening. The cold air temperature corresponds to the ambient air temperature downstream of the ventilation filters. The ambient air can be taken directly from the immediate environment of the alternator (IC 0 A1 according to DIN EN 60034-6) where it is routed from the outside of the package through the enclosure of the ventilation system.

1.6 GENERATOR DATA SHEET

Feature	Description
Manufacturer	Leroy Somer
Excitation	Brushless
Construction standard	According to IEC 34-1/3
Nominal voltage – Temperature class	11000V - Class F ±5%
Rated power output at 40°C (temperature class F)	6750 kVA
Frequency	50 Hz
Rotational speed	1500 rpm
Typical efficiency at full load p.f. = 0.8	97.4%
Short circuit current	3 x I_n for 10 s
Insulation class	H
Protection class	IP23 generator only IP54 for the generator inside the enclosure when the filters have been installed
Cooling mode	IC01 according to DIN EN 60034-6, self-ventilated air, air temperature >–20°C
Operating mode	Continuous, grid parallel
Mounting	IM1101
Bearings	Sleeve bearings
Vibration	According to VDI 2056, Group G, within range "Good"
Automatic voltage regulator	mounted in Control Panel
Power factor regulator	mounted in Control Panel

Accessories

Six temperature probes (PT100) are installed in the stator winding:

- Three temperature sensors measure the temperatures. The temperatures are analysed for thermal protection of the generator.
- Three temperature sensors are used as spares.

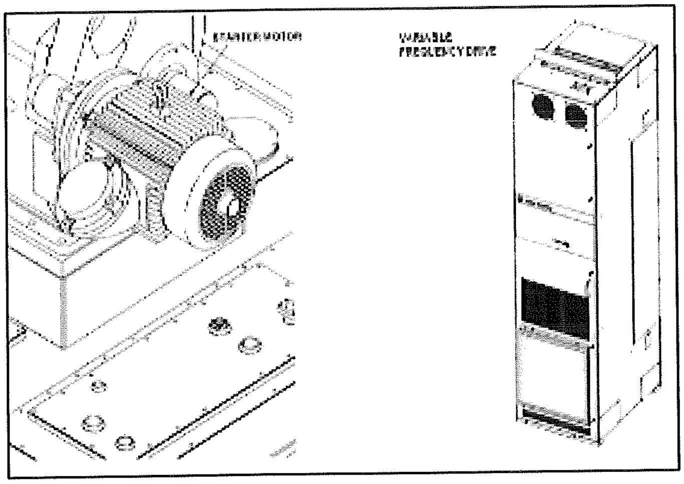
A temperature probe (PT100) is installed on the sleeve bearing. A standstill space heater is installed in the housing for condensation protection.

Three triple core current transformers are mounted on star point 1 x 0.5M5, 20 VA, 2 x 5P10, 20 VA for measuring and protection.

Three triple core voltage transformers are provided, two for measuring and one for protection (open triangle).

1.7 START SYSTEM

The start system includes a direct-drive AC starter motor(s) driven by a common 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.



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 de-energizes the starter motor, and the motor clutch assembly is disengaged.

Starter Motor

The starter motor provides high breakaway starting torque and acceleration from standstill to starter dropout speed. Starting power is transferred to the gas turbine via the reduction gearbox and over-running clutch and shaft assembly.

Variable Frequency Drive (VFD)

Controlled by the *Turbotronic 4* control system, the VFD provides pulse-width modulated power with variable frequency and voltage to the starter motor. The system is capable of performing up to six start attempts per hour, as well as extended purge cycles for heat recovery unit applications and engine wash cycles.

Power Wiring

The start system requires three phase AC input (by Others). The start contactor is not required for VFD operation. A fused disconnect at the VFD input is provided. Optional motor space heater wiring is available.

1.8 FUEL DELIVERY SYSTEM

The fuel system, in conjunction with the control system includes all necessary components to control ignition and fuel flow during all modes of gas turbine operation.

Solar has proposed the Natural Gas, SoLoNOx Combustion fuel system for this application.

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

Scope Exclusion:
The fuel and all associated interconnecting fuel piping for the installation, testing, and operation of the gas turbine generator set is supplied by Others.

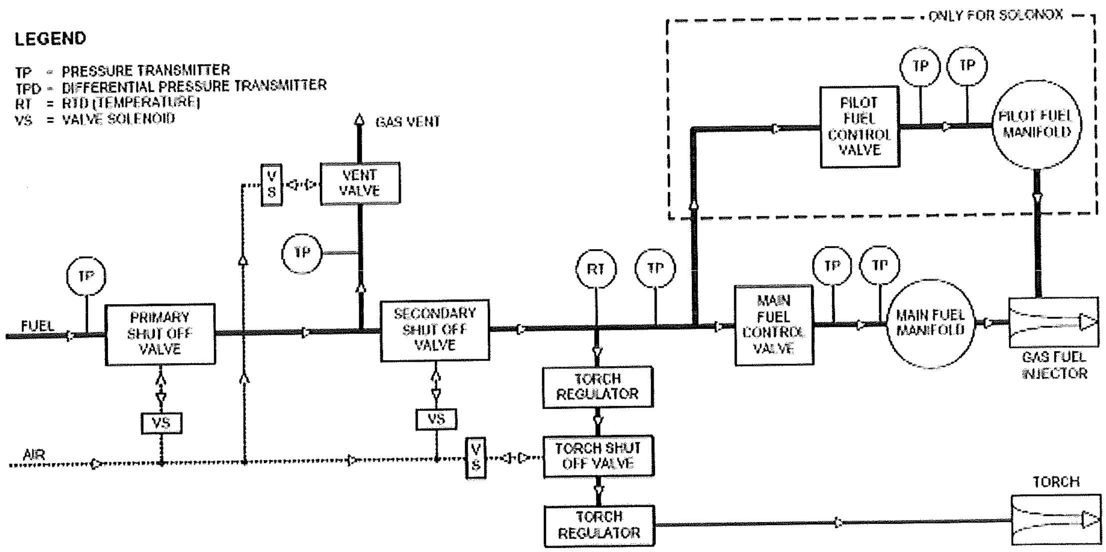
Note:
Any gas turbine fuels that do not meet Solar Specification ES9-98 can have an impact on engine performance, operating life, and engine warranty.

1.8.1 GAS FUEL SYSTEM

The gas fuel system includes the following components:

- Gas flow meter (**)
- Skid edge gas fuel filter
- Supply Pressure Transmitter
- Pilot air operated primary gas fuel shutoff valve
- Pilot air operated gas vent valve
- Air-operated secondary gas fuel shutoff valve
- Torch with associated shutoff valves/regulators
- Electrically-operated main fuel control valve
- Main fuel manifold
- Fuel injectors
- Electrically-operated pilot fuel control valve
- Pilot fuel manifold

(**) A Coriolis gas flow meter with a standard accuracy of 0.15% can be used to monitor the gas fuel input. The gas flow meter is not involved in the gas turbine control loop. The flow meter measures the mass flow of the gas fuel. No temperature or pressure compensation of the measured values is required. The flow meter has an internal sensor to measure the temperature of the vibrating tube.



GAS FUEL SYSTEM (DESIGN AND COMPONENT OPERATION)

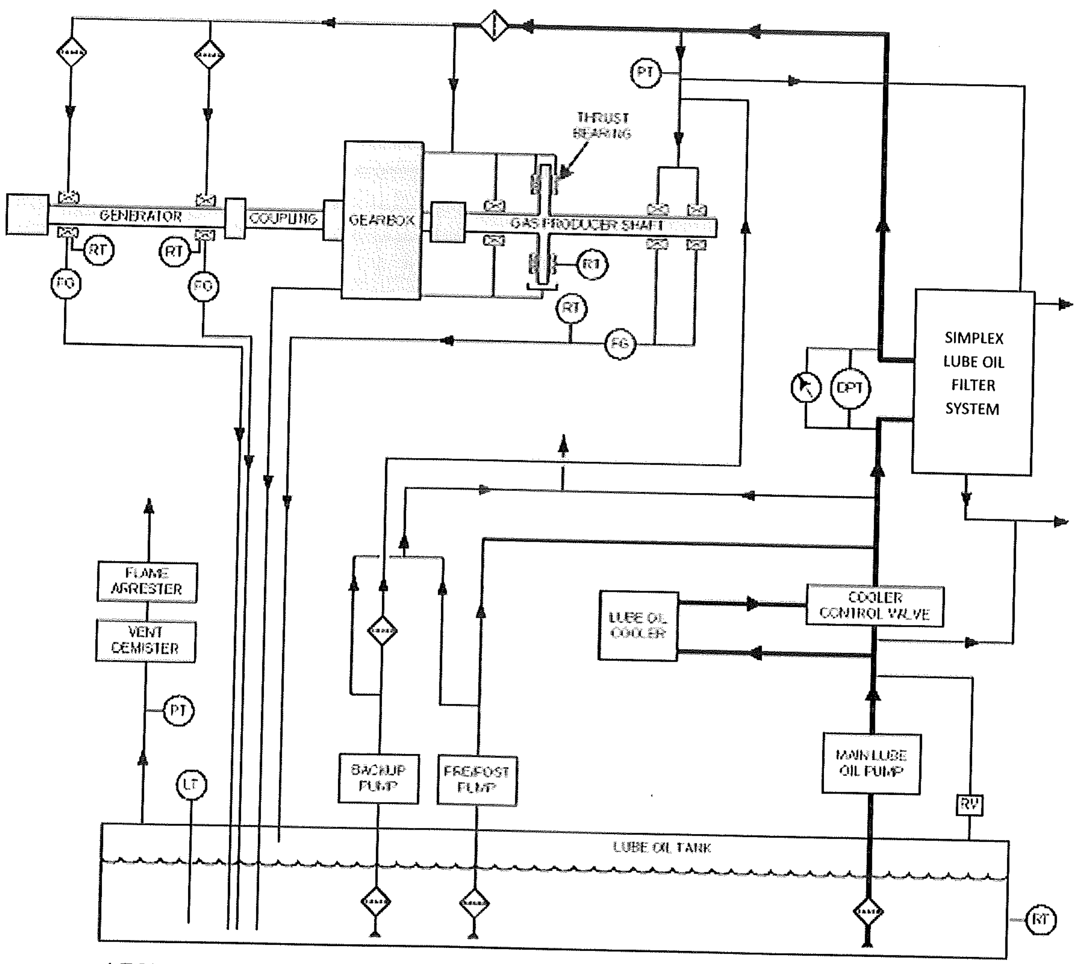
Pneumatically actuated primary and secondary gas fuel shutoff valves are controlled using pilot air pressure. For each valve, pilot air pressure is admitted to and exhausted from a pneumatic actuator through a solenoid valve. Fail-safe operation ensures both valves will close in case pilot air pressure is lost.

