7. Turbine-Generator

7.1 Gas Turbine Systems

The MS7001(EA) gas turbine has a single shaft, bolted rotor with the generator connected to the gas turbine at the turbine or “hot” end. Major components of the MS7001(EA) are described below.

7.1.1 Compressor Section

The axial flow compressor has 17 stages with modulating inlet guide vanes and provides a 12.6 to 1 pressure ratio. Interstage air extraction is used for cooling and sealing air for turbine nozzles, wheelspaces, and bearings, and for surge control during start up.

7.1.1.1 Compressor Rotor

The compressor rotor consists of a forward stub shaft with the 1st stage rotor blades, a fifteen blade and wheel assembly for stages 2 to 16, and an aft stub shaft with the stage 17 rotor blades. Rotor blades are inserted into broached slots located around the periphery of each wheel and wheel portion of the stub shaft. The rotor assembly is held together by fifteen axial bolts around the bolting circle. The wheels are positioned radially by a rabbeted fit near the center of the discs. Transmission of torque is accomplished by face friction at the bolting flange.

Selective positioning of the wheels is made during assembly to reduce the rotor balance correction. The compressor rotor is dynamically balanced after assembly and again after the compressor and turbine rotors are mated. They are precision balanced prior to assembly into the stator.

7.1.1.2 Compressor Blade Design

The airfoil shaped compressor rotor blades are designed to compress air efficiently at high blade tip velocities. These forged blades are attached to their wheels by dovetail connections. The dovetail is accurately machined to maintain each blade in the desired location on the wheel.

The blades in the first two stages of the compressor are Carpenter 450, a martensitic stainless steel with superior strength and corrosion resistance, which does not require a coating.
Stator blades utilize square bases for mounting in the casing slots. Blade stages zero through four are mounted by axial dovetails into blade ring segments. The blade ring segments are inserted into circumferential grooves in the casing and are secured with locking rings.

7.1.1.3 Compressor Stator

The casing is composed of three major subassemblies: the inlet casing, the compressor casing, and the compressor discharge casing. These components in conjunction with the turbine shell, exhaust frame/diffuser, and combustion wrapper form the compressor stator.

The casing bore is maintained to close tolerances with respect to the rotor blade tips for maximum aerodynamic efficiency. Borescope ports are located throughout the machine for component inspection. In addition all casings are horizontally split for ease of handling and maintenance.

7.1.1.3.1 Inlet Casing

The primary function of the inlet casing, located at the forward end of the gas turbine, is to direct the air uniformly from the inlet plenum into the compressor. The inlet casing also supports the number 1 radial bearing and thrust bearing assembly and the variable inlet guide vanes, located at the aft end.

7.1.1.3.2 Compressor Casing

The compressor casing contains compressor stages 1 through 12. Extraction ports in the casing allow bleeds to the exhaust plenum during start-up and extraction of air to cool the second and third stage nozzles.

7.1.1.3.3 Compressor Discharge Casing

The compressor discharge casing contains 13th- through 17th- stage compressor stators and one row of exit guide vanes. It also provides an inner support for the first-stage turbine nozzle assembly and supports the combustion components. Air is extracted from the compressor discharge plenum to cool the stage one nozzle vane, retaining ring, and shrouds.

The compressor discharge casing consists of two cylinders connected by radial struts. The outer cylinder is a continuation of the compressor casing and the inner cylinder surrounds the compressor aft stub shaft. A diffuser is formed by the tapered annulus between the outer and inner cylinders. The compressor
discharge casing is joined to the combustion wrapper at the flange on its outermost diameter.

7.1.2 Turbine Section

In the three stage turbine section, energy from hot pressurized gas produced by the compressor and combustion section is converted to mechanical energy. The turbine section is comprised of the combustion wrapper, turbine rotor, turbine shell, exhaust frame, exhaust diffuser, nozzles and diaphragms, stationary shrouds, and aft (number 3) bearing assembly.

7.1.2.1 Turbine Rotor

The turbine rotor assembly consists of a forward shaft, three turbine wheels, two turbine spacer wheels, and an aft turbine shaft which includes the number 3 journal bearing. The forward shaft extends from the compressor rotor aft stub shaft flange to the first stage turbine wheel. Each turbine wheel is axially separated from adjacent stage(s) with a spacer wheel. The spacer wheel faces have radial slots for cooling air passages, and the outer surfaces are machined to form labyrinth seals for interstage gas sealing.

Selective positioning of rotor members is performed during assembly to minimize balance corrections of the assembled rotor. Concentricity control is achieved with mating rabbets on the turbine wheels, spacers, and shafts. Turbine rotor components are held in compression by bolts. Rotor torque is accomplished by friction force on the wheel faces due to bolt compression.

The turbine rotor is cooled by air extracted from compressor stage 17. This air is also used to cool the turbine first- and second-stage buckets plus the rotor wheels and spacers.

7.1.2.2 Turbine Bucket Design

The first-stage buckets use forced air convection cooling in which turbulent air flow is forced through integral cast-in serpentine passages and discharged from holes at the tip of the trailing edge of the bucket. Second-stage buckets are cooled via radial holes drilled by a shaped tube electromechanical machining process. Third-stage buckets do not require air cooling.

First-stage buckets are coated for corrosion protection. Second- and third-stage buckets have integral tip shrouds which interlock buckets to provide vibration damping and seal teeth that reduce leakage flow. Turbine buckets are attached to the wheel with fir tree dovetails that fit into matching cutouts at
the rim of the turbine wheel. Bucket vanes are connected to the dovetails by shanks which separate the wheel from the hot gases and thereby reduce the temperature at the dovetail.

The turbine rotor assembly is arranged to allow buckets to be replaced without having to unstack the wheels, spacers and stub shaft assemblies. Similarly, buckets are selectively positioned such that they can be replaced individually or in sets without having to rebalance the wheel assembly.

7.1.2.3 Turbine Stator

The turbine stator is comprised of the combustion wrapper, turbine shell, and the exhaust frame. Like the compressor stator, the turbine stator is horizontally split for ease of handling and maintenance. (The aft diffuser is not split.)

7.1.2.3.1 Combustion Wrapper

The combustion wrapper, located between the compressor discharge casing and the turbine shell, facilitates removal and maintenance of the transition pieces and stage one nozzle.

7.1.2.3.2 Turbine Shell

The turbine shell provides internal support and axial and radial positions of the shrouds and nozzles relative to the turbine buckets. This positioning is critical to gas turbine performance. Borescope ports are provided for inspection of buckets and nozzles.

7.1.2.3.3 Exhaust Frame

The exhaust frame is bolted to the aft flange of the turbine shell and consists of an outer and an inner cylinder interconnected by radial struts. The inner cylinder supports the number 3 bearing. The tapered annulus between the outer and inner cylinders forms the axial exhaust diffuser. Gases from the third stage turbine enter the diffuser where the velocity is reduced by diffusion and pressure is recovered, improving performance.

Cooling of the exhaust frame, number 3 bearing, and diffuser tunnel is accomplished by off-base motor-driven blowers.
7.1.2.4 Turbine Nozzle Design

The turbine section has three stages of nozzles (stationary blades). The first- and second-stage nozzles are cooled by a combination of film cooling (gas path surface), impingement cooling, and convection cooling in the vane and sidewall regions. The third stage is not cooled.

Both the first- and second-stage nozzles consist of 24 segments with two vanes in each. The third stage has 32 segments with two vanes in each. First-stage turbine nozzle segments are contained by a retaining ring which remains centered in the turbine shell. The second- and third-stage nozzle segments are held in position by radial pins from the shell into axial slots in the nozzle outer sidewall.

7.1.2.5 Bearings

The MS7001(EA) gas turbine contains three journal bearings to support the turbine rotor and one dual direction thrust bearing to maintain the rotor-to-stator axial position. The bearings are located in three housings: one at the inlet, one in the discharge casing and one at the center of the exhaust frame. All bearings are pressure lubricated by oil supplied from the main lubrication oil system. The number 1 bearing (journal and thrust) is accessed by removing the top half of the compressor inlet casing, while number 2 is accessed during major overhaul. The number 3 bearing is readily accessible through the tunnel along the centerline of the exhaust diffuser. Bearing protection includes vibration sensors and drain oil temperature thermocouples.

7.1.3 Combustion System

The combustion system uses a reverse flow, multi-chamber (can annular) design in which combustion chambers are arranged around the periphery of the compressor discharge casing. Combustion chambers are connected to adjacent chambers by crossfire tubes as illustrated below.

Each chamber contains fuel nozzles and a combustion liner. Specific chambers also contain spark plugs and flame detectors. Transition pieces connect the combustion liners to the turbine nozzles. Each combustion liner, fuel nozzle, and transition piece may be individually replaced if needed for maintenance.

