Contents

INTRODUCTION

1.0 LAYOUT
1.1 Layout for Single-Shaft Plants
1.2 Layout for Multi-Shaft Configuration
1.3 Single-Shaft vs. 1x1 Multi-Shaft
1.4 Preferred Steam Turbine Exhaust Direction
1.5 Compact Gas Turbine Building for Multi-Shaft Configurations

2.0 SCHEDULE
2.1 Project Schedules for Single-Shaft and Multi-Shaft Plants
2.2 Modularized Gas Turbine Enclosure
2.3 Steam Turbine Installation and Constructability Features
2.4 Lube Oil System Flush Features

3.0 SIMPLIFICATION
3.1 Electric Inlet Guide Vane and Variable Stator Vane Actuators
3.2 Pressure Atomized Liquid Fuel System
3.3 Factory Commissioning of Accessory Skids
3.4 Consolidated Plant Electrical Room
3.5 Water Mist Fire Protection

4.0 PERFORMANCE
4.1 Heat Recovery Steam Generator Enhancements
4.2 600°C (1112°F) Main Steam and Reheat Steam Temperatures
4.3 Fuel Heating to 226°C (440°F)
4.4 Two Pressure Condenser for Steam Turbines with 4-Flow Low Pressure Sections

5.0 OPERABILITY
5.1 Plant Hot Starts in 30 minutes or less
5.2 Plant Shutdown Purge Credit
5.3 SSS Clutch for Single-Shaft Applications

6.0 CONTROLS/USER EXPERIENCE (UX)
6.1 Digital Bus Technology for Instrumentation and Controls
6.2 Plant AutoStart
6.3 State-of-the-Art Human-Machine Interfaces
6.4 Plant Level Alarm Management and Fault Tolerant Protection Systems
6.5 Intelligent Dual Control Redundancy

APPENDIX
Appendix A Requirements and Constraints
Appendix B Plant Functions
Appendix C Physical Implementation
Appendix D Definitions and Acronyms
Appendix E Document Creation and Revision List
Combined Cycle Power Plant Best Practices 2015

Introduction

What It Is
This is a single source document that describes GE’s best practices in the configuration and execution of combined cycle power plants (CCPPs). These best practices reflect GE’s involvement in hundreds of CCPPs built around the globe over the past 60+ years for all types of customers by numerous Engineering, Procurement and Construction companies (EPCs).

Why It Matters
The purpose of capturing these best practices in a single location is to ensure that customers, Owner’s Engineers, EPCs and developers understand how to extract the most value from GE-supplied equipment when designing and building a CCPP. This document is intended to document the benefits and impacts of these features on key customer imperatives.

How to Use This Document
The best practices developed by GE are grouped into the following six major categories:

- Layout
- Schedule
- Simplification
- Performance
- Operability
- Controls/User Experience (UX)

There is an introduction at the beginning of each of the six major categories that provides an overview of the overall benefit of that group of features. Within each category are chapters summarizing the benefits and application of each feature.

Each chapter is divided into sections that describe what the feature is, why it matters and what its key enablers are. The objective is to describe how this feature differs from legacy industry practices and the quantifiable benefit it brings to customer plant imperatives. Needs and limitations with respect to plant requirements and constraints are provided along with plant system impacts and critical engineering requirements. Implementation effects are also discussed.

Key Enablers
Each feature has a section that describes one or more technology enablers that make it possible. These critical attributes are described in this section.

Plant Systems-Based Structure
The GE Power Generation Products (PGP) systems-based structure has been utilized to describe each feature. This structure is broken into three top level categories called dimensions:

- Requirements & Constraints
- Function
- Physical Implementation
Together the plant location, interface needs and mission and goals define the requirements and constraints for the power plant. The various plant systems satisfy these requirements and constraints while accounting for physical implementation needs. Each feature contains a separate paragraph that discusses each of the three high-level dimensions. Within each dimension, the feature limitations, interactions and impacts are discussed in more detail.