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

> Note:
> 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.

1.9 LUBRICATION SYSTEM

The lubrication system circulates oil under pressure to the gas turbine and driven equipment. Lube oil is supplied from the lube oil tank incorporated into the baseframe. Oil temperature is maintained at optimal levels by a thermostatic control valve, oil tank heater, and off skid oil cooler. Below is a schematic depicting a typical lube oil system:



LEGEND

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

Note:
Actual configuration may change depending on gas turbine model, and selection of available options available with that equipment. See following pages under Lubrication System for additional clarification.

The lubrication system incorporates the following major components:

- Oil tank (carbon steel construction)
- Lube oil
- Gas turbine-driven main lube oil pump
- AC motor-driven pre/post lube oil pump
- DC motor-driven backup lube oil pump
- Simplex lube oil filter system with replaceable elements
- Oil level, pressure, and temperature indications
- Pressure and temperature regulators
- Strainers
- Oil tank vent separator
- Lube oil cooler

Oil Tank
The carbon steel lube oil tank and tank covers are integral to the package base frame. A tank drain connection is plumbed to the side of the package base.

Lube Oil
The lube oil is customer-furnished, quality must conform to Solar's Engineering Specification ES 9-224. This project will be configured for mineral, or petroleum based oil with an ISO viscosity grade of 32. It is rated for an ambient temperature range of +26°F to +110°F (-3°C to +43°C).

Per the referenced specification, it is required that the pour point must be at least 11°F (6°C) below the ambient air temperature surrounding the package, even in the coldest season. This requirement is to ensure oil flow at the start of the pre-lube cycle. If a different type of lubricating oil, or viscosity grade is preferred by the Customer, this must be communicated to Solar for consideration.

Main Lube Oil Pump
The main lube oil pump is mounted on, and driven by the reduction-drive gearbox. This positive-displacement pump provides lube oil pressure during normal operation.

AC Motor-driven Pre/Post Lube 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. Additionally, 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.

DC Motor-driven Back-up Lube Oil Pump
The back-up 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 back-up 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 back-up lube oil pump also provides lube oil pressure during an emergency condition such as a fire, control system failure, emergency stop, or if a turbine over speed is detected by the back-up system. Power to the motor is provided by Solar's 120 VDC battery system.

Simplex Lube Oil Filter
A simplex filter is supplied to remove contaminants from the lube oil system. It is contained entirely within the enclosed package, and a filter drain connection is plumbed to the side of the package base.

Note:
Both with a simplex or duplex filter configuration, the gas turbine must be shut down in order to change out the filter element.

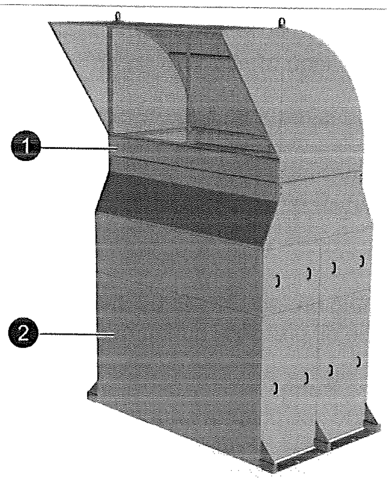
Vent Separator/Demister
A lube oil vent separator is provided to remove oil droplets entrained the vapour stream from the lube oil tank vent. Recovered oil drains back to the lube oil tank.

Lube Oil Immersion Tank Heater
The lube oil tank immersion heater ensures the lube oil tank temperature remains above 10° C (50° F). It also facilitates a short lube oil temperature warm-up period after a cold start.

Air/Oil Lube Oil Cooler
The lube oil cooling system cools the lube oil in order to allow a continuous operation through all seasons. The thermostatic valve directs a part of the oil flow to the cooler in such a way that the mixing of the cooled oil and the oil which has bypassed the cooler results within the temperature limits.

A safety interlock in the control logic prevents the turbine start-up if the oil temperature falls below a specific threshold (typically 11°C). In continuous operation, the minimum temperature of the lubricating oil is set to 43°C. When the temperature drops below this value an alarm is triggered.

The lube oil cooling system is a lube oil/air cooler. The lube oil/air cooler is installed outside the power train enclosure and is an integral part of the air filtration and ventilation structure.



1 Exhaust air duct *2 Cooling module*

The lube oil/air cooler consists of the following components:

- Exhaust air ducts (1): Drive the cooling air out of the cooling module.
- Cooling module (2): The pre-assembled cooling module contains the following components:
  - Aluminium heat exchanger
  - 2 fans, each driven by an AC electric motor. The fans produce the necessary cooling air flow. In the event of failure of one fan a warning signal is triggered. A turbine shut-down is initiated only if the cooling capacity is low and the oil temperature reaches the maximum limit. The cooling module is independently controlled by the gas turbine control system.

Manholes allow access to the fans and to the heat exchanger for maintenance works.

Technical data	
Tube material	Aluminium
Fin material	Aluminium
Installed cooling capacity at 40°C ambient temperature	200 kW
Air flow rate	31700 Nm^3/h
Number of fans	2 × 4.0 kW
Ambient temperature range	–20°C to 40°C

1.10 *TURBOTRONIC 4* CONTROL SYSTEM

Solar's *Turbotronic 4* control system is used for sequencing, control, and protection of the gas turbine package, and for providing an extensive range of options for monitoring and plant control.

The control system is a digital, fully-integrated system utilizing an Allen-Bradley ControlLogix programmable controller configured to Solar's requirements.

The control processor (controller) performs proportional control, start-up, operation and shutdown sequencing and protection functions, as well as detection and annunciation of abnormal operating conditions. Control for these functions comes from signals the controller receives from solid-state devices, control switches, speed, pressure and temperature transmitters, relays, solenoids, and vibration sensors. These components provide the controller with the data necessary to control and maintain desired process conditions, while maintaining engine speed and temperature at safe levels.

The control system provides the operator with the necessary information for operation of the equipment, and offers a variety of communications options for data exchange with external plant distributed control systems.

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)
- XM-120 Vibration Monitoring System (Rockwell Automation)
- ControlNet network (ControlNet International)
- TT4000S onskid local operator control panel (Solar Turbines)
- Independent back-up shutdown system (Solar Turbines)
- Fire and gas monitoring and control system (Detronics)

The ControlNet 1.5 network provides primary communications between components. Hardwire backup is provided for critical backups.

STANDARD CONTROL SYSTEM COMPONENT HARDWARE

Onskid Control System
The control system components are mounted in one or more carbon steel NEMA 4 panels located on the package skid. The panels contain all the controls hardware including the programmable controller, the I/O Modules, the Vibration Monitoring System, the CGCM and the TT4000S display unit.

Programmable Controller
The heart of the control system is the programmable controller. The programmable controller performs the following functions, in conjunction with the input and output signal modules:

- Sequencing of gas turbine and auxiliaries
- Control of turbine and driven equipment during start-up, loading, operation, and shutdown
- Protection of turbine from abnormal operating conditions
- Protection of driven equipment from abnormal operating conditions
- Response to commands from operator
- Analog and status outputs for display and monitoring

The programmable controller is programmed in a language called "relay ladder logic", or in "function block diagram" programming.

Input/Output Modules
In order to perform many of its functions, the programmable controller must gather physical data. This is accomplished through I/O modules that gather either discrete or analog data. Discrete inputs are typically used for alarms, shutdowns, or status indications, while analog inputs are used for scalable functions.

Internal Communication
Communication between the programmable controller and the I/O modules is via redundant ControlNet 1.5, a high speed, deterministic, serial communications link.

Note:
Deterministic is the ability to reliably predict when data will be delivered.

Power Supply
The power supply system supplies power to the programmable controller, I/O modules, video display unit, and relay backup systems. It consists of independent, voltage converting, DC-to-DC isolating power suppliers. The system receives 120 VDC input from the battery system and converts it into a regulated and filtered 28 VDC power at a maximum of 20 amps.