These major components of the combustion system are described below.
7.1.4 Dry Low NOx (DLN) Combustor

The DLN-1 combustor is a dual stage, multi-mode combustor. The major components of the combustor are arranged to form two stages in the combustor as illustrated below. A venturi assembly separates the two combustion zones. Multiple primary fuel nozzles are located around the circumference of the cap, and provide fuel to the first stage (primary zone) ahead of the venturi. A single secondary nozzle is located along the centerline of the combustor within the centerbody and provides fuel to the secondary zone downstream of the venturi.
The various modes of combustion using the DLN combustor are described below.

7.1.4.1.1 Primary Mode

The primary zone is utilized as a diffusion burning zone for ignition and low load operation.

7.1.4.1.2 Lean-Lean Mode

At a given fuel/air ratio in the combustor, fuel is introduced through the secondary fuel nozzle and flame is established in the secondary zone of the combustor while still maintaining flame in the primary zone. NOx emissions are lowered somewhat in this mode as compared to that of the primary mode.

7.1.4.1.3 Premixed Mode

When the combustor fuel/air ratio is sufficient to support a premixed (low NOx) flame, a transfer sequence occurs. All of the fuel is first directed through the secondary nozzle in order to extinguish the flame in the primary zone. Fuel is then reintroduced through the primary nozzles and the primary zone
becomes a premixing zone. A premixed flame is established in the secondary zone, anchored by the venturi. Flame is prevented from "flashing back" into the primary zone because the venturi accelerates the flow between the primary and secondary zones. The fuel is split between the primary and secondary fuel nozzles to optimize the emissions performance of the combustor. Premixed operation is utilized for mid to full load operation on gas fuel only.

### 7.1.4.2 Combustion Liners

Within each combustion chamber is a cylindrical liner or a liner made up of two cylindrical sections with a conical transition section between the two. Discharge air from the axial-flow compressor flows forward along the outside of the combustion liner, as guided by the flow sleeve. Liner cooling is achieved via film cooling with annular slots distributed along the length of the combustion liner.

Thermal barrier coatings are applied to the inner walls of the combustion liners for longer inspection intervals.

Air enters the combustor through a variety of holes in the liner and cap and swirlers which are typically a part of the fuel nozzles. Depending on the injection location, air is utilized for the actual combustion process, for cooling, or as dilution to tailor the exhaust gas profile.

### 7.1.4.3 Transition Pieces

Transition pieces direct hot gases from the liners to the turbine nozzles. The transition pieces have a circular inlet for the combustion liners and transition to an annular segment at the exit for the turbine nozzles. Seals are utilized at both connection locations to control leakage flows.

### 7.1.4.4 Spark Plugs

Combustion is initiated by discharge from two electrode spark plugs each in a different combustion chamber. At the time of firing, a spark at one or both of these plugs ignites a chamber.

### 7.1.4.5 Crossfire Tubes

The combustion chambers are interconnected by means of crossfire tubes. These tubes enable flame from the fired chambers to propagate to the unfired chambers.
7.1.4.6 Ultraviolet Flame Detectors

The control system continuously monitors for presence or absence of flame using flame detectors installed in four combustors.

7.1.5 Fuel System

7.1.5.1 Gas Fuel System

The gas fuel system modulates the gas fuel flow to the turbine. Proper operation of the gas fuel system requires that the gas be supplied to the gas fuel control system at the proper pressure and temperature. The pressure is required to maintain proper flow control. The fuel gas temperature must ensure that the required hydrocarbon superheat is maintained. For discussion of fuel gas supply requirements in the Reference Documents - Process Specification Fuel Gases for Combustion in Heavy-Duty Gas Turbines. Major system components, as shown in the illustration which follows, are described below.
7.1.5.1.1 **Strainer**

A duplex strainer is used to remove impurities from the gas. A pressure switch which monitors the differential across the strainers will signal an alarm through the gas turbine control system when the pressure drop across the strainer indicates cleaning is required.

7.1.5.1.2 **Fuel Gas Stop/Speed Ratio and Control Valves**

The fuel gas stop/speed ratio and control valves allow fuel flow when the turbine starts and runs, control the fuel flow, and provide protective fuel isolation when the turbine is shutdown. In systems with multiple control valve configuration, the control valves also maintain the fuel split among the fuel nozzles.

7.1.5.1.3 **Vent Valve**

When the gas fuel system is shut off, both the stop valve and the control valve(s) are shut. A vent valve is opened between the stop valve and the control valve(s). The vent valve permits the fuel gas to exit to the atmosphere when the turbine is shutdown or switched to an alternate fuel.

7.1.5.1.4 **Fuel Manifold and Nozzles**

The fuel manifold connects the gas fuel nozzles which distribute the gas fuel into the combustion chambers. For staged combustion systems, more than one manifold is used.

7.1.5.1.5 **Piping**

The gas fuel system uses stainless steel fuel gas piping with carbon steel flanges.

7.1.5.1.6 **Liquid Fuel Filter**

Duplex low pressure fuel oil filters remove particles from the fuel before it reaches the main fuel oil pump. Pressure switches monitor the differential across each filter will signal an alarm through the gas turbine control system when transfer or changeout is required.
7.1.6 Lubricating and Hydraulic Systems

The lubricating provisions for the turbine, generator and accessory gear are incorporated into a common lubrication system. Oil is taken from this system, pumped to a higher pressure, and used in the hydraulic system for all hydraulic oil control system components. The lubrication system includes oil pumps, coolers, filters, instrumentation and control devices, a mist elimination device and an oil reservoir as shown in the system illustration below. Following the illustration is a brief description of the major system components.
Lube Oil System
MS7001(EA) with Air Cooled Generator
(Typical)
7.1.6.1 Pumps

The lubrication system relies on several pumps to distribute oil from the oil reservoir to the systems which need lubrication. Similarly, redundant pumps are used to distribute high pressure oil to all hydraulic oil control system components. These and other oil pumps are listed below.

- **Lubrication oil pumps**
  - The main lubrication oil gear pump is shaft-driven from the accessory gear.
  - A full flow ac motor-driven auxiliary lubrication oil centrifugal pump is provided as backup to the main pump.
  - A partial flow, dc motor-driven, emergency lubrication oil centrifugal pump is included as a back-up to the main and auxiliary pumps.

- **Hydraulic pumps**
  - The main hydraulic variable displacement piston pump is shaft-driven from the accessory gear.
  - An auxiliary ac motor-driven hydraulic pump is provided as backup to the main hydraulic pump.

7.1.6.2 Coolers

The oil is cooled by dual lubrication oil-to-coolant finned 90-10 Cu-Ni tube heat exchangers with transfer valve. The coolers are U-tube and shell configuration with pull out, removable tube bundles. The coolers have an ASME code stamp.

7.1.6.3 Filters

Dual, full flow filters with transfer valves clean the oil used for lubrication. Each filter includes a differential pressure transmitter to signal an alarm through the gas turbine control system when cleaning is required. A replaceable cartridge is utilized for easy maintenance. Filters have an ASME code stamp.

Dual filters with transfer valves clean the oil for the hydraulic system. Each filter includes a differential pressure transmitter to signal an alarm through the gas turbine control system when cleaning is required. A replaceable cartridge is utilized for easy maintenance. Filters have an ASME code stamp.
7.1.6.4 Mist Elimination

Lubrication oil mist particles are entrained in the system vent lines by sealing air returns of the gas turbine lubricating system. In order to remove the particles, a lube vent demister is used as an air-exhaust filtration unit. The demister filters the mist particles and vents the air to the atmosphere while draining any collected oil back to the oil reservoir.

The lube vent demister assembly consists of a holding tank with filter elements, motor-driven blower, and relief valve. One assembly is provided for the vent line from the lubrication oil reservoir.

7.1.6.5 Oil Reservoir

The oil reservoir has a nominal capacity of 2500 gallons (9463 liters) and is mounted within the accessory base. It is equipped with lubrication oil level switches to indicate full, empty, high level alarm, low level alarm, and low level trip. In addition the following are mounted on the reservoir:

- Oil tank thermocouples
- Oil heaters
- Oil filling filter
- Oil reservoir drains

7.1.7 Inlet System

7.1.7.1 General

Gas turbine performance and reliability are a function of the quality and cleanliness of the inlet air entering the turbine. Therefore, for most efficient operation, it is necessary to treat the ambient air entering the turbine and filter out contaminants. It is the function of the air inlet system with its specially designed equipment and ducting to modify the quality of the air under various temperature, humidity, and contamination situations and make it more suitable for use. The inlet system consists of the equipment and materials defined in the Scope of Supply chapter of this proposal. The following paragraphs provide a brief description of the major components of the inlet system.
7.1.7.2 Inlet Filtration

7.1.7.2.1 Inlet Filter Compartment

The self-cleaning inlet filter compartment utilizes high efficiency media filters which are automatically cleaned of accumulated dust, thereby maintaining the inlet pressure drop below a preset upper limit. This design provides single-stage high efficiency filtration for prolonged periods without frequent replacements. Appropriate filter media is provided based on the site specific environmental conditions.