Requirements & Constraints
This section considers the plant mission and goals and how they influence the infrastructure and location-based constraints. These are broken down into six categories:

- Operations
- Site
- Fuel
- Grid
- Environmental
- Schedule

The purpose of this dimension is to capture the requirements and constraints that drive the product configuration.

Plant Systems or Functions: Interactions & Engineering Requirements
The primary goal of the system interaction section is to describe which functions of the power plant are affected by the particular feature. The functions of the plant are split into five primary systems. Along with defining the functionality of the power plant, it also provides the common language or system breakdown structure (SBS) for use across the GE Power Generation Products team. Functional system engineering balances physical implementation needs with the plant requirements and constraints.

The five primary systems are:

**Topping Cycle**
The gas turbine and its dedicated systems.

**Bottoming Cycle**
The steam turbine, HRSG, condensate, feed water and associated systems.

**Heat Rejection**
Systems that reject heat to the environment.

**Electrical**
Systems that export power to the grid or supply power to plant equipment.

**Plant Integration**
Systems that support the power train equipment in converting fuel to electrical power.

Appendix B provides a detailed list of the 96 systems.

Physical Implementation
Physical Implementation of the plant considers how the plant is built, operated and maintained. The implementation methods also address the functional needs of the plant along with plant requirements and constraints. Physical implementation of the plant should be adaptable to meet requirements and constraints such as manpower availability and logistical issues. Impacts of each feature are described in this section.

A detailed breakdown and discussion of these attributes are in Appendix C.
Combined Cycle Plant Configurations

There are two main CCPP configurations, single-shaft (SS) and multi-shaft (MS). The defining characteristic of the SS configuration is that the steam turbine, generator and gas turbine are connected together and share one shaft. The defining characteristic of the MS configuration is that a steam turbine and its associated generator are separate from one or more gas turbine(s) and generator shaft lines. In a MS, the steam turbine and generator are designated the ST island. The gas turbine, its generator and associated Heat Recovery Steam Generator (HRSG) are designated the GT-HRSG island. Each main configuration has variations that impact the plant and power train layout. Because of the significant differences in these two configurations, this guide often treats them separately. Chapter 2 elaborates on these differences and the applicability of various GE best practices.

Feedback

GE appreciates the time you’ve taken to familiarize yourself with these best practices. In order to continuously improve this document and all of our power generation products, we would be grateful to receive your suggestions for additional best practices or feedback from experience that differs from GE’s. Please contact your GE Account Manager with any feedback and they will ensure it is transmitted to the GE PGP Product Management team responsible for this document.
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1.0 Layout

There are two main combined cycle plant configurations, single-shaft (SS) and multi-shaft (MS). Each of these configurations has its own specific plant and power train layout. These are described in the first two chapters of this section. In 1x1 configurations, both SS and MS layout configurations are possible. The Single-Shaft vs. 1x1 Multi-Shaft chapter discusses which of these configurations is the best choice considering plant requirements and constraints as well as customer needs. Within each main configuration (SS or MS), the steam turbine last stage bucket selection (single flow, double flow or four flow) affects the layout details in the steam turbine area. The Preferred Steam Turbine Exhaust Direction chapter provides configuration requirements for these bucket selections. The MS layout is offered with both outdoor and indoor GT configurations. The Compact Gas Turbine Building chapter provides recommendations for the indoor GT configuration. All of the layouts have features that are critical to the construction schedule, total installed cost and maintainability of the plant. GE recommends utilizing these features unless prohibited by the customer or site requirements and constraints.

1.1 Layout for Single-Shaft Plants
1.2 Layout for Multi-Shaft Configuration
1.3 Single-Shaft vs. 1x1 Multi-Shaft
1.4 Preferred Steam Turbine Exhaust Direction
1.5 Compact Gas Turbine Building for Multi-Shaft Configurations
Combined Cycle Power Plant Best Practices 2015

1.1 Layout for Single-Shaft Plants

What It Is
The Single-Shaft (SS) Combined Cycle Plant layout has features that are very important to the construction schedule, total installed cost and maintainability. These features include low power train centerline height, side access roadway, pier foundations, generator in the center of the rotor train and segregation of construction disciplines. Each of these features is discussed below.