Backup System
The basic control system is equipped with an independent relay backup system that serves to initiate emergency shutdown of the gas turbine, and to control the post-lube cycle. Critical input signals monitored by the backup system include the:

- Backup power turbine overspeed monitor
- Manual emergency stop switch
- Programmable controller fail "watchdog" timer, and
- Fire and gas monitoring system relay contacts

When activated by any of the above faults, the relay backup system initiates a safe shutdown of the turbine and driven equipment. The backup control system is a combination of instantaneous and time-delay relays.

Once a shutdown is initiated by the backup system, operation can only be restored manually, and locally by a dedicated backup system reset switch after all the faults have been cleared. This action re-energizes the master control relay and its associated relays and timers are restored to their normal position.

Vibration Monitoring System

The vibration monitoring system provides vibration indication and protection for the gas turbine, gearbox, and driven equipment. Depending on the unacceptable vibration level, either a warning is indicated, or a turbine shutdown is initiated. With the appropriate options, the system provides information that can be used to evaluate vibration problems and enable the user to trace the root cause before equipment availability is affected.

Solar has integrated Rockwell Automation's XM-120 product line principally due to its seamless integration with the existing ControlNet-based Flex I/O control system. By integrating the vibration system, the diagnostic information is readily obtained through the existing network configuration, and allows more complete condition monitoring of the gas turbine system.

Features. The XM system incorporates the following features:

Feature	What's Included	HMI Display
Overall vibration amplitude:	yes	standard
Gap voltage:	yes	standard
Discrete Band amplitude (four configurable bands)	yes	standard
Discrete amplitude (1x, 2x, 3x)**See Note a**	yes	standard
Discrete phase angle (1x, 2x) **See Note a**	yes	standard
Spectrum plot	yes	optional upgrade
Time-Waveform plot	yes	optional upgrade
Orbit plot	yes	optional upgrade
Integrated Combustor monitoring	*SoLoNOx* only	*SoLoNOx* only
Historical logging	yes	standard

Notes

(a) Refers to multiples of engine running speed

VOLTAGE REGULATION

The voltage regulator characteristics are:

- Solid State
- Three-phase sensing (single-phase sensing can be accommodated)

Steady-state Stability

Steady-state voltage regulation is defined as constant frequency and load. When the generator is operating steady state an any load, the generator voltage varies no more than ±0.1%.

No Load to Full Load Accuracy

At constant frequency and at rated power factor, the voltage regulation varies no more than ±0.25%.

Voltage Drift
With the generator operating at rated voltage, and with a constant load between 0 – 100% at rated power factor, the change in the regulated output will not exceed 1.0% of rated voltage for any 30-minute period at a constant ambient temperature.

Automatic Voltage Regulator (AVR)
The voltage adjustment range about the selected nominal value is ±10%. The resolution of the voltage is 0.1%. Voltage metering accuracy is ±0.2%.

OPERATOR INTERFACE

The control system operator interface has three major components:

- Onskid NEMA 4 turbine control panel
- Onskid "Touch screen" video display unit (VDU)
- Off skid video display unit (VDU) for non-hazardous area location

Turbine Control Panel
The turbine control panel provides the essential controls to start or stop the turbine, to adjust the gas generator speed, and other optional control functions. Some typical gas turbine controls and indications that appear on the control panel include the following:

- Off/Local/Remote (control selector with lockable positions)
- Emergency Stop (shutdown without cool down)
- Normal Stop (shutdown with normal no-load cool down)
- Speed Control (increase/decrease)
- Start
- Horn Silence (audible alarm)
- Acknowledge (alarms and shutdowns)
- Backup System (Active/Reset)

Operation Indication Lights:

- Starting
- Backup Active
- Stopping

Onskid Video Display Unit
The video display unit (VDU) is used to present an extensive selection of the turbomachinery operating parameters. The display system consists of several screens organized by systems and functions to allow the operator to easily locate and monitor a given parameter. It also includes a password protected screen, which allows the operator to input or modify certain values such as process control setpoints.

The onskid VDU makes use of Solar's TT4000S display and monitoring system, which performs several key functions to facilitate operation of the turbomachinery equipment through a user-friendly interface. The TT4000S system monitors the turbine and generator parameters, and offers basic control capabilities, as well as annunciating alarms, reporting on the running status of the equipment, and providing a comprehensive set of analysis tools.

Data storage consists of:

- Discrete event log containing the last 5,000 events
- Six (6) trigger logs containing 1 sec tag samples surrounding the last six (6) shutdowns
- Hourly log containing snapshot data for the last 24 months

The TT4000S display and monitoring system uses the Embedded Windows operating system, and offers the following industry-standard features:

- Complies with TCP/IP
- Supports Object Linking and Embedding for Process Control (OPC)
- Supports ActiveX controls

The display screens listed below are for a typical package, and are provided as standard equipment for all turbine packages:

- Main Menu
- Operation Summary
- Engine Temperature
- Shaft and Bearing
- Lube System
- Generator Summary
- Bus Summary
- Generator Control Modes
- Generator Setpoints
- Gas Fuel System (as applicable)
- Liquid Fuel System (as applicable)
- Enclosure
- Alarm Summary
- Alarm Log
- Event Log
- Strip Chart
- Maintenance Modes
- VFD Configuration

Auxiliary Video Display Unit
The auxiliary VDU consists of an industrial desktop computer (with MS Windows operating system) and the TT4000 display and monitoring system. It has all the features of the standard skid-mounted VDU plus the following enhancements:

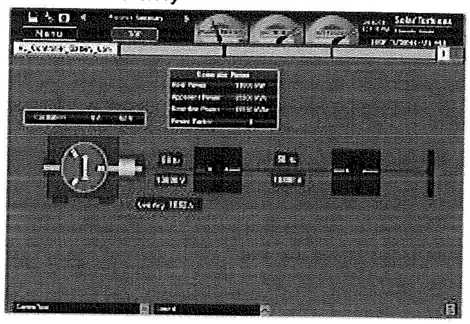
- Additional Historical Data, including:
  - 2-minute Log.One month of daily files with data points taken every two minutes.
  - 10-second Log.Data are read at 10-sec intervals for the last 14 days.
- Larger Trigger Log.The Trigger Log function stores up to 25 triggered files, each containing 6-minutes of 1-second data points (The onskid VDU stores five triggered files)
- Accommodates Additional Options, including:
  - Gas turbine performance calculations
  - Printer
  - Remote VDU
- Higher resolution screen and graphics capability
- More memory, including RAM and non-volatile storage

The auxiliary VDU communicates with the onskid controller through ControlNet 1.5. The total cable run must be no longer than 2500 feet (750 meters). Cable run lengths for the auxiliary VDU vary from project to project depending upon how close the operator station/control room is to the gas turbine generator set package.

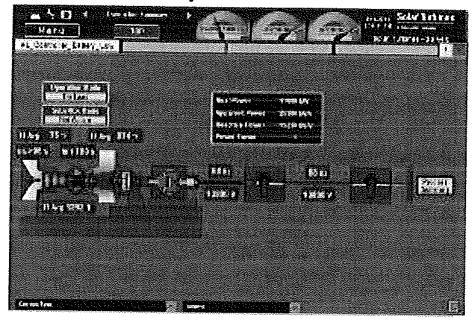
Scope Exclusion: The interconnecting ControlNet cabling between the auxiliary VDU and the generator set package is supplied by Others.

Sample Screens from the Video Display Unit
The following are sample screen shots for the VDU:

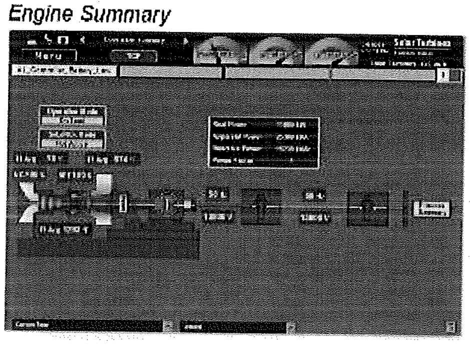
Process Summary



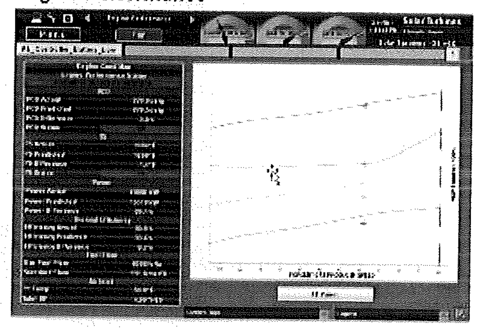
Operation Summary



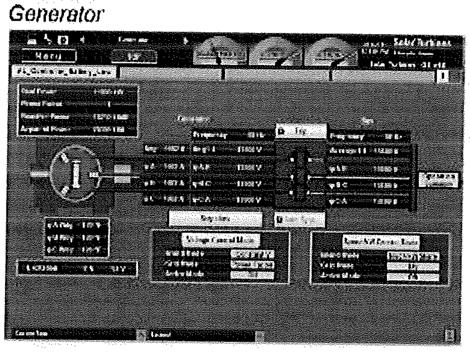
Engine Summary



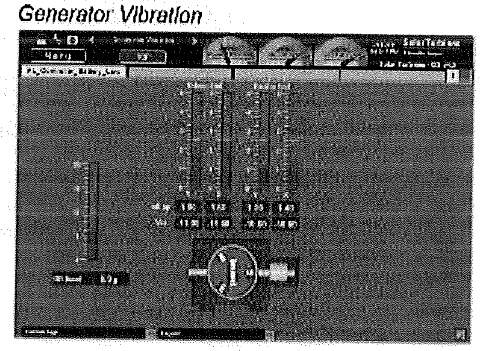
Engine Performance



Generator



Generator Vibration



Note:
Availability of some screens is dependent upon selection of corresponding gas turbine generator set configuration options.