Dust-laden ambient air flows at a very low velocity into filter modules which are grouped around a clean-air plenum. The filter elements are pleated to provide an extended surface. The air, after being filtered, passes through venturis to the clean air plenum and into the inlet ductwork.

As the outside of the filter elements become laden with dust, increasing differential pressure is sensed by a pressure switch in the plenum. When the setpoint is reached, a cleaning cycle is initiated. The elements are cleaned in a specific order, controlled by an automatic sequencer.

The sequencer operates a series of solenoid-operated valves, each of which controls the cleaning of a small number of filters. Each valve releases a brief pulse of high pressure air into a blowpipe which has orifices located just above the filters. This pulse shocks the filters and causes a momentary reverse flow, disturbing the filter cake. Accumulated dust breaks loose, falls, and disperses. The cleaning cycle continues until enough dust is removed for the compartment pressure drop to reach the lower setpoint. The design of the sequencer is such that only a few of the many filter elements are cleaned at the same time. As a consequence, the airflow to the gas turbine is not significantly disturbed by the cleaning process.

The filter elements are contained within a fabricated steel enclosure which has been specially designed for proper air flow management and weather protection.

Self-cleaning filters require a source of clean air for pulse-cleaning. Compressor discharge air is used as the pulse air source for filter cleaning. It is reduced in pressure, cooled and dried. This air is already clean because it has been filtered by the gas turbine’s inlet air filter. When compressor discharge air is used to pulse the filter, cleaning is possible only when the gas turbine is running.
7.1.7.3 Inlet System Instrumentation

7.1.7.3.1 Inlet System Differential Pressure Indicator

Standard pressure drop indicator (gauge) displays the pressure differential across the inlet filters in inches of water.

7.1.7.3.2 Inlet System Differential Pressure Alarm

When the pressure differential across the inlet filters reaches a preset value, an alarm is initiated. This alarm may signify a need to change the filter elements.

7.1.8 Exhaust System

The side and up exhaust system arrangement includes the exhaust plenum, expansion joint, ducting, silencing and stack. After exiting the last turbine stage, the exhaust gases enter an exhaust diffuser section which terminates in a series of turning vanes directing the gases from an axial to a radial direction into the plenum. The gas then flows to the side, into the exhaust ducting, and into the stack. The exhaust gas then exits to atmosphere.

7.1.9 Couplings

7.1.9.1 Accessory Drive System

The auxiliary components driven directly by the accessory gear are:

- Lubricating oil pump
- Hydraulic oil pump

7.1.10 Gas Turbine Packaging

7.1.10.1 Enclosures

Gas turbine enclosures consist of several connected sections forming an all weather protective housing which may be structurally attached to each compartment base or mounted on an off-base foundation. Enclosures provide thermal insulation, acoustical attenuation, and fire extinguishing media containment. For optimum performance of installed equipment, compartments include the following as needed:
• Ventilation
• Cooling

In addition, enclosures are designed to allow access to equipment for routine inspections and maintenance.

7.1.10.2 Acoustics

Measuring procedures will be in accordance with ASME PTC 36 (near field) and/or ANSI B133.8 (far field).

7.1.10.3 Painting

The exteriors of all compartments and other equipment are painted with two coats of alkyd primer prior to shipment. The exterior surfaces of the inlet compartment and inlet and exhaust duct are painted with one coat of inorganic zinc primer.

Interiors of all compartments are painted as well with the turbine compartment interior receiving high-temperature paint. The interior and exterior of the inlet system is painted with zinc rich paint.

7.1.10.4 Lighting

AC lighting on automatic circuit is provided in the accessory compartment. When ac power is not available, a dc battery-operated circuit supplies a lower level of light automatically.

Florescent lighting is also provided in the PEECC.

7.1.10.5 Wiring

The gas turbine electrical interconnection system includes on-base wiring, terminal boards, junction boxes, etc. as well as compartment interconnecting cables. Junction boxes are selected to meet the environmental requirement of the Customer but are, in general, of steel or cast aluminum construction. Terminal boards within junction boxes are of the heavy duty industrial type selected for the particular environment in which the junction box is located. On-base gas turbine wire termination uses spring tongue crimped type terminals. Generator wire termination are ring type. Control panel wiring is General Electric type SIS Vulkene insulated switchboard wire, AWG #14-41 Strand SI-57275. Ribbon cables are used as appropriate.
7.1.11 Fire Protection System

Fixed temperature sensing fire detectors are provided in the gas turbine and accessory compartments, and #3 bearing tunnel. The detectors provide signals to actuate the low pressure carbon dioxide (CO2) automatic multi-zone fire protection system. Nozzles in these compartments direct the CO2 to the compartments at a concentration sufficient for extinguishing flame. This concentration is maintained by gradual addition of CO2 for an extended period.

The fire protection system is capable of achieving a non-combustible atmosphere in less than one minute, which meets the requirements of the United States National Fire Protection Association (NFPA) #12.

The supply system is composed of a low pressure CO2 tank with refrigeration system mounted off base, a manifold and a release mechanism. Initiation of the system will trip the unit, provide an alarm on the annunciator, turn-off ventilation fans and close ventilation openings.

7.1.12 Cleaning Systems

7.1.12.1 On-Line and Off-Line Compressor Water Wash

Compressor water wash is used to remove fouling deposits which accumulate on compressor blades and to restore unit performance. Deposits such as dirt, oil mist, industrial or other atmospheric contaminants from the surrounding site environment, reduce air flow, lower compressor efficiency, and lower compressor pressure ratio, which reduce thermal efficiency and output of the unit. Compressor cleaning removes these deposits to restore performance and slows the progress of corrosion in the process, thereby increasing blade wheel life.

On–line cleaning is the process of injecting water into the compressor while running at full speed and some percentage of load. Off–line cleaning is the process of injecting cleaning solution into the compressor while it is being turned at cranking speed. The advantage of on–line cleaning is that washing can be done without having to shut down the machine. On–line washing, however, is not as effective as off–line washing; therefore on–line washing is used to supplement off–line washing, not replace it.

The on–base compressor washing features are described and illustrated below.
7.1.12.1.1 On–Line Manifold and Nozzles

The on–line washing components consist of two piping manifolds, spray nozzles (one in the forward bellmouth and one in the aft bellmouth), and an on/off control valve which is also controlled by the turbine control panel. The turbine control system is equipped with software to perform an automatic on–line wash by simply initiating the wash from the turbine control panel.

7.1.12.1.2 Off–Line Manifold and Nozzles

Off-line washing is a manual operation because of the large number of manual valves on the turbine which need to be manipulated in order to perform an off-line wash. During off-line washing, cleaning solution (water and/or detergent) is injected into the compressor while it is being turned at crank speed. The cleaning solution is sprayed into the compressor inlet, covering the entire circumference. This should continue until the runoff is free of contaminants.

7.1.12.1.3 Water Wash Skid

The off–base water wash skid is used for injecting cleaning solution into the compressor for off–line cleaning. The skid contains a water pump, a detergent storage tank, piping, and a venturi eductor capable of delivering solution at the proper flow, pressure and mix ratio.

In addition, the water wash skid is equipped with the following features:
- Water storage tank with freeze protection
- Immersion heaters to heat the water to 180°F (82°C)
- Enclosure for outdoor installation

Typical water wash skid features are shown in the illustration which follows.

### 7.1.13 Cooling Water System

The closed type cooling water system provides pressure regulated and temperature controlled water flow to dissipate heat rejected from the turbine equipment including:

- Lube oil system
- Turbine support legs
- Flame detectors

The system is comprised of on-base accessory module and turbine compartment mounted components and an off-base cooling water module.
7.1.13.1 On-Base Components

Major components and control devices associated with the accessory module and turbine compartment are as follows:

- Water flow regulating valve with capillary temperature sensors (turbine bearing header temperature)
- Turbine support legs when necessary, and flame detectors (located in the turbine compartment)
- Water side interface, i.e., tubes or plates, with lube oil heat exchangers (located in the accessory module)

7.1.13.1.1 Gas Turbine Base

- Turbine support legs and flame detectors

7.1.13.2 Cooling Water Module

The off-base cooling water module is a packaged industrial type sized to accommodate the total water flow and heat rejection requirements of the gas turbine unit, accessories and load equipment. The water module system operates at a positive pressure resulting from the pumping and the recirculation of the system flow water. The module consists of the following major components and control devices:

- Water surge tank with level indicator
- Finned tube air-to-water heat exchanger assemblies
- Motor-driven cooling fans
- Two (2) motor-driven cooling water pumps
- “Y” type water strainer
- Temperature switch

7.1.13.3 System Operation

Cooling water from the surge tank is pumped by the primary cooling water pump to the inlet of the bearing header temperature regulating valve, flame detector bodies, and through control orifices to the turbine support legs. The water supplied to the bearing header temperature regulating valve is then circulated to the inlet of the lube oil heat exchanger(s).
7.1.14 Starting System

7.1.14.1 Electric Motor Start

The starting system uses an ac motor to bring the gas turbine to self-sustaining speed during the starting cycle. Power is transferred to the gas turbine via a hydraulic torque converter. Sequencing is accomplished by the gas turbine controls.