Reduced Building Height
- Mechanical Discipline Scope Concentration
- Low Bay for Condenser
- Generator in the Center
- Low Centerline Height
- Pier Foundation
- Electrical Discipline Scope Concentration
- Side Access Roadway
1.1.1 Low Centerline Height

Why It Matters

The low power train centerline height (relative to previous configurations) results in lower cost for equipment foundations, reduced building height and enhanced installation/maintenance access. The chapter “Preferred ST Exhaust Direction” provides the details of the benefits associated with the lower centerline height.

Key Enablers

A single side or axial exhaust steam turbine is required to achieve the low centerline height. Refer to the Chapter “Preferred ST Exhaust Direction” for additional detail on when this configuration can be offered. In general, every two flow ST is available with a side exhaust. An axial exhaust ST can be used when the exhaust area is met with a single flow low pressure section.

Requirements & Constraints

Schedule and total installed cost are the biggest factors affected by centerline height. Any increase in centerline height impacts civil costs in unit foundations, building size and unit interconnects. Increasing the civil work also adds additional schedule risk due to more complex foundation requirements involving more formwork and pours. Low centerline can help reduce unit installation schedule risk with simplified heavy lifts, lift height for all components and fewer scaffolding requirements. Lower lift heights typically reduce the crane capacity required for a given lift. Lower capacity cranes have improved availability. These advantages translate directly to improved maintenance outage predictability.

System Interactions & Engineering Requirements

Low centerline height impacts:

**P90 Structures**

Low centerline impacts unit interconnect structures set by centerline height. These include GT inlet, GT exhaust, generator bus and neutral connections, control valves and steam turbine stop.

**P91 Foundations**

Lower centerline results in less complex and less costly foundations.

**P92 Buildings**

The turbine hall height is determined by rotor lifting requirements.

**P93 Cranes**

The lower building height requires smaller cable drum sizing for lifts to the deck.

**P70 HVAC**

The resulting smaller building size will require less ventilation.

**T40 GT Exhaust**

The lower centerline results in reduced need for GT exhaust support.

**T50 GT Inlet**

The lower centerline will decrease GT inlet structural requirements.

**E20 Electrical Evacuation**

The lower centerline will decrease generator Isolated Phase Bus (IPB) duct length and structural requirements.

Physical Implementation

**Interfaces**

Impacts all unit accessories connections.
1.1.2 Side Access Roadway

Why It Matters

The side access road has multiple functions. It creates a flow-through material delivery path. This is especially important for movement-intensive construction and maintenance activities such as centerline equipment installation, piping disassembly, and GT compartment breakdown.

The roadway also provides enough laydown space in the building for GT or ST maintenance-critical parts while allowing deliveries at the opposite end bay.

The roadway creates the footprint necessary to take advantage of low centerline side heavy lift options for major equipment like the GT, ST and generator. This is a significant schedule risk reduction feature. It takes these heavy lifts from a series to a possible parallel schedule if needed due to delivery delays.

The roadway also allows easy access to some of the most critical auxiliary systems such as lube/seal oil, stator cooling water and the GT compartment itself.

Key Enablers

The key enablers to achieve these benefits are a building sized for the roadway, low centerline height, generator interconnect via isolated phase bus (IPB) bridge, and accessories modularization/location.

Requirements & Constraints

Site considerations often require adapting reference layouts. In the case of very narrow plant footprints, serious consideration should be given to relocating other balance of plant equipment in lieu of eliminating the side access roadway. Maintenance and construction schedules are the largest requirements affected by the side access roadways. Changing these features will require alternative planning or designs to maintain the same schedules.

System Interactions & Engineering Requirements

The side roadway impacts:

P90 Structures
Unit interconnect structures and generator IPB bridge.

P91 Foundations
Loading on roadway to allow rotor laydown and heavy lift delivery.

P92 Buildings
Turbine hall width to accommodate roadway.

P93 Cranes
 Longer crane trolley to span roadway.

P70 HVAC
Larger building size will require extra ventilation.