ENGINEERING UNITS

The following engineering units will be displayed:

Type	Pressure	Temp	Length
Metric	bar	deg C	mm

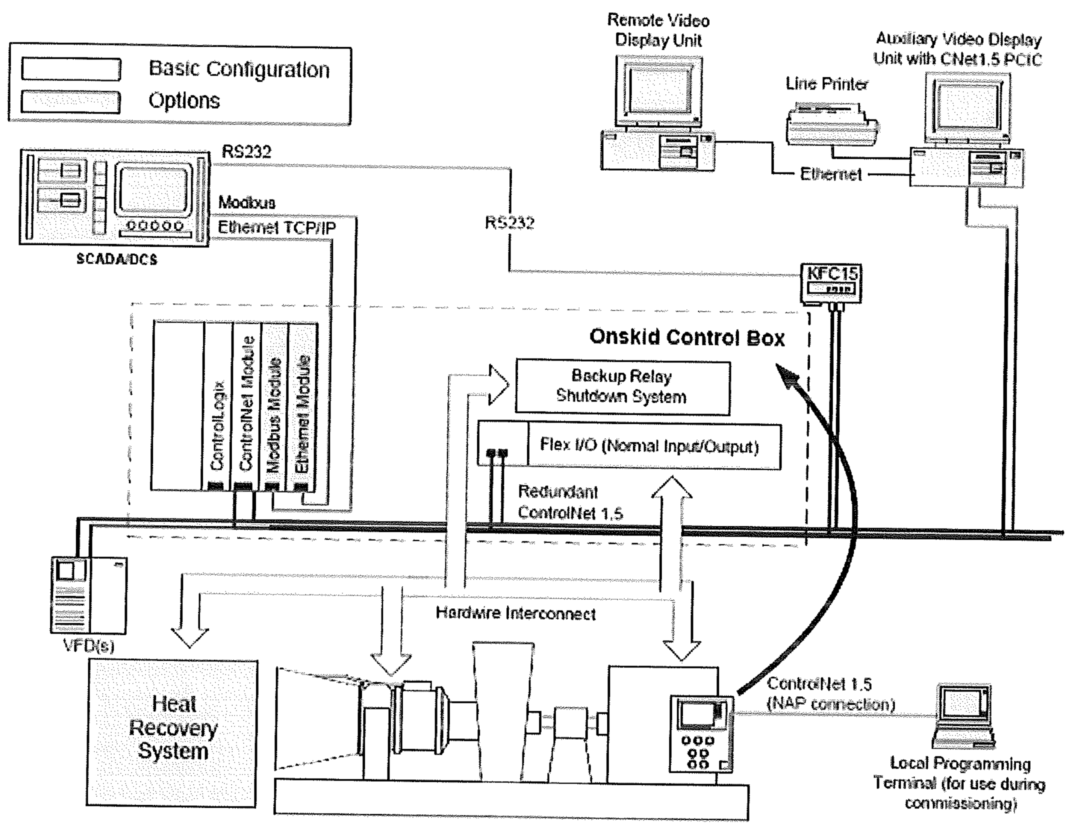
LANGUAGE

Display Screens
The video display unit (VDU) screen displays will be in English.

Labels
The turbomachinery package labels and control console labels will be in English.

COMMUNICATIONS: TURBINE CONTROL TO SUPERVISORY SYSTEM

Communication between the gas turbine control system and the user's supervisory control and data acquisition (SCADA), distributed control system (DCS), or other supervisory system is available. *Turbotronic 4* control systems can be provided with an interface that allows the supervisory system to communicate with the programmable controller, obtain data, and have the control capability required.



Data for Transmission
The following information from the turbine package is available to be accessed by the supervisory system:

- Analog instrumentation values
- Discrete status values
- Discrete alarms and shutdowns

The following information can be sent by the supervisory system:

- Discrete control commands (start, stop, acknowledge/reset, and change mode of operations)
- Analog operating setpoints (kW control, speed, kVAR, pf, and voltage)

The specific addressing for the data transfer is provided for each turbine package.

Protocol
The communication language used between programmable controller systems usually follows a set of rules or format called a "protocol". The protocol defines the sequence and organization of the transmitted data. The RSLogix controller uses an internal proprietary bus protocol called "control and information protocol", or CIP. Communication modules allow different communication networks to interface with this internal bus. The DCSmust be CIP capable. The Allen-Bradley communications software RSLinx provides all the necessary drivers to communicate with all turbine package control networks and network devices (except Modbus), and is required for most applications.

Where full CIP capability is not available, for example on an existing DCS system configured for DF1 type data, Solar can provide emulation files in the processor that canbe read in a similar way as the N11 file on a PLC-5.

Supervisory Interface Options
The availble supervisory interface options are serial communication (RS232, RS422, RS485), ethernet TCP/IP, ControlNet 1.5, and Modbus.

For this application, we have proposed the following:

Ethernet TCP/IP
Data transmission rates are high, the communication is non-deterministic, and cabling and connectivity is well known throughout most industries (common office computer network technology).

- Physical media: twisted pair (10BaseT)
- Protocol: CIP over TCP/IP
- Topology: star
- Maximum distance (per Rockwell specifications):
  - 328 ft (100 m) to hub
- Maximum data transmission rate: 10 Mbps
- Maximum number of nodes: unlimited (8-24 nodes per hub typical)

Typical Application. The turbine package Ethernet module is usually connected to a local hub that is connected to an Ethernet backbone for data transfer to a remote supervisory system over longer distances. 10BaseFL fiber lines support 6560 ft (2000 m) segments.

1.10.1 CONTROLS FOR WASTE HEAT RECOVERY APPLICATIONS

Waste Heat Recovery System (WHRS) Interface

The Waste Heat Recovery System (WHRS) interface is designed to provide the necessary communication between the Turbotronic 4 Gas Turbine Control System and the WHRS control system to facilitate start and stop, and input signals for proper purging of the gas turbine exhaust and WHRS. Some status monitoring may also be included. The standard Waste Heat Recovery System Interface is designed for the following configuration.

- The Waste Heat Recovery System has its own discrete control system
- A single gas turbine package is operating in conjunction with a single WHRS
- No duct burner interface is required
- WHRS diverter valve is not controlled or supervised by the gas turbine package control system
- Purge air flow is provided by the turbine

The Turbotronic 4 gas turbine control panel interfaces with the Waste Heat Recovery System, and receives the following signals:

- Waste Heat Recovery System malfunction summary (alarm / status display)
- Waste Heat Recovery System malfunction summary (turbine shutdown)
- Waste Heat Recovery System system purge complete (permissive to ignite)
- Turbine start permissive

The following hardwire signals are sent from the Turbotronic 4 gas turbine control panel to the Waste Heat Recovery System:

- Purge flow established or exhaust flow sufficient for purge (Typically Turbine 15% speed)
- Turbine starting or running status
- Turbine running status (Turbine has completed start sequence and is running)

In addition, the Waste Heat Recovery System may use the turbine running status signal as an indicator to begin its operation.

1.10.2 GENERATOR CONTROL AND PROTECTION

For generator control and monitoring, the *Turbotronic 4* control system incorporates a Rockwell Automation/Allen-Bradley combination generator control module (CGCM). The CGCM combines the following into one module:

- Load sharing
- Synchronization
- Voltage control
- Reactive power control, and
- Generator protective functions

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

The protection functions of the CGCM are designed to respond to the following events to protect the Turbomachinery Package and Generator from damage and/or catastrophic failure:

- Over-excitation voltage (59F)
- Generator over voltage (59)
- Generator under voltage (27)
- Loss of sensing (60FL)
- Loss of excitation (40Q)
- Over frequency (81O)
- Under frequency (81U)
- Reverse power (32R)
- Phase rotation error (47)
- Over current (51)
- Rotating diode monitor (58)
- Reverse VAR (40)

> **Note**:
> The protection features integrated in the CGCM do NOT meet the requirements of power utility companies for the general protection of power distribution systems. The relay settings are standard (not as a result of a system study) and are in place to protect the Turbine Generator Set from damage or catastrophic failure due to any of the above conditions.