7.1.14.2 Cooldown System

The cooldown system provides uniform cooling of the rotor after shutdown. This is accomplished by furnishing oil from the alternating current motor-driven auxiliary lubrication oil pump to the hydraulic ratchet mounted on the torque converter. The hydraulic ratchet is an electro-hydraulic rotor turning device. Sequencing of the hydraulic ratchet is accomplished by the gas turbine controls with the use of position limit switches with reverse solenoids. The gas turbine is ready to restart, subject to all start permissives being cleared and the ability to re-initiate combustion (approximately 10% rated speed.)

7.1.15 Miscellaneous Parts

As a service to the customer and to facilitate an efficient installation of the gas turbine, GE provides for shipment of miscellaneous parts needed during field installation.

Shipment is in a single weather-tight cargo container. The plywood container, which can be opened from one end, is outfitted with shelves and bins for parts storage. The container comprises what amounts to a “mobile stockroom” and is designed for transport by truck or rail.

Within the container, each part is packed, identified with its own label or tag, and stowed in an assigned bin or shelf. A master inventory list furnished with the container provides the location of each part for ease in locating the item.

An additional box is furnished for the interconnecting piping.

7.2 Generator

The generator compartment has the same general appearance as the turbine compartment, and provides for maintenance and inspection via doors on the sides of the outdoor enclosure.
The inner side panels of the compartment, including the access doors, are lagged to establish minimum sound levels.

The entire generator is mounted on a single fabricated base, which supports the pedestals, the inner and outer frames, and the brush rigging or the exciter.

The generator line leads exit the side of the generator stator frame, with the neutral leads exiting the opposite side. A non-segregated bus duct flange allows for connection to either a generator line accessory compartment (GLAC) or a bus duct run from the generator to a switchgear compartment. The neutral tie is made up in the generator neutral accessory compartment (GNAC), that also houses the neutral grounding equipment and neutral current transformers.

7.2.1 Rotor Design

The rotor is a simple single-piece forging, pedestal mounted, with tilting pad bearings for smooth operation. The retaining ring is nonmagnetic 18 Cr 18 Mn stainless steel for low losses and high stress-corrosion resistance. The rings are shrunk onto the rotor body, thus eliminating any risk of top turn breakage. A snap ring is used to secure the retaining ring to the rotor body which minimizes the stresses in the tip of the retaining ring. An illustration of the rotor is provided below.

Radial-flow fans are mounted on the centering ring at each end of the rotor. The fan is a high efficiency design, and provides cooling air for the stator winding and core. The rotor winding, which is a directly cooled radial flow design, is self-pumping and does not rely on the fan for air flow.
The rotor winding fits in a rectangular slot and is retained by non-magnetic steel, full-length wedges. Where cross slots are required on longer rotors, several wedges are used in each slot. The slot insulation is a Class F rigid epoxy glass design that fits into the bottom of the slot. A class F epoxy glass laminate subslot cover locates the lowest turn of the winding. The turns are separated by epoxy glass insulation strips, and the winding is covered by a high-pressure resin laminate creepage block. Please see the field winding support illustration below.

The rotor slot armor, and all the insulation materials in contact with the winding, are full class F materials and are proven reliable materials through use on other generator designs.

The rotor winding coils are round cornered, with a single braze in each end strap. This significantly reduces the number of parts in each coil and cuts the number of braze joints by a factor of four. This is typical of the type of production simplification which, in turn, leads to improved quality and reliability.
7.2.2 Stator Design

The stator frame is divided into an inner and an outer section, both of which mount on a single base fabrication. The inner frame is a simple structure, designed to support the stator core and winding, while providing some guidance to the air flow in the machine. Mounted rigidly in the inner frame is the stator core made from grain-oriented silicon steel for low loss and high permeability. Reliability of core insulation is improved by applying a thermosetting varnish to the punchings. Isolation of the core vibration from the remainder of the structure is accomplished through the use of flexible pads between the feet on the inner frame and the base structure. The combined core and inner frame are designed to have a 4-nodal natural frequency well removed from 100 Hz or 120 Hz.

The outer frame is a simple fabricated enclosure, which supports the air inlets and silencers and acts as an air guide to complete the ventilation paths. The outer frame further acts as a soundproof enclosure to keep noise levels low. Since the rotor is pedestal mounted, the end shields are simple structures. As with the inner frame, the outer frame is designed to be free of resonances below 80 Hz.

The bars are secured in the slots with fillers and top-ripple springs to restrain the bars radially, and with side-ripple springs to increase friction between the bar and the slot wall. The side-ripple springs are also conducting to ensure proper grounding of the bar surface. Electrical connection to the top and bottom bars are made via a brazed connection with solid copper blocks to provide assurance that the connections will not loosen or overheat. Please refer to the stator slot section illustration below.
One design improvement made in recent years changed the manner in which the series connection between top and bottom bars is made. Until recently this was accomplished by brazing individual strands together and then solidifying the package with an epoxy. The improved system is to braze all the strands together in a solid block and then to braze top and bottom bars together with solid copper plates. This provides a solid electrical connection and a rugged mechanical joint.

The end winding support system is the proven approach used on conventionally cooled stators on all sizes built by GE. The complete end winding structure design has been vibration tested to ensure freedom from critical resonances.

7.2.3 Open-Ventilated Cooling

Cooling air for the generator compartment is drawn through the roof of the generator enclosure by radial-flow fans on each end of the generator rotor assembly. Ventilating air is drawn through a cartridge type filtration and silencing into the generator. The rotor is cooled externally by the air flowing along the gap over the rotor surface. The rotor windings are cooled by air
which passes under the rotor end windings, into the rotor subslots and radially outward to the gap, through holes in the field coils and slot wedges. Since the rotor is self pumping, it does not rely on the fan for air flow. The stator cooling air is forced by the fans into the air gap and also around behind the stator core. The air exits through silencing and air duct work to the outside.

7.2.4 Lubrication System

Lubrication for the generator bearings is supplied from the turbine lubrication system. Generator bearing oil feed and drain interconnecting lines are provided, and have a flanged connection at the turbine end of the generator package for connection to the turbine package.

7.2.5 Instrumentation

Pressure switches are provided in the lube oil feed piping at the aft end of the generator for monitoring oil pressure.

Six resistance-type temperature detectors, two per phase, are installed in the generator stator winding, with leads brought out to the junction box.

Two RTDs are installed in the hot gas path of the cooling air.

Two RTDs are installed in the cold gas path of the cooling air.

Three velocity-type vibration detectors are provided on the pedestal bearing caps, one at the turbine end and two at the collector end.

Proximity probe assemblies are supplied on each bearing pedestal.

7.2.6 Switchgear Compartment

The switchgear compartment is a walk-in weather-protected enclosure made of carbon steel with a steel frame around the perimeter designed to support the enclosure. The walls, doors, floor, and ceiling are made of steel panels which are bolted together. The exterior is painted beige with rust inhibited primer and the interior is painted gray.

The switchgear is convection or forced-air cooled. In addition, electric space heaters are provided for moisture control.
The switchgear compartment is divided into two sections, a medium voltage section containing the energized medium voltage electrical conductors and a low voltage maintenance walk–in section as described below.

7.2.6.1 Medium Voltage Section

The generator power goes straight through the medium voltage section with no phase rotation change. The bus runs from the generator incoming non–segregated phase flange connection through the generator breaker (52G) to the customer line connection. Access to this compartment is through bolted access doors. All current carrying conductors are copper.

The medium voltage section contains the following equipment:

- Medium voltage flange connecting to the generator non–segregated phase bus (500 lb capacity)
- Potential transformers (VT1, VT2)
- Current transformers (CTs)
- Provision for auxiliary power tap
- Lightning arresters
- Surge capacitors
- Medium voltage connecting to the line (utility)
  - Non seg bus duct outgoing connection

7.2.6.2 Low Voltage Section

The low voltage maintenance walk–in section has, a low voltage distribution panel, lights, convenience receptacle, and emergency light. Access to this section is through hinged door(s). The compartment provides access to the following equipment:

- Generator circuit breaker (52G)
- Control cable terminations
- Low voltage output of the VTs and CTs
7.2.6.3 Interface Points

The primary interface points to the switchgear compartment are:

- Generator power connection – end(side), non-segregated phase bus flange connection
- Line power connection (to step-up transformer) – top/roof, non-segregated phase bus flange connection
- Provision for auxiliary power tap – bottom(floor), entry through gland plate

7.3 Gas Turbine-Generator Controls and Electric Auxiliaries

7.3.1 Packaged Electronic and Electrical Control Compartment (PEECC)

The PEECC is a completely enclosed compartment suitable for outdoor installation. Heating, air conditioning, compartment lighting, power outlets, temperature alarms, and smoke detectors are provided for convenience and protection of the equipment in the PEECC.