Physical Implementation

Layout
When customizing the layout for project needs, keep the roadway clear of permanent equipment. Ensure interface changes don’t encroach on the roadway. Ensure IPB duct bridge height remains at sufficient elevation to allow truck passage through the building.

Lifting Capability/Availability Heavy Haul Gantry
Provide sufficient side footprint for loading of GT, ST and generator to foundation.

Material Handling
Speeds material handling operations by limiting travel distance needed for crane hook. Also facilitates the option for additional rubber tire lifting equipment to supplement building crane and further expedite installation and maintenance.

Maintenance Laydown
Provide indoor laydown for critical equipment.
**Maintenance**

The GE suggested layout provides access to critical equipment and accessories.

**Maintenance Predictivity**

Schedules assume short travel of building crane from equipment centerline to roadway. Roadway also offers the option of adding rubber tire cranes to improve outage schedule.
1.1.3 Pier Foundations

Why It Matters
ST and generator pier foundations reduce the complexity and cost of the unit foundations. There is significant reduction in concrete volume, formwork and installation hours. Savings are elaborated later in the chapter titled “Preferred Steam Turbine Exhaust Direction.” Additionally, the pier foundations open space for unit close-in piping and lube oil connections when compared to traditional table top foundation configurations. A table top foundation consists of a large slab of reinforced concrete joining multiple piers together. It resembles a table with legs. The standard table top foundation makes close coupling ST stop/ control valves highly impractical because of the amount of table top concrete close to the ST shell.

Key Enablers
A side exhaust or axial exhaust steam turbine is required to implement pier foundations. The low centerline height eliminates the need to tie the piers together in a table top configuration or increase the pier dimensions to a size that makes the pier configuration impractical.

Requirements & Constraints

Location-Geologic-Seismic Zone
The standard plant pier configuration is based on a moderate seismic zone and can be used for most sites. It is expected only minor modifications to the pier configuration are needed for higher degree seismic locations.

Schedule – Predictability
Pier construction, with its single concrete pours, can be accomplished in less time than a table top foundation. It also provides better access and less interference during remaining construction activities.

Engineering Cycles
Pier configuration has no special conditions to extend engineering cycles.

System Interactions & Engineering Requirements
Due to their less intrusive shape, pier foundations have less interference with unit piping and require no special tooling or methods for installation.

The pier foundations will impact:

P91 Foundations
Design loads on roadway must allow rotor laydown and heavy lift (example assembled GT and generator) delivery.

B31 Steam Turbine Unit
High pressure (HP) and intermediate pressure (IP) steam turbine standards are engineered considering pier foundation interface requirements.

E10 Generator
Generator is engineered for four point pier type support. Accessory system engineering must consider locations of piers in equipment layout and connection routing. To avoid construction interferences, field connections are made a sufficient distance from the pier to allow access for assembly.

Physical Implementation

Construction and Operation & Maintenance (O&M)
Construction accessibility is improved due to elimination of the concrete table top. In a similar manner, O&M activities also benefit from improved accessibility.
1.1.4 Generator in the Center

Why It Matters
Generator in the center allows multiple single-shaft configuration options without major changes in the GT-Gen configuration. These include incorporation of a clutch between the ST and generator, axial and side exhaust ST configurations, and district heating provisions.

During shutdowns, the clutch facilitates rapid access to the gas turbine for maintenance. The GT cools down faster than the ST. An open clutch allows the ST to cool down on its separate turning gear. This provides access to the GT for maintenance up to three days earlier compared to a direct coupled unit. Further discussion on the clutch is provided later in this document.

Key Enablers
The key enabler to achieve the benefit of the generator in the center is one-piece frame construction for four point support. Other factors are generator leg structures for jack and slide maintenance provisions, removable generator connections to support jack and slide and plant civil engineering to support jack and slide provisions. In addition, the generator is capable of receiving steam turbine torque from the collector end.
Requirements & Constraints

Availability
The jack and slide provisions for the generator shorten generator outages. As previously described, GT outage durations are shorter than solid coupled single-shaft units because the clutch allows access to the GT for maintenance up to 3 days earlier.

Grid Connection
The center-mounted generator requires a slightly longer path to the grid interconnect vs. the end-mounted generator.