Generator Main Protections

The protection system consists of multifunction digital protection relay assembled with its accessories inside a dedicated panel. The protection is supplied completely wired and tested to simplify installation and commissioning.
Main characteristics of the protection relays:

- Programmable thresholds and timers
- Event memory
- Relay outputs
- Display of the real time measurements and the setting parameters
- LEDs for operational and fault indications
- Keyboard for entering parameters
- Internal self-diagnosis
- Remote connection option

Protection function	ANSI code
Differential protection relay	87T
Overcurrent (time independent) for short circuit protection	50
Overcurrent (time dependent) for overload protection	51
Earth fault over current (time independent) for stator earth fault (95%) protection, via current transformers (if required)	64S
Negative sequence over current for unbalanced load protection	46
3-phase undervoltage protection	27
3-phase overvoltage protection	59
Residual voltage (time independent) for stator earth fault (95%) protection, via open delta transformer	64S
Loss of excitation	40
Reverse power	32

Main generator protections: ANSI codes (ANSI/IEEE C37.2-2008)

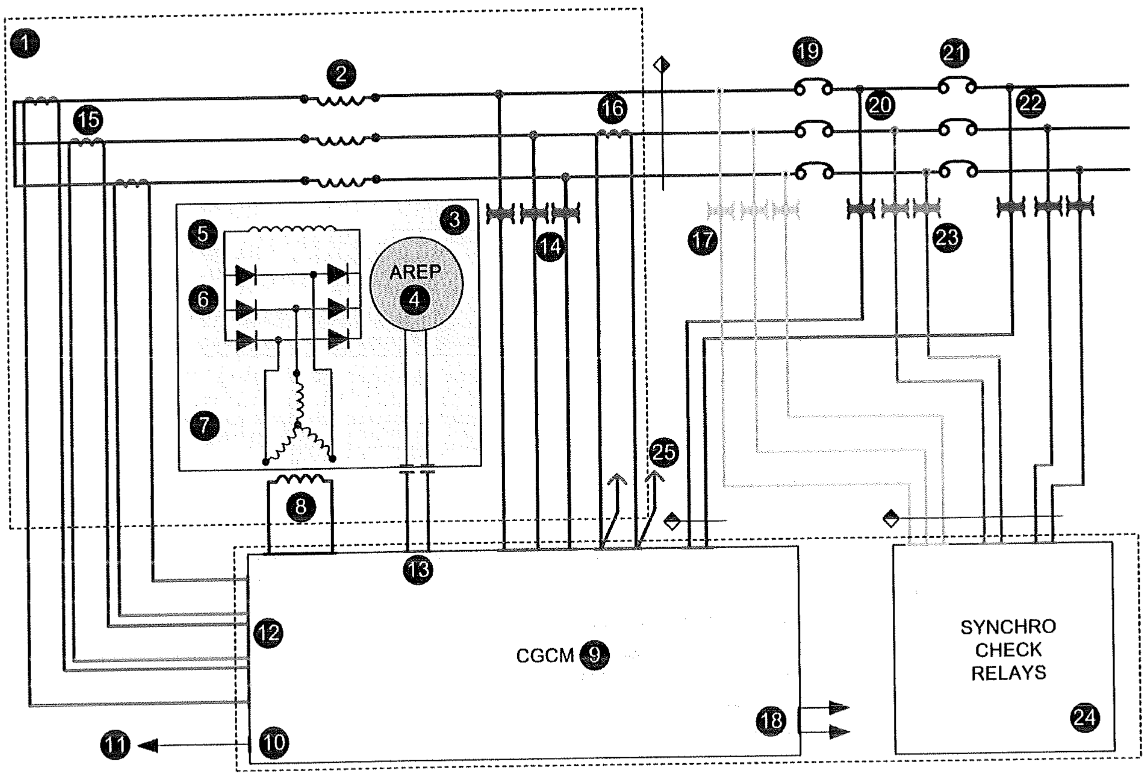
In the event of perturbances, the generator main protections decouple the turbogenerator from the busbar by opening the generator circuit breaker. These protections are to be considered only as generator protections. The main decoupling protections (grid protection) must be installed on the MV system. Only in particular cases grid protection can be installed in the gas turbine control panel. The main decoupling protections are not part of the scope of supply.

FUNCTIONAL DESCRIPTION

The Allen-Bradley/Basler electric combination generator control module (CGCM) provides extensive generator control and backup protection functions.

The functions are integrated into the control system by connecting the CGCM to the system's ControlNet network. The combination generator control module (CGCM) includes:

- Generator data measurements
- Generator excitation regulation
- Synchronizer
- Active and reactive load sharing
- Generator backup protection



Combination generator control module (CGCM)

1: Generator
2: Generator armature (stationary)
3: Rotating portion
4: Auxiliary Winding Regulation Excitation Principle (AREP)
5: Generator field
6: Rectifier assembly
7: Exciter armature
8: Exciter field (stationary)
9: Combination generator control module (CGCM)
10: ControlNet
11: To Turbotronic 4 control processor
12: Generator current
13: Excitation supply
14: Generator potential transformers
15: Generator current transformers
16: Cross current compensation transformer
17: Generator CB cubicle potential transformer
18: Active power load sharing lines (to other CGCM or load share module)
19: Generator circuit breaker
20: Plant busbar voltage reference
21: Utility circuit breaker
22: Grid utility voltage reference
23: Bus potential transformers
24: Synchro-check relays
24: Reactive power load sharing lines

Generator data measurements

The CGCM measures in real time all relevant generator parameters and transmits them via ControlNet to the control system.
Most important parameters:

- Voltage / V
- Current / A
- Frequency / Hz
- Power factor / cos φ
- Active Power / kW
- Apparent Power / kVA
- Reactive Power / kVAR

Generator excitation regulation

The CGCM controls the field excitation current output. Three modes of regulation are available:

- ➔ Automatic voltage regulation (AVR):In AVR mode the excitation current is automatically controlled. The CGCM unit controls the field excitation current output to maintain the generator voltage setpoint. The voltage feedback loop includes adjustable proportional, integral and derivative gains.
- ➔ Power factor regulation (PFR):The power factor (of the generator or of the utility) is controlled by varying the generator field current. In PFR mode the CGCM unit controls the field excitation current output to maintain the power factor setpoint. The CGCM unit calculates the power factor from the measured voltages and currents of the generator or utility. The power factor feedback loop includes adjustable proportional and integral gains.
- ➔ Reactive power regulation (RPR):In reactive power mode the CGCM unit controls the field excitation current output to maintain the reactive power setpoint. The CGCM unit calculates the reactive power from the measured voltages and currents of the generator or utility. The reactive power loop includes adjustable proportional and integral gains.

The following table describes the main generator operational modes available on the system.

CGCM control mode	Operating mode	Regulated parameter	Remarks
Constant voltage control mode	Island (single unit)	Voltage (automatic)	Generator voltage setting by the operator via HMI Typical adjustment rate: 95 to 105% of the generator rated voltage
Voltage droop control mode	Island (multiple units)	Voltage (automatic)	During commissioning, voltage droop is typically set at approximately 4% Generators are able to share the reactive power, which helps to minimize the circulating current between the generators in steady conditions
Reactive power load sharing(1)	Island (multiple units)	Voltage (automatic)	Reactive power load sharing is achieved with a cross current control with compensation circuit. When all generators are sharing reactive load equally, the current flows are equally opposed.
Generator power factor (cos φ) control mode	Parallel to grid	Power Factor	Generator power factor setting by the operator via HMI
Generator reactive power (kVAR) control mode	Parallel to grid	Reactive Power	Generator reactive power setting by the operator via HMI
Grid power factor (cos φ) control mode	Parallel to grid	Power Factor	Grid power factor setting by the operator via HMI Requires one of the following signals (supplied by the customer): Two analog signals representing the power factor and the active power exchanged between the plant and the utility grid Two analog signals representing the active and reactive power exchanged between the plant and the utility grid
Grid reactive power (kVAR) control mode	Parallel to grid	Reactive Power	Grid reactive power setting by the operator via HMI Requires one of the following signals (supplied by the customer): Two analog signals representing the power factor and the active power exchanged between the plant and the utility grid Two analog signals representing the active and reactive power exchanged between the plant and the utility grid

Main generator operational modes (overview)
(1) Option: To be discussed. In case of reactive power load sharing, characteristics of paralleled generators have to be investigated.

The following table describes the main governor operational modes which may be available on the system.

Governor regulation mode	Operating mode	Regulated parameter	Remarks
Constant speed control	Island (single unit)	Speed/frequency	Turbine speed setting by the operator via HMI Typical adjustment rate: 96.5 to 103.5% of the turbine rated speed
Speed droop	Island (multiple units)	Speed/frequency	During commissioning, speed droop is typically set at approximately 3.5% Generators are able to share the active power
Active power load sharing(2)	Island (multiple units)	Speed/frequency	Active power load sharing is achieved with a load sharing line connected between the turbine controls.
KW control	Parallel to grid	KW	Generator active power setting by the operator via HMI
Utility grid active power control(3) KW/Import	Parallel to grid	KW	Generator active power (import power) setting by the operator via HMI

Main governor operational modes (overview)
(2) Constant speed control with active power load sharing: In case of multiple units in parallel, the governors work in isochronous mode (constant speed) and are connected by a load sharing line.
(3) Import/export power control

1.11 GAS TURBINE GENERATOR SET PACKAGE ENCLOSURE

The all-steel full-length enclosure is completely self-contained, weatherproof, insulated, sound attenuated, and assembled to mount on the generator set baseframe. It incorporates the following features:

- Standard Features
- Ventilation System
- Dust Protection
- Fire and Gas Detection and Monitoring System
- Fire Supression System

Basic Construction
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 applicable doors and narrow panels are removed. 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 is constructed to support a roof load of 50 pounds per square foot and to withstand a wind load of 120 miles per hour.

The electrical operating devices and controlled devices installed in the power train enclosure are wired according to the standard industrial wiring practices. The cables are placed in conduits for physical protection. The cable feedthroughs in the power train enclosure wall are sealed to prevent escape of gas in case of gas leakage inside the power train enclosure. The package control panel is installed in the exterior wall of the enclosure.

Enclosure lighting
The power train enclosure interior is lighted with explosion proof neon lamps. The lamps are suitable for installation in hazardous area zone 2. The lamps are equipped with a protective grid.

Combustion air plenum
At the opening for the combustion air system connection a combustion air plenum is installed. A flexible bellow is installed between the turbine combustion air plenum and the power train enclosure.