Electrical monitoring and control of the unit are accomplished by the turbine control panel and the generator control panel, which are mounted on a common skid and located in the PEECC. The customer control local interface is also located in the PEECC. In addition to the control systems, the PEECC also houses the gas turbine motor control centers and batteries, rack and charger(s). The arrangement of the equipment is shown in the typical compartment layout below.
7.3.2 SPEEDTRONIC™ Mark V Gas Turbine Control System

The gas turbine control system is a state–of–the–art Triple Modular Redundant (TMR) microprocessor control system. The core of this system is the three separate but identical controllers called <R>, <S>, and <T>. All critical control algorithms, protective functions, and sequencing are performed by these processors. In so doing, they also acquire the data needed to generate outputs to the turbine. Protective outputs are routed through the <P> protective module consisting of triple redundant processors <X>, <Y>, and <Z>, which also provide independent protection for critical functions such as overspeed.

The three control processors, <R>, <S>, and <T>, acquire data from triple–redundant sensors as well as from dual or single sensors. All critical sensors

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for continuous controls, as well as protection, are triple–redundant. Other sensors are dual or single devices fanned out to all three control processors. The extremely high reliability achieved by TMR control systems is due in considerable measure to the use of triple sensors for all critical parameters.

7.3.2.1 Electronics

All of the microprocessor–based controls have a modular design for ease of maintenance. Each module or controller contains up to five cards, including a power supply. Multiple microprocessors reside in each controller which distribute the processing for maximum performance. Individual microprocessors are dedicated to specific I/O assignments, application software communications, etc., and the processing is performed in a real–time, multi–tasking operating system. Communication between the controller five cards is accomplished with ribbon cables and gas–tight connectors. Communication between individual controllers is performed on high–speed Arcnet links.

7.3.2.2 Shared Voting

Software Implemented Fault Tolerance (SIFT) and hardware voting are utilized by the SPEEDTRONIC Mark V TMR control system. At the beginning of each computing time frame, each controller independently reads its sensors and exchanges these data with the data from the other two controllers. The median value of each analog input is calculated in each controller and then used as the resultant control parameter for that controller. Diagnostic algorithms monitor a predefined deadband for each analog input to each controller, and if one of the analog inputs deviates from this deadband, a diagnostic alarm is initiated to advise maintenance personnel.

Contact inputs are voted in a similar manner. Each contact input connects to a single terminal point and is parallel wired to three contact input cards. Each card optically isolates the 125 or 24 V dc input, and then a dedicated 80196 processor in each card time stamps the input to within 1 ms resolution. These signals are then transmitted to the <R>, <S>, and <T> controllers for voting and execution of the application software. This technique eliminates any single point failure in the software voting system. Redundant contact inputs for certain functions such as low lube oil pressure are connected to three separate terminal points and then individually voted. With this SIFT technique, multiple failures of contact or analog inputs can be accepted by the control system without causing an erroneous trip command from any of the three controllers as long as the failures are not from the same circuit.
Another form of voting is accomplished through hardware voting of analog outputs. Three coil servos on the valve actuators are separately driven from each controller, and the position feedback is provided by three LVDTs. The normal position of each valve is the average of the three commands from <R>, <S>, and <T>. The resultant averaging circuit has sufficient gain to override a gross failure of any controller, such as a controller output being driven to saturation. Diagnostics monitor the servo coil currents and the D/A converters in addition to the LVDTs.

7.3.2.3 PC Based Operator Interface

The operator interface, consists of a PC, color monitor, cursor positioning device, keyboard, and printer. The keyboard is primarily used for maintenance such as editing application software or alarm messages. While the keyboard is not necessary, it is convenient for accessing displays with dedicated function keys and adjusting setpoints by entering a numeric value rather than issuing a manual raise/lower command. Setpoint and logic commands require an initial selection which is followed by a confirming execute command.

7.3.2.4 Direct Sensor Interface

Input/output (I/O) is designed for direct interface to turbine and generator devices such as thermocouples, RTDs and vibration sensors, flame sensors, and proximity probes. Direct monitoring of these sensors eliminates the cost and potential reliability factors associated with interposing transducers and instrumentation. All of the resultant data are visible to the operator from the SPEEDTRONIC Mark V operator interface.

7.3.2.5 Built–in Diagnostics

The control system has extensive built–in diagnostics and includes “power–up”, background and manually initiated diagnostic routines capable of identifying both control panel, sensor, and output device faults. These faults are identified down to the board level for the panel, and to the circuit level for the sensor or actuator component. On–line replacement of boards is made possible by the triply redundant design and is also available for those sensors where physical access and system isolation are feasible.

7.3.2.6 Generator Interface and Control

The primary point of control for the generator is through the operator interface. However, the control system is integrated with the EX2000BR
brushless excitation system over an Arcnet local area network (LAN). The SPEEDTRONIC Mark V is used to control megawatt output and the EX2000BR is used to control megavar output. The generator control panel is used to provide primary protection for the generator. This protection is further augmented by protection features located in the EX2000BR and the SPEEDTRONIC Mark V.

### 7.3.2.7 Synchronizing Control and Monitoring

Automatic synchronization is performed by the <X>, <Y>, and <Z> cards in conjunction with the <R>, <S>, and <T> controllers. The controllers match speed and voltage and issue a command to close the breaker based on a predefined breaker closure time. Diagnostics monitor the actual breaker closure time and self-correct each command.

Another feature of the system is the ability to synchronize manually via the operator interface instead of using the traditional synchroscope on the generator protective panel. Operators can choose one additional mode of operation by selecting the monitor mode, which automatically matches speed and voltage, but waits for the operator to review all pertinent data on the CRT display before issuing a breaker close command.

### 7.3.2.8 Architecture

The SPEEDTRONIC Mark V control configuration diagram depicts several advantages for increased reliability and ease of interface. For example:

- Local <HMI> interface PC control
- Remote <HMI> interface PC control
- Back-up display wired directly to <R>, <S>, and <T> controllers
- Hard wire protective signal from <R> <S> <T> controllers
- Additional protective processors <X>, <Y>, <Z>

The protective block diagram shows the built-in redundancy/reliability of the SPEEDTRONIC Mark V control system. For example, if there is an overspeed condition requiring a trip of the unit, the first line of defense would be the primary overspeed protection via the <R>, <S>, and <T> controllers. All three trip signals then pass to the <P> protective module trip card where two out of three voting occurs prior to sending the automatic fuel supply trip signal. The secondary overspeed protection is via the <X>, <Y>, and <Z> protective...
control processor cards which similarly send their independent trip signals to the protective module trip card for voting.
7.3.2.9 **Scope of Control**

The SPEEDTRONIC Mark V control system provides complete monitoring control and protection for gas turbine–generator and auxiliary systems. The scope of control is broken down into three (3) sections: Control, Sequencing and Protection.

- **Control**
  - Start–up control
  - Speed/load setpoint and governor
  - Temperature Control
  - Guide vane control
  - Fuel control
  - Generator excitation setpoints
  - Synchronizing control (speed/voltage matching)
  - Emissions control

- **Sequencing**
  - GT auxiliary systems (MCC starters)
  - Start–up, running and shutdown
  - Purge and ignition
  - Alarm management
  - Synchronizing
  - Hydraulic ratchet
  - Maintain starts, trips and hours counters
  - Event counters
    - Manually initiated starts
    - Fired starts
    - Fast load starts
    - Emergency trips
  - Time meters
  - Fired time

- **Protection**
  - Overspeed, redundant electronic
  - Overtemperature (including generator)
  - Vibration
  - Loss of flame
— Combustion monitor
— Redundant sensor CO2 fire protection
— Low lube oil pressure, high lube oil temperature, etc.

7.3.2.10 Gas Turbine Plant Operating Modes

7.3.2.10.1 Starting/Loading

All starting is done automatically, with the operator given the opportunity to hold the start-up sequence at either the crank (pre-ignition) or fire (post-ignition, pre-accelerate) points of the start-up. An “Auto” mode selection results in a start without any holds.

Either before issuing a start command, or during the start, the operator may make the following selections:

1. Select or disable the automatic synchronization capability of the SPEEDTRONIC Mark V control. Automatic synchronization utilizes the microsynchronizer to provide accurate and repeatable breaker closures based on phase angle, slip, the rate of change of slip, and the response time of the breaker which is in the system memory.