System Interactions & Engineering Requirements

GENERATOR IN THE CENTER IMPACTS:

P90 Structures
Unit interconnect structures and generator IPB bridge.

P91 Foundations
Foundation designs with jack and slide provisions for generator maintenance.

B30 Steam Turbine Unit
Front standard with clutch.

E10 Generator
Generator requires one piece frame for 4 point jack and slide foundation application.

E20 Electrical Evacuation
ISO-phase bus shifted to center of building compared to generator on end design.

Physical Implementation

Construction
With the incorporation jack and slide provisions, the erector has the option of threading the generator rotor (when required) outside the building or in the maintenance position prior to setting on the foundation. This may be advantageous at locations where lay down space is not available.

Maintenance Special Tooling
The GE standard offer utilizes jack and slide tooling for generator maintenance. Alternatively, other provisions can be requested, such as maintenance heavy lift gantry plan or a building crane capable of lifting the generator with the stator installed.
1.1.5 Segregation of Construction Disciplines and Layout Considerations for Construction Scheduling

Why It Matters
By segregating the majority of mechanical and electrical BOP components, the contractor has less interference during the execution of the installation scope. This segregation and scope planning allows for a more centralized work focus for the individual trades and limits work area interferences and delays due to readiness for trade handover. Generally the order of trade installation is Civil, Structural, Mechanical, Electrical, and Controls. Segregating the majority of the electrical and mechanical scope allows prioritization of civil structural work needed to support early mechanical installation. That in turn enables a high level of parallel electrical installation to take place. GE’s preferred layouts consider these construction sequencing and equipment segregation attributes. These layout attributes are key contributors to improving the notice to proceed (NTP) to commercial operating date (COD) schedule.

This work split also simplifies planning for constructors who have adopted Work Face Planning. By enhancing the layout for schedule, the customer benefits from reduced project overhead and lower total installed cost for the project.

Key Enablers
GE’s layout segregates mechanical and electrical disciplines. This segregation delivers a balanced approach to equipment positioning, interconnection methods, scheduling and material quantities to reduce total installed cost.

GE-preferred layouts support shorter installation schedules by utilizing preformed/modular components such as the consolidated plant electrical room described later in this document. The layouts also reduce complex site installation activities and consider the overall schedule when specifying configuration elements. An example of this is avoiding the routing of drains or services under main circulating water (MCW) piping. MCW piping is normally the first underground system installed. Installing drains under MCW requires either early engineering of the system or extra excavation later in the schedule to install the drains. This adds interference in the work areas for the deep excavation, risk to MCW installation and complicates what should be a very simple work phase. GE’s preferred layouts avoid many of these complex system intersections and scheduling issues.

Requirements & Constraints
Site considerations often require adapting reference layouts. In the case of constricted plant footprints, consideration should be given to relocating other balance of plant equipment in lieu of modifying the power island layout. Construction schedules significantly benefit from the layout. Changes to this layout concept could increase construction and maintenance schedules or require alternate features and perhaps cost to maintain these schedules.

System Interactions & Engineering Requirements
Because this plant layout governs the placement of almost all plant power island equipment, the engineering of almost all systems are affected. Each system must consider the interface needs to integrate with other equipment in the layout drawing.

Physical Implementation
The GE suggested layout provides significant benefits to multiple physical implementation attributes across the construction, commissioning and O&M areas. Examples include opportunities for parallel work efforts, commissioning simplification and maintenance access.
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1.2 Layout for Multi-Shaft Configuration

What It Is

The Multi-Shaft (MS) Combined Cycle Plant layout has many features which support schedule, total installed cost and maintainability needs. Each feature will be discussed in more detail in their individual chapters. They are:

- Side exhaust steam turbine (ST)
- Modularized gas turbine (GT) compartment
- MS side exhaust steam turbine generator in low bay
- Enhanced GT building for MS configurations
- MS Electrical Room (E-Room)
- Low ST centerline height

The enhanced layout includes additional attributes:

- A separate turbine hall or space allocation for a maintenance gantry crane to support gas turbine servicing
- Segregated electrical discipline scope including MS E-Room
- Truck access and crane planning for gas turbine maintenance
- Low bays utilized for generators and BOP equipment
- Heat Recovery Steam Generator (HRSG) feed pumps located outboard (for large HRSGs) to relieve piping congestion and improve construction access

Compact GT Power Island based on Modular GT Compartment with GE Engineered Interconnecting Systems

- Lower Bays Utilized for Generators and BOP Equipment
- For Large HRSGs Locate HRSG Feed Pumps Outboard to Relieve Piping Congestion and Improve Construction Access Between HRSGs
- Gas Turbine Separate Turbine Hall or External Maintenance Gantry Crane
- Truck Access and Crane Planning for Gas Turbine Maintenance
- Segregate Electrical Discipline Scope Including Optional MS E-Room
- Roadway for Construction and Maintenance Access
1.2.1 Layout Provision for Gas Turbine Hall or Maintenance Gantry

Why It Matters
As the GT units are growing in output, size and weight, the mobile cranes needed to perform maintenance activities are becoming more difficult to obtain, schedule and erect on site, especially in small footprint sites. GE-preferred layouts allocate space for an optional gas turbine hall or gantry crane. The hall design includes a crane sized to support GT rotor removal. For plants with outdoor gas turbines, the layout includes space reserved for gantry support columns. This supports the option to install a gantry crane to span both GT units. A permanent gantry crane will reduce outage schedule risk by being immediately available for planned or unplanned outage events.
Key Enablers

The gas turbine power island layout includes spacing provisions for columns adjacent to the GT compartment to support a maintenance gantry, and access roadway space for lift and laydown zones under the crane’s rails. An angled GT air inlet reduces the crane rail height.

Requirements & Constraints

Availability requirements may require a permanent maintenance crane or a GT building to reduce outage durations. The main constraints for the crane/building design are seismic, wind and snow loads for local code compliance.

System Interactions & Engineering Requirements

The turbine hall or external maintenance crane options for GT maintenance impacts these major systems:

**P90 Structures**
Additional crane structure and interfaces with adjacent equipment.

**P91 Foundations**
Outdoor units – consider column footings in original configuration for lowest capital expenditure (CAPEX) retrofit.

**P92 Buildings**
Additional hall (building) for the GT with turbine hall option.

**P93 Cranes**
Additional crane(s) for GT installation and servicing.

**P70 HVAC**
Additional HVAC for GT hall option.

**T40 GT Exhaust**
Interface with turbine hall.

**T50 GT Inlet**
Interface with turbine hall.

Physical Implementation

**Construction**
Material handling and laydown.

**Operations & Maintenance**
Maintenance predictivity, laydown and lifting needs.
1.2.2 Access Roadways and Crane Planning

Why It Matters

Access roadways with the necessary gas turbine centerline spacing have multiple functions. The roadways (shown in gray below) create a flow through the material delivery path. This is important for movement-intensive construction and maintenance activities such as GT installation, maintenance piping disassembly and GT compartment breakdown. They also provide laydown space for critical parts while allowing access for deliveries.

The roadways offer the footprint necessary to take advantage of side load, heavy lift options for major equipment like the gas turbine, generator and ST inlet and exhaust. This is a significant schedule risk reduction feature that takes these heavy lifts from a sequential series to a possible parallel schedule to accommodate delivery delays.

The roadways also provide easy access to some of the most critical auxiliary systems including lube/seal oil, HRSG feed pumps and power evacuation equipment.
Key Enablers
The key enablers to achieve these benefits are GT centerline spacing to allow roadways, layout reservations for crane placement, and suitable placement of auxiliary equipment.

Requirements & Constraints
Site considerations often require adapting reference layouts. In the case of very narrow plant footprints, serious consideration should be given to relocating other balance of plant equipment in lieu of eliminating the side access roadway. Maintenance and construction schedules are the primary requirements affected by the side access roadways and crane placement recommendations. Changing these features will require alternative planning or designs to maintain the same schedules. Alternative configurations require review for impact.