Exhaust interface flange
The external flange of the exhaust opening is rigidly mounted (fixed point) on the power train enclosure. A heat-resistant metal-type compensator is installed on the turbine diffuser, which is connected to the external flange. The compensator absorbs the heat expansion of the gas turbine.

Enclosure ventilation dampers
Pneumatic driven enclosure ventilation dampers in the ventilation air inlet opening and ventilation air outlet openings are used for:

- ➔ shutting in case of fire-fighting, to keep the fire-extinguishing agent in the power train enclosure,
- ➔ closing the power train enclosure when the ventilation is turned off.

Enclosure heater
When the gas turbine is not in operation, the power train enclosure is thermostatically controlled to adjust the required temperature.

GAS DETECTION AND MONITORING SYSTEM

The gas detection system is designed for continuous monitoring of the gas concentration level inside the power train enclosure. If, in case of leakage, a gas concentration in the power train enclosure reaches the pre-selected level, the following safety-related actions are initiated to protect personnel and equipment:

- Optical and acoustical warnings are given outside the power train enclosure
- Alarm messages are triggered at the *HMI*s
- A safety sequence, including the turbine emergency shutdown, is started

The gas concentration levels are set as a percentage of the lower explosion limit (LEL). Typically, there are 10% of LEL for warning and 20% of LEL for alarm and shutdown.

Gas sensors

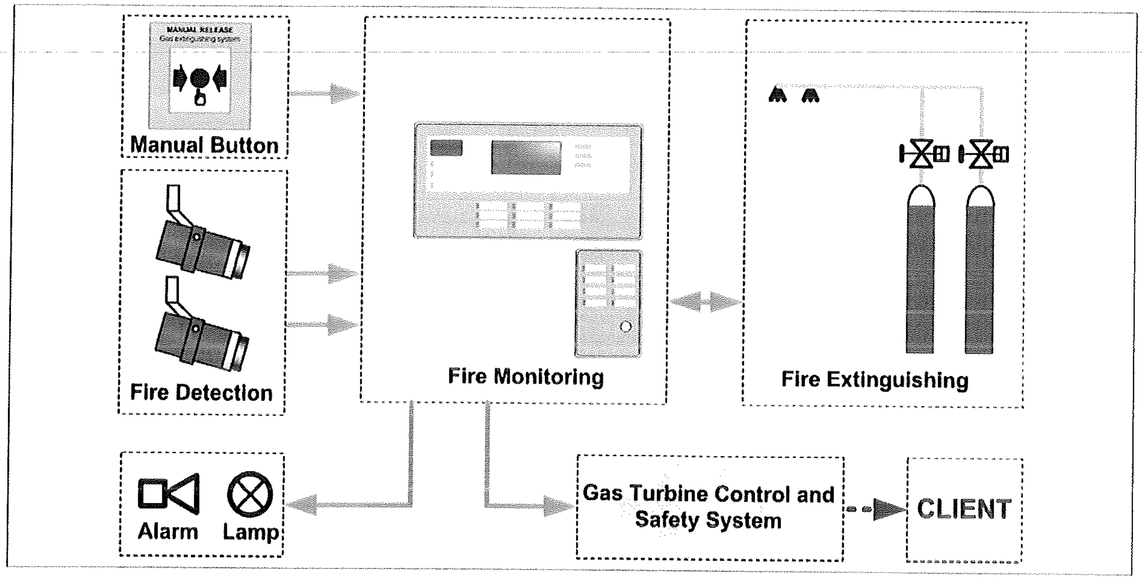
The system consists of gas sensors installed in the power train enclosure.
The gas sensors are of diffusion base, infrared type. Flammable hydrocarbon gases diffuse into the sensor internal measurement chamber, which is illuminated by an infrared (IR) source. As the IR passes through the gas within the chamber, certain IR wavelengths are absorbed by the gas. The amount of IR absorption is determined by the concentration of the hydrocarbon gas. A pair of optical detectors and associated electronics measures the absorption. The change in intensity of the absorbed light (active signal) is measured relative to the intensity of transmitted light (reference signal). The microprocessor computes the gas concentration and converts the value into a 4 mA to 20 mA current output or digital process variable signal. The signal is then communicated to the main controller.

The value is displayed in percent of LEL. An indication of 100% LEL means that the gas has reached a concentration at which the gas/air mixture is sufficient to generate an explosion (=5% by volume of CH_4 in air).

FIRE FIGHTING SYSTEM

The fire-fighting system is installed to protect personnel and equipment against fire inside the power train enclosure. The fire-fighting system consists of the following sub-systems:

- Fire detection system
- Fire monitoring system
- Fire extinguishing system



Sub-systems of the fire-fighting system

Fire detection system

The fire detection system includes:

- **IR detectors**
  The IR detectors are located inside the power train enclosure.

- **CO_2 release push-buttons**
  Manually operated CO_2 release push-buttons are installed on the outside of the power train enclosure. If required, the operator can manually release the fire extinguishing system by pushing one of these buttons.

Fire monitoring system

The flame detectors contain a multi-spectrum infrared (IR) sensor module and control circuitry in an explosion proof housing. The detector is equipped with automatic and manual optical integrity (OI) test capability.

The flame detectors are connected to a controller through a LON (Local Operating Network). The LON and signalling line circuit is a fault-tolerant, digital-communication network loop that starts and ends at the controller. System devices are tied directly into the LON loop or to an enhanced digital input/output module that is also tied into the LON loop. The LON loop is monitored by the controller.

The controller performs all communication, command, and control functions for the system. During normal operation, the controller continuously checks the system for fault conditions and executes user defined programmed logic that coordinates the control of the system devices. The controller contains pushbuttons for operator interface, system status indicators and a text display.

The controller unit activates the extinguishing system as well as the alarm light and the alarm horn, installed on the power train enclosure.

Fire-extinguishing system

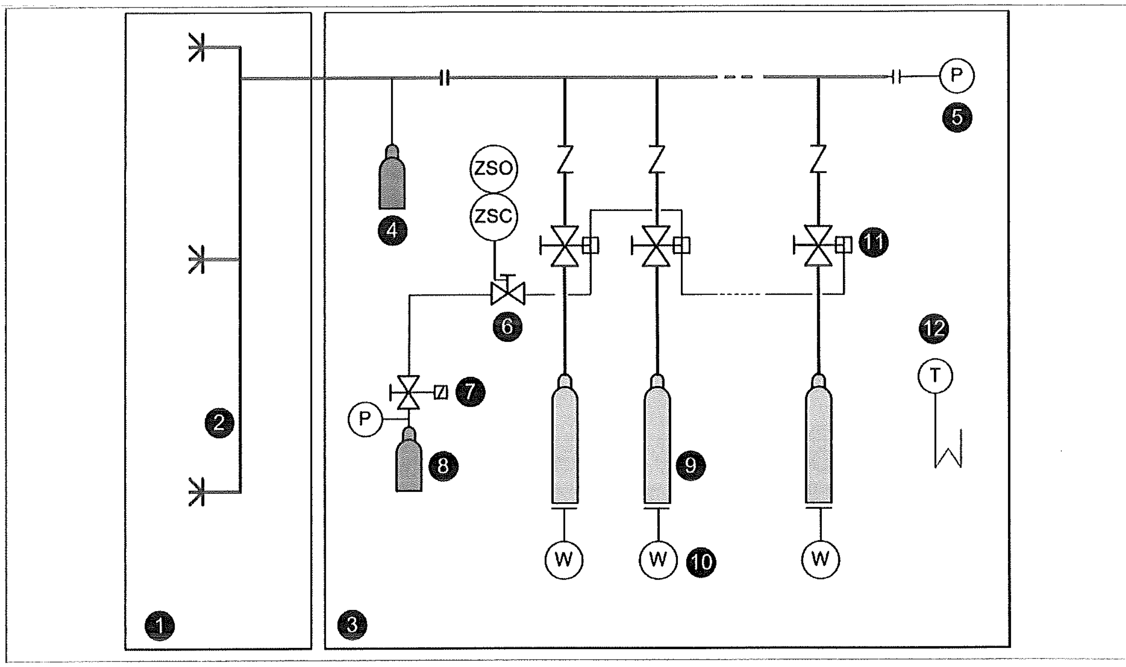


Fig. 1: Fire-extinguishing system

1 *Power train enclosure*
2 *Distribution piping and spray nozzles*
3 *CO_2 bottle cabinet*
4 *Odorizer bottle*
5 *Pressure switch*
6 *Manual CO_2 blocking release valve*
7 *Solenoid valve*
8 *N_2 bottle*
9 *CO_2 bottle set*
10 *Weight switch*
11 *Shutoff valve*
12 *Cubicle heater*

The fire-extinguishing system is activated as follows:

- Automatic activation by the fire detection system
- Manual activation by pressing the push-button installed outside the power train enclosure

Once activated, the fire-extinguishing system releases extinguishing agent into the power train enclosure. The fire-extinguishing system consists of the following main components:

- CO_2 fire cylinder cabinet:

  The CO_2 fire cylinder cabinet houses the extinguishing agent bottles. The CO_2 fire cylinder cabinet is located outside the power train enclosure next to the *package* control room. The CO_2 fire cylinder cabinet includes the following components:
  - CO_2 bottle set (9):
    The CO_2 bottles contain sufficient filling for one extinguishing action.
  - Weight switches:
    The filling levels of the CO_2 bottles are monitored by weight switches (10). An alarm is triggered in case of 10% loss of weight.
  - Pressure switch (5):
    The pressure switch in the main line monitors the CO_2 release during the extinguishing sequence.