2. Select preselected load, base load or peak load. If a selection is made the unit will automatically load to the selected point and control there. If no selection is made the unit will load to a low load referred to as “Spinning Reserve” automatically upon synchronization; be it automatic or manual. The turbine governor is automatically regulated to maintain the megawatt setting assigned to “Spinning Reserve”.

7.3.2.10.2 Operating

Once the unit is on line, it may be controlled either manually or automatically from the control operator interface. Manual control is provided by the governor raise/lower control displayed on the operator interface screen. Automatic operation is switched on when the operator selects a load point from the turbine control interface.

For a fully automatic start with automatic loading to base load, the operator selects the “Auto” operating mode, enables auto synchronization and selects “Base’ load. Given a “Start” signal, the unit will then start, synchronize and load to Base load with no further input on the part of the operator.
7.3.2.10.3 Shutdown

On shutdown, the system will automatically unload and return to ratchet motor operation. The unit will stay on ratchet until an operator turns it off.

7.3.2.11 Communications

7.3.2.11.1 Internal Communications

Internal communications consist of a high speed Arcnet link. The SPEEDTRONIC Mark V internal Arcnet communication link is isolated from external communication links at the operator interface processor.

7.3.2.11.2 External Communications

The open architecture of the <HMI> processor facilitates a wide range of external communications links.

An RS232 link with the MODBUS protocol is included for general compatibility with most DCSs. In distances greater than 50 ft (15 m), line drivers are required. The standard line drivers provided by GE require power from the RS232 interface of the DCS (pin 4, 10 V dc, 5 ma). Please verify that your DCS vendor can support this requirement. If not, special limited distance data sets that are powered by external power must be specified.

Multiple operator interfaces may be used to communicate to a SPEEDTRONIC Mark V. This capability changes the maximum allowable distance of a remote operator interface.

7.3.2.11.3 MODBUS Protocol

MODBUS protocol is a two–way serial data link used as an interface between a GE SPEEDTRONIC Mark V turbine control system and a customer Distributed Control System (DCS). MODBUS protocol offers a high degree of flexibility to the end–user. A standard list of points used to communicate with the Distributed Control System (DCS) is entered at the factory. An operator or GE field engineer can modify this list of points at any time. The different points can be installed quickly on any unit – typically, in fifteen minutes or less.
7.3.2.11.3.1 Link Layer

The operator interface communications port is configured as a slave station with programmable station ID. The customer DCS computer is assumed to be the master station requesting data from or sending data to the turbine control. Since multiple slave stations are allowed on the link, the turbine control port will send data upon request only. No periodic transmission of data is possible. A maximum of eight units may be connected over one MODBUS link when multi–unit functionality is implemented; one or two units for this protocol is recommended.

The MODBUS protocol consists of a set of messages initiated by the master station. Each message contains an address indicating which slave station is to respond (broadcast messages are possible), a message code, the data and a CRC checksum. The transmission mode is RTU (Remote Terminal Unit), and the ASCII mode is not supported.

7.3.2.11.3.2 Application Layer

The communication port is fully programmable to allow customizing of the data being requested by a DCS or the commands being sent to the turbine. Using MODBUS terminology, there are three types of data:

- Inputs (not used, same function provided by outputs/coils)
- Outputs/coils (logic—“Read” & “Write”)
- Registers (logic & analog—“Read” & “Write”)

These data arrays can be programmed to provide the critical turbine data for the DCS. The input array (not used for this application) contains logic data that the DCS can “Read” from but not “Write” to. The output array contains logic data (LDATA) that the DCS can both “Read” and “Write”. The register array contains either analog values (IDATA) (ie. 16 bit quantities) or packed logicals (LDATA) (ie. 16 logicals per register). Registers are “Read” or “Write”.

The DCS can send logical commands to the turbine control such as selecting START, STOP, RAISE, LOWER, ETC. A site specific list is created for each job of the appropriate remote command signals that will be accepted from the DCS. An automatic reset of the array protects the turbine against sticky bits or a failed link where a command such as “raise target” could fail activated. The automatic reset forces the DCS to repeatedly send raise/lower commands until the desired level is reached.
It is up to the master DCS to control the frequency of data transmissions. Turbine control data is updated at rates between 8 hz and 1 hz depending on how many data points are assigned to the MODBUS list.

7.3.2.11.4 GSM - Ethernet Protocol

Ethernet protocol is a two–way serial data link used as an interface between a GE SPEEDTRONIC Mark V turbine control system and a customer Distributed Control System (DCS). Ethernet protocol offers a high degree of flexibility, including time lagging, to the end–user. A standard list of points used to communicate with the Distributed Control System (DCS) is entered at the factory. An operator or GE field engineer can modify this list of points at any time. The different points can be installed quickly on any unit – typically, in fifteen minutes or less.

7.3.2.11.4.1 Link Layer

The operator interface communications port is configured as a slave station with programmable station ID. The customer DCS computer is assumed to be the master station requesting data from or sending data to the turbine control. Since multiple slave stations are allowed on the link, the turbine control port will send data upon request only. No periodic transmission of data is possible. A maximum of eight units may be connected over one Ethernet link when multi–unit functionality is implemented; one or two units for this protocol is recommended.

The Ethernet protocol consists of a set of messages initiated by the master station. Each message contains an address indicating which slave station is to respond (broadcast messages are possible), a message code, the data and a CRC checksum. The transmission mode is RTU (Remote Terminal Unit), and the ASCII mode is not supported.

7.3.2.11.4.2 Application Layer

The communication port is fully programmable to allow customizing of the data being requested by a DCS or the commands being sent to the turbine. Using Ethernet terminology, there are three types of data:

- Inputs (not used, same function provided by outputs/coils)
- Outputs/coils (logic—“Read” & “Write”)
- Registers (logic & analog—“Read” & “Write”)
These data arrays can be programmed to provide the critical turbine data for the DCS. The input array (not used for this application) contains logic data that the DCS can “Read” from but not “Write” to. The output array contains logic data (LDATA) that the DCS can both “Read” and “Write”. The register array contains either analog values (IDATA) (ie. 16 bit quantities) or packed logicals (LDATA) (ie. 16 logicals per register). Registers are “Read” or “Write”.

The DCS can send logical commands to the turbine control such as selecting START, STOP, RAISE, LOWER, ETC. A site specific list is created for each job of the appropriate remote command signals that will be accepted from the DCS. An automatic reset of the array protects the turbine against sticky bits or a failed link where a command such as “raise target” could fail activated. The automatic reset forces the DCS to repeatedly send raise/lower commands until the desired level is reached.

It is up to the master DCS to control the frequency of data transmissions. Turbine control data is updated at rates between 8 hz and 1 hz depending on how many data points are assigned to the Ethernet list.

7.3.2.12 Backup Interface

In the unusual event that the operator interface becomes unavailable, a small backup interface is provided on the SPEEDTRONIC Mark V cabinet door. It uses a liquid crystal display with two (2) lines of forty (40) characters per line to display key control parameters and alarms. The control panel accepts operator commands from this backup interface.

7.3.2.13 Printer

The standard operator interface printer has these convenient features:

- Alarm logging
- Event logging
- Historical trip display printing capability
- User defined display printing capability
- Periodic log display printing capability
- CRT screen copy
Each alarm and event is logged with a high resolution time tag. Contact inputs are logged to 1 millisecond. Separate alarm queues are maintained for turbine/generator system alarms and for SPEEDTRONIC Mark V internal self–diagnostic alarms. System alarms can be silenced, acknowledged and reset locally. Any intermittent alarms can be locked out with a permanent lockout message residing in the alarm queue.

In addition, system alarms can be silenced, acknowledged and reset from a DCS via a two–way communication link or hardwired contacts if desired.

If a trip occurs, the historical trip display automatically captures in memory all key control parameters and alarm messages at the time of the trip and at several time intervals preceding the trip. The operator can print the historical trip display when required. A start signal triggers the display to start collecting new data and all previous data is deleted from the current log. Display logs can be saved at any time to a memory buffer.

A user–defined display allows selection of any desired data for viewing or printing. The periodic log allows a user to define points to be collected and printed periodically to a printer. The period of each list is defined in minutes, from 1 to 10,080 (one week).

7.3.2.14 Human Machine Interface (HMI)

The Human Machine Interface is a single powerful, flexible and user friendly operator interface which brings together all of the displays and functions needed for real-time control and monitoring of turbomachinery processes, auxiliary equipment, driven devices and process alarms associated with power plant control.

The HMI system provides the infrastructure needed to meet the demanding requirements of delivering process information from a broader spectrum of controllers and compute platforms as well as accessing and delivering information to a customer enterprise system and balance of plant control system.