System Interactions & Engineering Requirements
The side roadway and crane placement reservations impact:

**P90 Structures**
Unit centerline spacing.

**P91 Foundations**
Loading on roadway to allow rotor laydown and heavy lift delivery.

**P92 Buildings**
For units with a gas turbine hall, sufficient width between gas turbines to accommodate roadway.

**P93 Cranes**
Longer crane trolley needed to span roadway.

Physical Implementation

**Layout**
When customizing the layout for project needs, keep roadway locations clear of permanent equipment. Ensure interface changes don’t encroach on the roadway.

**Lifting Capability/Availability Heavy Haul Gantry**
Provide sufficient footprint along side shaft line for loading of GT generator, GT inlet and GT exhaust to foundation.

**Material Handling**
Speeds material handling operations by limiting the travel distance for the crane hook and facilitates the option for additional rubber tire lifting equipment to supplement the building crane to expedite installation and maintenance.

**Maintenance Laydown**
For units with a gas turbine hall, indoor laydown is provided for critical equipment.

**Maintenance**
The GE-suggested layout provides access to critical unit and accessories.

**Maintenance Predictivity**
Schedules assume short crane travel from equipment centerline to roadway. The roadway also offers the option of adding rubber tire cranes to improve outage schedules.
1.2.3 Low Bays Utilized for Generators and BOP Equipment

Why It Matters

Equipment that has to be enclosed but doesn’t need a building crane can be housed in a low bay building to achieve significant cost savings (see MS, ST, generator sections). Use of low bays for these portions of the layout can reduce both total installed cost and schedule risk.

- Low Bay Over Condensate Pumps
- Low Bay Over Condenser
- Low Bay Over Generator For ST
- Low Bay Over Generator For GT

NOTE: If the gas turbines are in a building there would be an additional low bay over the GT lube oil module
Key Enablers

- A side exhaust or axial steam turbine to allow low centerline height. Raising centerline height makes generator servicing unmanageable from the ground level. That means the building crane and large operating deck space would be needed for generator rotor removal.

- Removable low bay roof panels and other mobile crane access points for major component replacement. Examples would be condensate pumps, generator rotor transport and condenser water boxes for tube pull.

- A generator rotor removal system that does not require a permanent crane. Examples are a portable lift or rail system with low capacity trolley hoists at the generator end covers.

Requirements & Constraints

The building configuration and features must support the installation and maintenance requirements of components in these areas. The CAPEX savings from the low bays should be balanced against any special maintenance or installation needs for the site. The low bays in this ST building design reduce initial cost, even when special features like removable roof panels are incorporated.

Location Geologic-Seismic Zone

The standard plant pier configuration is based on a moderate seismic zone. Minor modifications are required to accommodate higher seismic locations.

Availability

Equipment maintenance requirements.

System Interactions & Engineering Requirements

Due to their smaller size, low bays and their related systems have reduced material quantities compared to high bay sections.

P91 Foundations

Low bay foundations have smaller dimensions due to reduced load.

P92 Buildings

A smaller building structure is required.

P93 Cranes

Lower travel distance requirements for building crane.

P74 HVAC

Lower building volume reduces the HVAC system size.

Physical Implementation

- Normal construction methods
- Maintenance lifting and access needs
1.2.4 **Outboard HRSG Feed Pumps for Large HRSGs to Relieve Piping Congestion and Improve Construction Access**

**Why It Matters**

For multi-shaft gas turbine combined cycle (CC) plants under construction or in maintenance mode, the area between the HRSGs and the main steam pipe rack can be extremely congested. It is one of the critical construction pinch points and interference zones due to the high density of activities later in the project cycle. There is a lot of competition for mission-critical equipment such as cranes and scaffolding. Locating the feed pumps outboard of the HRSGs removes a portion of the pipework and electrical scope to reduce congestion. Additional benefits include better feed pump maintenance access, room for an access roadway and more space for the central crane needed for HRSG erection.
Key Enablers
To achieve the benefits of an outboard feed pump, an HRSG with low pressure (LP) drum downcomers with economizer connections mirrored to outboard is needed.