- Pilot system:

  The pilot system contains the following components:
  - N_2 pilot bottle (8):
    The N_2 pilot bottle contains pressurized N_2 for opening the CO_2 bottle shutoff valves (11). The filling of the N_2 pilot bottle is monitored by a pressure switch.
  - Solenoid valve (7):
    The monitoring unit opens the solenoid valve (7) of the pilot bottle. The N_2 flow released from the N_2 pilot bottle opens the shutoff valves (11) of the CO_2 bottles.
  - Pressure switch (5):
    The pressure switch verifies that the release of the extinguishing agent was successful.
  - Manual CO_2 blocking release valve (6):
    For maintenance purpose, in case access to the power train enclosure is necessary, the pilot system can be isolated and the CO_2 release can be blocked by closing the manual CO_2 blocking release valve.
  - Valve position monitoring:
    The position of the manual CO_2 blocking release valve is monitored by position switches (ZSO, ZSC).

- Piping:

  - Odorizer (4):
    An odorizer bottle is connected to the CO_2 piping for odorizing the odorless CO_2.
  - Piping:
    The distribution piping is located inside the power train enclosure.
  - Spray nozzles (2):
    The spray nozzles distribute the extinguishing agent in the power train enclosure

- CO_2 system cubicle:

  - Cubicle:
    The CO_2 bottle system is installed in a cubicle.
  - Heater:
    In case of installation in cold environment, the bottle cabinet is equipped with a thermostatically controlled heater which is powered by the *package* supply panel.

Fire system operation

When the fire monitoring system detects fire in the power train enclosure, the gas turbine is shut down immediately, the fuel supply is cut off and the ventilation of the power train enclosure is stopped in order to stop the supply of fresh air. Acoustical and visual warnings are activated to warn the operators. Alarms are transmitted to the *HMI*. Once the alarms are triggered, the CO_2 is released with a delay time of typically 30 s in order to allow the personnel to leave the *package* area. After a delay time the power train enclosure dampers are closed. The delay time is necessary to avoid overpressure in the power train enclosure during CO_2 release.

1.12 AIR INLET SYSTEM

AIR INLET SYSTEM
The gas turbine package major components are installed on a heavy-steel baseframe, also referred to throughout this document as the "skid". The skid is a structural steel assembly with beam sections and cross members welded together to form a rigid foundation. Machined mounting surfaces on the skid facilitate major component alignment. Drip pans are welded within the base to collect any potential liquid spills. Main functions of the air filtration system:

- Reducing airborne contaminants entering the gas turbine and the power train enclosure
- Attenuating noise
- The air filtration system is divided into the following sections:
- Combustion air system
- Ventilation air system
- Oil to air cooling module

In order to meet the required noise levels in the *package* surrounding area, the noise produced by the turbine, the gearbox, the generator and the fans, is attenuated by the power train enclosure and by the air filtration system.
The standard air filtration system is designed for **outdoor installation**.
The air filtration system consists of the following components:
→Housings and ducting:

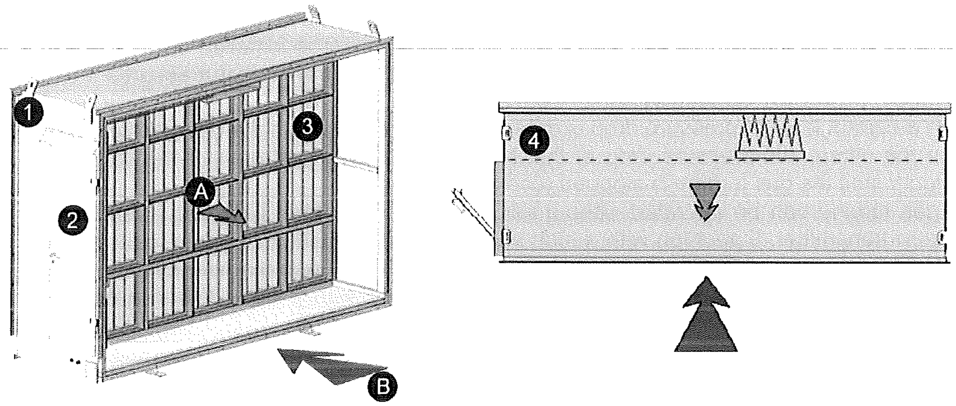
- Completely welded filter housings of painted carbon steel (separate filter housings for ventilation air and combustion air): The filter housings prevent air from entering the system without passing through the filter elements. The easy installable filter housings are compact structures which are bolted to the top of the power train enclosure and supported from the ground. Joints are sealed air-tight with adhesive neoprene strips.
- Ducting which connect the filter housings with the roof flanges of the power train enclosure. The ventilation air is discharged from the power train enclosure via an outlet duct mounted on the enclosure roof. This outlet duct directs the warm air out of the *package* backend away from the inlet systems.

→Combustion air system with filtering modules in the combustion air inlet
→Ventilation air system with filtering modules in the ventilation air inlet
→Silencers in the combustion air inlet and in the ventilation air inlet and outlet. The silencers reduce the sound level. All air inlets and outlets (combustion and ventilation) contain silencers. The silencers contain baffles made of perforated steel sheets and sound absorbent material.
→Access equipment:

- Maintenance platforms with handrails for easy and secure access to the components of the air filtration system
- Ladders from ground level to the enclosure roof and from the enclosure roof to the maintenance platforms

Combustion Air System
The combustion air inlet duct channels air into the gas turbine. Air at ground level can be contaminated with various pollutants (dust, dirt, sand, salts, factory discharge dusts, oil vapors). Contaminants which pass through the gas turbine can have severe impacts on performance, reliability and durability of the components. The combustion air filtration system cleans the inlet air in order to maintain the intended turbine performance and lifetime.
The combustion air is drawn through the filtration module and through the silencer. The silencer consists of several baffles which reduce the noise. A fabric expansion compensator is installed between the air ducting and the gas turbine inlet plenum. The expansion compensator absorbs the movement between the gas turbine and the air duct. The compensator also prevents the transmission of noise-generating vibrations from the gas turbine to the air filtration system.

Modular filtration systems of the combustion air system
Two-stage modular filtration sytem
The two-stage modular filtration system is an assembly of two one-stage modules. Each module contains all the filters for a particular stage.



Standard module of the one-stage modular filtration system for combustion air

Module structure (perspective view)
Maintenance door (installation side is defined during projecting phase)
V-type cassette filters or bag-type pre-filters
Module structure (top view)
A Green arrows: Filter removal direction
B Blue arrows = Air flow direction

The first module has a weather hood which protects the filtration system from penetrating rainwater. A bird screen is also part of this module. The first module contains bag-type pre-filter elements. These filter elements remove larger contaminants from the air and allow the second stage filter to work more efficiently.
The second module contains the main filter elements. These high-efficient V-type cassette filters are specifically designed for usage in gas turbine air filtration systems.
Each module has access doors for easy maintenance of the filters. In the modular filtration system all filters are mounted vertically.

Prefilter filtration class	G4 (according to EN 779)
Prefilter type	Bag-type
Prefilter material	Synthetic
Main filter filtration class	F8 (according to EN 779)
Main filter type	Compact cassette (V-type)
Main filter material	Polyester
Number of filters per stage	24
Filter element dimensions	Universal size (592 x 592 mm)
Filter element nominal flow rate	4250 m^3/h
Filter element operating flow rate	2708 m^3/h
Material of the filter frames	Stainless steel

Characteristics of the combustion air modular filtration system

The lifetime of the filters largely depends on the dust load of the air in the area of operation and on the atmospheric conditions. Ladders allow access to the filtration system. As an option, a manual or motorized hoist for lifting the filters from the ground level to the filtration system level can be delivered. The hoist can be used for combustion filter and ventilation filter replacement.

Modular filter instrumentation

In the combustion air circuit a differential pressure transmitter is installed on each filtration stage to measure its pressure drop. An additional differential pressure transmitter measures the total pressure drop of the turbine air filtration system.
When a certain level of pressure drop is detected an alarm requests the operator to change the filters. When the differential pressure drop of the last filtration stage upstream of the compressor exceeds the upper limit the gas turbine is stopped (cooldown alarm).
The gas turbine can be operated without risk up to the first alarm limit measured by the differential pressure transmitter. Operation with a high pressure drop in the filter system leads to reduced power and lower efficiency of the gas turbine. When the pressure drop in the filter system is high, the filters must be changed or cleaned. Every module is equipped with a door. When a door is opened for maintenance, a limit switch activates a warning signal on the *HMI*.

Ventilation air system

The ventilation air system channels air into and out of the power train enclosure. The ventilation air filtration system cleans the air entering the enclosure through its roof. It is necessary to clean this air to maintain a certain level of protection of the equipment within the power train enclosure. The gas turbine produces a big amount of heat. Much of the heat is dissipated into the power train enclosure which contains temperature-sensitive equipment (devices, electrical junction boxes). The ventilation air system is used for the following:

- Keeping the temperature in the power train enclosure within the permissible operating limits of the equipment.
- Purging the power train enclosure prior to energizing the electrical system before a gas turbine start.
- Guaranteeing that an explosive area is not generated inside the power train enclosure during operation.

Electric motor driven fans on the inlet and on the outlet ducts of the power train enclosure draw the ventilation air through the system in the following order: filtration module, air intake ducting, silencer, power train enclosure, silencer, outlet air ducting
The power train enclosure is equipped with instrument air driven enclosure dampers to seal the power train enclosure in case of CO_2 release.