Designed with an open system concept, the system uses standard open hardware and operating system software. The HMI software system uses the Windows NT client-server architecture from Microsoft which provides built-in multi-tasking, networking and security features. The ability to run the system on conventional PC based platforms minimizes cost, promotes open interfaces, permits system scalability, and ensures longevity of investment and future enhancement.
7.3.2.14.1 HMI Product Structure

The GE Fanuc CIMPLICITY HMI system serves as the basic core system, which is enhanced by the addition of power plant control hardware and software from GE Industrial Systems. The HMI configuration consists of several distinct elements:

- HMI Server - The server is the hub of the system and provides data support and system management. The HMI server also has the responsibility for device communication for both internal and external interchanges. The gas turbine control system can have redundant communications with two HMI servers.

- HMI Viewer (Client) - (If provided) the viewer provides the visualization function for the system and is the client of the distributed client-server system. The viewer contains the operator interface application software for issuing commands, viewing screen graphics, data values, alarms and trends, and providing system logs and reports. The gas turbine control system can have redundant communications with up to four HMI servers and/or viewers. The first HMI will be a server; additional HMIs can be a server or viewer depending on the plant control configuration.

7.3.2.14.2 HMI Product Features

- Graphics - The key functions of the HMI system are performed by its graphic system, which provides the operator with process visualization and control in a real-time environment. In the HMI system this important interface is accomplished using CimEdit, a graphics editing package, and CimView, a high performance runtime viewing package.

- Alarm Viewer - The alarm management functions of the HMI system are provided by Alarm Viewer. Alarm Viewer handles routing of alarms to the proper operator and alarm sorting and filtering by priority, plant unit, time, or source device.

- Trending - HMI trending, based on object linking and embedding technology, provides powerful data analysis capabilities. Trending capabilities include graphing collected data and making data comparisons between current and past variable data for quick identification of process problems.

- Point Control Panel - The HMI point panel provides a listing of points in the system with dynamically updating point values and alarm status. Operators have the ability to view and set local and remote points, enable
and disable alarm generation, modify alarm limits, and filter and sort points selectively.

- **Basic Control Engine** - The basic control engine allows users to define control actions to take in response to system events. It monitors event occurrence and executes configured actions in response. The basic control engine is supported by an event editor for defining actions in response to system events and a program editor for programming more complex actions.

- **User Roles and Privileges** - CIMPLICITY allows configuration of system users to control access and privileges.

- **DDE Application Interface** - The DDE Interface allows other Windows applications that use Microsoft standard and Advanced DDE to obtain easy access to HMI point data. Users can integrate software that supports DDE to monitor, analyze, report or modify the HMI point data. In addition the HMI provides advances DDE client communication for data collection from third party devices.

### 7.3.2.14.3 Operator Functions

- **Display Management** - Display management provides overall display functions to meet the needs of the turbine plant. Displayed data is a combination of data received over Ethernet from GE third party servers and over the Stage Link from gas turbine controllers. Alarm display includes both connection to gas turbine alarm queues and external PLC systems.

- **Hold List Display** - The hold list is a set of conditions which must be met at certain times, speeds and operating modes in the turbine startup for systems which have Automatic Turbine Startup functions. The HMI provides for creation, modification, display, printing, down and uploading, compiling and reverse translation of a hold list of up to 64 points.

- **Timer, Counter, Accumulator Display** - This function shows the settings and totals in the turbine controllers.

- **Screen Copy** - Screen copy makes a copy of screen image and stores it in the Window clipboard for display, printing, directing to a file, or electronic transmission.

- **Trip History** - Trip history data collected from each turbine controller can be plotted, printed as tabular data, or transmitted electronically for remote analysis.
• Process Alarm Management - The features of process alarm management help the operator to make a proper response to alarms and include the following:
  – Alarm queue display for each turbine unit controller
  – Main alarm display including all plant alarms
  – Alarm lockout for toggling alarm conditions
  – Alarm notepad function for adding explanatory notes to each active alarm drop number for each panel
  – Linking alarms to pre-selected display screens
  – Alarm help utilities for storing more detailed descriptions of alarms and their intended functions
  – Distinguishing display of control system diagnostic alarms from regular alarm or events

7.3.2.14.4 Maintenance and Tool Support

• Remote, On-Plant Maintenance Access - The HMI system supports remote maintenance access for field installation, troubleshooting, and resolving general maintenance problems of the controller and HMI systems. In remote access, a computer in the remote location appears as a view node on the site system. Capabilities include operation displays, configuration of the HMI, real-time and historical data retrieval, and diagnostic alarms.

• Diagnostic Alarms - Diagnostic alarms specifically pertain to the control system and help operators and maintenance personnel respond to control system problems. Functions associated with diagnostic alarms include sorting and grouping capabilities, printing alarms on the HMI alarm printer (if selected), and help utilities to identify alarm and intended response.

• View Programs - This special data collection programs provide collection of data necessary to troubleshoot the turbine unit control systems. These programs create diagnostic data files that are stored for later analysis. Files can be displayed, trended, printed, faxed or transferred.

• Logic Forcing - The HMI supports logic forcing and maintains the identity and status of forced points.

• Control Constants - Control constants are tune-up parameters and variables that change with each application and may change from time to time during the life of an installation. The HMI displays control constants values for a given control unit and allows adjustment of the values with appropriate ramp rates and min and max values. A tool is included to
create and maintain a control constant file on a unit basis which can be downloaded to the unit controller.

- Configuration Tools - The HMI system provides tools to configure a turbine control panel including:
  - Control Sequence Program (CSP) editor to edit existing control program segments and to create new program segments
  - I/O configurator for embedded turbine control I/O software
  - Panel configuration including maintenance of the Data Dictionary File System (DDFS) and the Control Signal Data Base (CSDB)
  - Ability to configure the turbine control unit trip logs

### 7.3.2.14.5 Operator Displays

The operator/maintenance interface is commonly referred to as the Human Machine Interface (HMI). It is a PC with a GE CIMPLICITY graphics display system and a Microsoft Windows NTR operating system. This facilitates client / server capability and integration of third party software. It can be applied as:

- The primary operator interface for one or multiple units
- A backup operator interface to the plant DCS operator interface
- A gateway for communication links to other control systems
- A permanent or temporary maintenance station
- An engineer station

All control and protection is resident in the turbine control which allows the HMI to be a non-essential component of the control system. It can be reinitialized or replaced with the turbine running with no impact on the control system. The HMI communicates with the processor card in the turbine control via the Ethernet based Unit Data Highway (UDH). The Main Display shows all of the pertinent control data on one screen to minimize the need for operators to change screens. A typical Main display is shown below. Data is displayed in either English or Metric engineering units with a 1 second refresh rate and a maximum of 1 second to repaint a typical display graphic. Operator commands can be issued by either incrementing / decrementing a setpoint with the up/down arrows or entering a numerical value for the new setpoint. Responses to these commands can be observed on the display one (1) second from the time the command was issued.
Some areas of the display have templates assigned to them. For example, some control valves show a rectangle around the graphic when the mouse is moved to the graphic symbol for that device. This identifies the underlying template that can be selected by the mouse as a pop-up. These pop-ups can be moved or resized on the Main Display and used to issue a command to the valve and observe the response of the valve via a numerical value, a bar chart, or a trend. Trend windows can be resized or moved to convenient locations on the display. Operators can select as many parameters as they feel comfortable viewing and trend at the control frame rate. Specific events can be pre-selected to trigger a trend with either pre-event data or post-event data.

An alarm field is provided in the lower left-hand corner of the Main Display. Each alarm message contains a 40ms time tag which originates in the turbine control, not in the HMI; therefore, the time tag resolution is the “frame rate” which the application software is running. Similarly, Sequence Of Events (SOE) time tagging for contact inputs originates in the turbine control contact input cards to enable the HMI to display 1ms resolution. Some alarms can become nuisance alarms such as an intermittent field ground. These types of
alarms can be locked out / filtered by the Alarm Management system to avoid filling up the queue or logging numerous undesirable points. Operators can also add comments to alarm messages or link specific alarm messages to supporting graphics. Various methods of sorting alarms are supported including sorting by ID, Resource, Device, Time, and Priority.

Approximately 200 total graphics pages can be provided per operator station with up to 200 dynamic fields per display without impacting update time for multi unit sites. Displays have a maximum of 65k foreground and background colors, and the graphics are stored on the PC hard disk.

Security for the users of the HMI is important to restrict access to certain maintenance functions such as editors and tuning capability, and to limit certain operations. A system called “User Accounts” is provided to limit access or use of particular HMI features. This is done through the Windows NT User Manager administration program that supports five (5) user account levels.

7.3.2.14.6 Communications Interfaces

The HMI uses Stage Link as its mechanism for communication with GE turbine controllers and ancillary equipment. Stage Link allows the HMI to be located remotely and enables a single HMI to communicate with up to eight turbine controllers.

The Ethernet Plant Data Highway (PDH) serves to integrate the unit turbine control systems with the overall plant communications requirements. The HMI viewer stations connect to the PDH and receive their data from the servers over this network. Since this network is intended to provide external interface, it uses open and widely used communication interfaces such as TCP/IP.

The HMI allows Modbus interfaces with other systems such as DCS.

7.3.3 Bently Nevada 3500 Monitoring System

The gas turbine and generator are equipped with orthogonal proximity probes at each bearing to detect radial motion of the shaft relative to the bearing. Axial position of the gas turbine rotor is sensed by two axial position proximity probes. Each probe is connected to a proximitor.

The Bently Nevada 3500 Monitor is a 19 in., sixteen position (fourteen available), panel mount rack containing four proximitor cards each of which
can accept up to four channels. (The cards must be programmed for the application.) The system has one monitor card for each of the two turbine rotor axial position probe inputs, one monitor card for the radial X-Y probes from the two turbine bearings and one monitor card for the radial X-Y probes from the two generator bearings. The radial bearing monitor provides values for the overall amplitude, 1X amplitude, 1X phase, 2X amplitude and 2X phase.

Features of the system include:

- Alert and danger relay outputs – one pair for the axial position monitor and one pair which is shared by all the radial monitors
- A communication card for serial data interface to the GE on-site monitor
- AC power supply
- KeyPhasor card
- Rack configuration software for programming the rack functions including a serial interface cable for connecting the RIM card to the customer’s computer. (A customer-supplied Microsoft Windows based computer is required.)

7.3.4 Motor Control Center

The motor control center contains circuit protective devices and power distribution equipment to supply electrical power to all packaged power plant devices as defined on the electrical one line diagram. The motor control center is manufactured and tested in accordance with NEMA ICS–2 and UL Standard No. 845. Vertical sections and individual units will be UL (CSA) Labeled where possible. The motor control center is located in the PEECC.

7.3.5 Generator Protection Panel

The heart of the generator protection panel is the digital multifunction relay integration with the gas turbine control system panel. The generator protection panel incorporates this feature along with generator metering and watt and VAR transducers for turbine control.

In addition, the panel includes pre-engineered protective modules for the following:

- Auxiliary transformer
The following page presents a typical one-line diagram for the generator protection panel. The diagram and the tables which follow it illustrate the digital protection features and metering. For job-specific details please refer to the oneline diagram in the drawings section of the proposal.

![Diagram of Standard Generator Panel (Typical)]
7.3.5.1 Digital Generator Protection (DGP) Features

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overexcitation</td>
<td>24</td>
</tr>
<tr>
<td>Generator Undervoltage</td>
<td>27G</td>
</tr>
<tr>
<td>Reverse Power / Anti-Motoring</td>
<td>32-1</td>
</tr>
<tr>
<td>Loss of Excitation</td>
<td>40-1,2</td>
</tr>
<tr>
<td>Current Unbalance / Negative Phase Sequence</td>
<td>46</td>
</tr>
<tr>
<td>System Phase Fault</td>
<td>51V</td>
</tr>
<tr>
<td>Generator Overvoltage</td>
<td>59</td>
</tr>
<tr>
<td>Stator Ground Detection</td>
<td>64G/59GN</td>
</tr>
<tr>
<td>Generator Over Frequency</td>
<td>81O-1,2</td>
</tr>
<tr>
<td>Generator Under Frequency</td>
<td>81U-1,2</td>
</tr>
<tr>
<td>Generator Differential</td>
<td>87G</td>
</tr>
<tr>
<td>Voltage Transformer Fuse Failure</td>
<td>VTFF</td>
</tr>
</tbody>
</table>

7.3.5.2 Generator Digital Multimeter

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator Volts</td>
<td>VM</td>
</tr>
<tr>
<td>Generator Amps</td>
<td>AM</td>
</tr>
<tr>
<td>Generator megawatts</td>
<td>MW</td>
</tr>
<tr>
<td>Generator megaVARs</td>
<td>MVAR</td>
</tr>
<tr>
<td>Generator MVA</td>
<td>MVA</td>
</tr>
<tr>
<td>Generator megawatt-hours</td>
<td>MWH</td>
</tr>
<tr>
<td>Generator MVA-hours</td>
<td>MVAH</td>
</tr>
<tr>
<td>Generator frequency</td>
<td>FM</td>
</tr>
<tr>
<td>Generator Power Factor</td>
<td>PF</td>
</tr>
</tbody>
</table>

7.3.5.3 Digital Generator Protection (DGP)

The digital generator protection system uses microprocessor technology to obtain a numerical relay system for a wide range of protection, monitoring, control and recording functions for the generator. Redundant internal power supplies and extensive diagnostic and self-test routines provide dependability and system security.
The DGP provides the commonly used protective functions in one package. Adaptive frequency sampling is used to provide better fault protection during off-normal frequencies such as startup.

The DGP can store in memory the last 100 sequence of events, 120 cycles of oscillography fault recording, and the last three fault reports.

The system features a local Human-Machine Interface with integral keypad, 16 character display, and target LEDs for entering settings, displaying present values, viewing fault target information, and accessing stored data. In addition, two RS-232 serial communication ports are provided for local and remote computer access. (Please Note: The Personal Computer (PC) is not part of this offering.)

7.3.5.4 **Auxiliary Transformer Protection**

Auxiliary transformer protection is provided by a digital non-directional overcurrent relay which protects against overloads and faults. The module includes four measuring units, one for each of the three phase currents and one for ground or residual current. The phase and ground units contain settings for time overcurrent (TOC) and instantaneous overcurrent (IOC). In addition, the module has control inputs and outputs that can be used for a zone interlocking scheme. A local user interface is included with scrolling display and eight LEDs.

7.3.5.5 **Generator Breaker Failure Protection (50/62BF)**

A digital breaker failure relay is used for timing and detecting current flow in conjunction with a lockout relay (86BF). The timer initiation is accomplished using an auxiliary high speed relay (94BFI) in parallel with the breaker trip coil. If the generator breaker remains closed and/or the current level detectors sense a current, the (50/62BF) relay starts timing. At the end of the time out period, the (50/62BF) relay trips the lockout relay (86BF). Contacts from this lockout are brought out to terminal boards for customer use in tripping associated breakers. Lockout relay (86BF) also trips the turbine.

Most faults involving the generator require tripping the generator breaker. Failure of the protection schemes to trip this breaker results in loss of protection to the generator. Also, if one or two poles of the breaker fail to open, the result can be a single phase load and negative sequence current on the generator stator. The purpose of the breaker failure protection is to act as a backup to any of the other generator protection schemes. This serves to protect the generator when the breaker fails to open properly.
7.3.5.6 Gas Turbine Control System Integration

In addition to the relaying mounted in the generator protection panel, the gas turbine control system handles protective functions such as generator temperature protection, synchronizing check, backup frequency and reverse power.

Generator control and monitoring are primarily accomplished via the gas turbine control system operator interface. The operator interface handles manual and auto-synchronizing, speed raise/lower, voltage raise/lower, and generator breaker control. Also displayed are frequency and voltage for the generator and bus, breaker status, field current and voltage, along with the status of permissives.

7.3.6 EX2000BR Static Voltage Regulator for Brushless Excitation

The EX2000BR is a digital, static, voltage regulator for use with rotating ac brushless exciters. The system supplies dc excitation power to the field winding of the rotating brushless exciter. In addition, all control and protective functions are implemented in the system software. Digital technology allows the EX2000BR to maintain 99.98% availability.

A simplified one-line diagram of the EX2000BR excitation system is shown below:
The voltage regulator accepts inputs from the generator terminals or auxiliary bus. In addition the regulator will accept a dc input from the station battery as a backup power source to the primary ac source.

7.3.6.1 System Features

Following are descriptions of selected features of the EX2000BR system. For a complete list of system features and accessories, please refer to the Scope of Supply section of the proposal.

7.3.6.1.1 Communication (ARCNET) Interface

For communication to the EX2000BR, an ARCNET (local area network) controller with modified ARCNET drivers is provided. The ARCNET controller adheres to the standard ARCNET protocol.

7.3.6.1.2 Interface with the SPEEDTRONIC Mark V Gas Turbine Control System

The EX2000BR is connected to the gas turbine control system through a coaxial cable on the ARCNET LAN. This enables the gas turbine control
system to provide a digital window into the EX2000BR through which all pertinent variables can be monitored and controlled.

7.3.6.1.3 **Regulator Panel**

The regulator panel contains the SCR power conversion module and regulator with all standard control and protection functions, plus auxiliary functions such as de-excitation module, dc field flashing module, and shaft voltage suppression circuit.