Modular ventilation air systems

One-stage modular ventilation air system

The one-stage modular ventilation filtration system has a weather hood which protects the filtration system from penetrating rainwater. A bird screen is also part of this module. The module contains bag-type filter elements. These filter elements clean the ventilation air. The module has access doors for easy maintenance of the filters.

Filtration class	G4 (according to EN 779)
Filter type	Bag-type
Filter material	Synthetic
Number of filters per stage	12
Filter element dimensions	Universal size (592 x 592 mm)
Filter element nominal flow rate	4250 m^3/h
Filter element operating flow rate	4167 m^3/h

Modular filter instrumentation

In the ventilation air circuit a differential pressure transmitter is installed to measure the pressure drop across each filtration stage. When a certain level of pressure drop is detected, an alarm requests the operator to change the filters. Every module is equipped with a door.

1.12 ACCESSORY EQUIPMENT

LOW VOLTAGE PANEL

The 400 V AC panels have to be installed in the client electrical room. Two separate external connections (supplied by customer) feed the two three-phase 400 V AC panels:

- Supply panel
- Starting panel

The external distribution system must be protected by a fuse or circuit breaker. The electrical system shall be TN-S, 5 wires (3-phase, neutral and PE). All cables between the panels and the turbine have to be laid at site. The calculated maximum distance between the package and the panelboards is 10m. Cables are included in the scope and will be supplied loose.

SUPPLY PANEL

The supply panel supplies power to the 400 V AC *package* components, except to the start-up motor that is directly fed by the starting panel. The supply panel is typically installed in client's electrical room: connection from supply panel to package used is specified in Scope of Supply document.
In the supply panel the power is distributed via distribution feeders. The distribution bus-bar in the supply panel powers the following 400 V AC consumers:

- Liquid fuel pump (if applicable)
- Lube oil cooler fans (if applicable)
- Water purge pump (if applicable)
- Enclosure ventilation fans
- Enclosure heaters (if applicable)
- Lube oil heater/heaters
- Lube oil pre/post pump
- Socket to feed compressor water washing pump
- Voltage control
- Internal-auxiliary transformer 400 V/230 V AC

230 V AC supply
The 230 V AC auxiliary distribution powers the following components:

- Battery charger 120 V DC
- *Package* control room heating (if applicable)
- Fire monitoring panel
- Starting panel internal supply
- Generator heater
- CO_2 bottle cubicle heater (if applicable)
- Spare connectors
- Sockets and lighting for control panels and power train enclosure

BATTERY CHARGER SYSTEM AND BATTERIES

The DC supply system ensures a continuous non-interruptible power supply of 120 V DC for the entire turbine *package*.
Main components of the DC supply system:

- Battery charger
- Batteries
- Distribution system

The DC supply system supplies a continuous non-interruptible power for the following components:

- Lube oil emergency pump
- Main control processors
- Flex I/O modules
- Vibration monitoring system
- *CGCM*
- Safety relay chain
- Generator and grid decoupling protections
- Display systems (e.g., local *HMI*)
- Main gas valve
- Pilot gas valve (if applicable)
- *IGV* actuator
- *Bleed* valve actuator
- Ignition coil
- Synchronization devices
- Modem

DC battery charger

The battery charger, the battery and the loads are connected in parallel. This way the battery can be charged and the DC loads are supplied at the same time.
If supply voltage is present, the battery charger provides the current and keeps the battery fully charged. The battery can supply additional current if load exceeds the nominal current of the battery charger. In the event of a power supply failure, the batteries take over the power supply without interruption.
The battery charger is equipped with a controller and a plug-and-play modular rectifier. The regulation is carried out automatically with voltage compensation for the battery temperature.
The device is equipped with an input switch and a battery under-voltage relay.

DC batteries

The batteries guarantees a stable power supply for the *package* components in the event of a failure of the battery charger (e.g., as a result of a mains power failure).
The battery voltage is monitored by the main controller and can be read on the *HMI* monitor.

DC distribution system

The DC distribution system distributes the power to different panels. Each output is provided with an MCB (Miniature Circuit Breaker) and an auxiliary contact which triggers an alarm signal in case the MCB opens.

<u>STARTING PANEL</u>

The starting panel includes a variable frequency drive (VFD) which powers the squirrel cage induction motor. The three-phase 400 V AC power supply required for the starting system is fed by the external customer distribution system. A dedicated feeder line has to be installed. Inside the starting panel a circuit breaker is installed for maintenance purposes. The auxiliary DC and 230 V AC power supplies are fed by the adjacent supply panel.
The starting panel is installed in in the client electrical room. The starting panel includes filters and the circuit breaker.
The circuit breaker is controlled by the control system. The control system closes and opens the circuit breaker, turning the power supply on and off.
The starting panel is composed of the following main components:

- Inlet power supply with a circuit breaker
- Inlet EMC filters
- Variable frequency drive (VFD)

Variable frequency drive (VFD)
The variable frequency drive changes the input AC voltage into constant DC voltage. An inverter IGBT (insulated gate bipolar transistor) transforms the DC current into a three-phase voltage with variable frequency. This voltage powers the starting motor. The starting motor turns the turbine at the speed required by the ongoing sequences:

- Acceleration to crank speed
- Crank speed
- Acceleration to starter dropout
- Slow roll speed (if applicable)

Other circuits protect the converter and the motor against overload and faults.
The VFD is controlled by the main controller via ControlNet in open loop operation. All the parameters and configuration data are part of the control logic and are transmitted to the VFD via ControlNet.

EMC Filter
The converter is a non-linear component in the electric circuit. Therefore, the current is not sinusoidal and contains harmonic components. The harmonic currents cause distortion in the line voltage and interference. The installed three-phase EMC filter reduces the high frequency perturbation. To attenuate the voltage distortions on the main line the customer power supply must be adequately sized for the required power and distortion characteristics.

ELECTRICAL CABLES

All electrical cables inside the power train enclosure are self-extinguishing in case of fire. The cables do not produce hazardous gases or smoke.
All cables between the power supply panel, the starting panel, the starting system and the electrical consumers in the *package* are foreseen for a maximum length of 10 meters between the package the panelboard installed in the client electrical room.

GAS TURBINE CLEANING SYSTEM

During normal operation of the gas turbine, foreign material on the gas turbine compressor blading may be built up. Substances (dust, hydrocarbon vapors, oil, soot etc.) become entrained in the inlet air. The substances deposit on the rotating and on the stationary compressor blading, predominantly on the first few rows. This contamination decreases the compressor flow and consequently the compressor discharge pressure. This results in a decrease of the gas turbine power output and efficiency. A contaminated compressor may cause a difficult startup and performance deterioration.
Compressor washing removes the deposits from the compressor blades and improves the turbine performance. The washing medium is drawn in through the compressor inlet. The cleaning medium must reach all parts of the compressor in order to clean the rotor and the stator blades.
For best results the compressor is washed with water-based detergent solutions (concentration of 20%–25%). The cleaning agent is formulated for not leaving a residue on the blading and not causing chemical attack of gas turbine components. The quality of washing water, detergents and other additives in the washing media must comply with Solar specifications ES 9-98 and ES-9-62. Detergents are excluded from the scope of supply and can be offered optionally.

***On-crank* washing system**
On-crank washing of the compressor is performed while the starting system drives the compressor (*crank* mode). Washing in *crank* mode is usually more effective than *on-line* washing.
Therefore, *on-crank* washing should be applied when the contaminants cannot be removed by *on-line* washing.

The compressor contamination can be detected by observing the change in compressor discharge pressure. In general, the following observations indicate that the compressor is probably contaminated and washing is required:
The compressor shell pressure decreases by 0.15 bar at rated speed and load
The load capacity decreases by 3% to 5% and the combustor discharge pressure for given ambient conditions decreases correspondingly.
The *on-crank* compressor washing system is installed on a skid and consists of the following components:

- 120 l portable plastic tank
- Portable water pump
- Manual flow control valve
- Portable hand lance

The starter motor drives the compressor during the *on-crank* washing sequence. The movable tank and the water pump are connected to the portable hand lance. Water is sprayed into the compressor inlet. When the washing sequence is finished, the operator has to start the rinse sequence.
The portable washing skid is typically powered by the gas turbine *package* supply panel.
Required water quantity per cycle in litre (wash/rinse): 50:100

On-line washing system
In very dusty atmospheres or above-average air pollution, the compressor washing procedure must be carried out more frequently in order to maintain the output power of the gas turbine generator set.
During the *crank* sequence the normal washing procedure results in a turbine standstill of a few hours. Uninterrupted operation is possible by *on-line* washing.
On-line washing is based on the same principle as the *on-crank* procedure with the use of a water/detergent solution. *On-line* washing is performed by the same portable system that is connected at the skid edge to the flange of the internal distribution piping. The internal distribution piping provides water to the set of nozzles located in the compressor inlet plenum.

The following conditions for *on-line* washing are applied:

- Operation in utility parallel mode
- Gas turbine operation range: 0–100% load
- Ambient temperature: ≥4°C

On-line compressor washing is dangerous particularly at low temperatures. At low temperatures the water vapour contained in the air condensates and the resulting water droplet may freeze and build ice on the compressor blades. The ice can cause dangerous unbalancing which may lead to damage of the compressor itself.
Required water quantity per cycle in litre (wash/rinse): 50:100