Requirements & Constraints

Schedule Predictability
Reduced interference and scope loading in the HRSG “valley” area.

Availability
Improved access to feed pumps for installation and maintenance.

System Interactions & Engineering
Requirements

OUTBOARD HRSG FEED PUMPS IMPACT:

TP90 Structures
Pipe Rack.

B10 Feedwater
Routing to outboard of HRSG.

B20 HRSG
LP drum and economizer connections.

P91 Foundations
Foundations feed pump and pipe rack.

P95 Roads
Enables access roadway.

Physical Implementation

Interfaces
HRSG LP drum and economizer connections mirrored.

Lifting/cranes
More space for cranes in HRSG “valley”.

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1.2.5 Segregation of Mechanical and Electrical Disciplines and Layout for Installation Schedule

Why It Matters

By segregating the majority of mechanical and electrical Balance of Plant components, the contractor experiences less interference in the execution of the installation. It allows for a more centralized scope of work for the individual trades and limits work area interferences and delays due to trade handover issues. Generally the order of trade installation is Civil, Structural, Mechanical, Electrical, and Controls. Segregating the majority of the electrical and mechanical scope allows prioritization of civil structural work to support early mechanical installation. That in turn enables a high level of parallel electrical installation. GE’s preferred layouts consider these construction sequencing and equipment segregation attributes. These layout attributes are key contributors to improving the construction schedule. This work split also simplifies planning for constructors who have adopted Work Face Planning. By enhancing the layout for schedule, the customer benefits from reduced project overhead and lower total installed cost for the project.
Key Enablers
The segregation of mechanical and electrical disciplines delivers a balanced approach to equipment positioning, interconnection methods, scheduling and material quantities to reduce total installed cost.

GE-preferred layouts support shorter installation schedules by utilizing preformed/modular components such as the consolidated plant electrical room described later in this document. The layouts also reduce complex site installation activities and consider overall schedule when specifying configuration elements. An example of this is avoiding the routing of drains or services under main circulating water (MCW) piping. The MCW piping is normally the first underground system installed. Installing drains under the MCW piping requires either early engineering of the system or extra excavation later in the schedule to install the drains.

This adds interference in the work areas for the deep excavation, risk to MCW installation and complicates what should be a very simple work phase. GE’s preferred layouts avoid many of these complex system intersections and scheduling issues.

Requirements & Constraints
Site considerations often require adapting reference layouts. In the case of constricted plant footprints, consideration should be given to relocating other balance of plant equipment in lieu of modifying the power island layout. Construction schedules significantly benefit from the layout. Changes to this layout concept could increase construction and maintenance schedules or require alternate features and perhaps additional cost to maintain these schedules.

System Interactions & Engineering Requirements
Because this plant layout governs the placement of almost all plant power island equipment, the engineering of almost all systems is affected. Each system must consider the interface needs to integrate with other equipment in the layout drawing.

Physical Implementation
The GE-preferred plant layout provides significant benefits to multiple physical implementation attributes across the construction, commissioning and O&M areas. Examples include opportunities for parallel work efforts, commissioning simplification and maintenance access.
1.3 Single-Shaft vs. 1x1 Multi-Shaft

What It Is

Single-Shaft (SS) denotes the power island configuration where the gas turbine and steam turbine share one generator and are connected on one shaft. Multi-shaft (MS) refers to power island configurations where the gas turbine(s) and generator(s) are separate from the steam turbine and its generator. 1x1 denotes that there is one gas turbine supplying steam energy to one steam turbine.

Why It Matters

For power generation and most cogeneration applications, a single-shaft is typically the lowest cost integrated solution when compared to a 1x1 Multi-shaft configuration. The primary driver to lower cost is the need to purchase and install one less generator, associated electrical bus, step up transformer, high yard connection, power train foundation and building.

Occasionally, plant requirements and constraints may not support applying the single-shaft solution. These exceptions are noted in the Requirements & Constraints section below.

Key Enablers

The key enablers of a 1x1 single-shaft configuration are:

1. An integrated rotating power train of gas turbine, steam turbine and generator. A key effort is ensuring acceptable rotor dynamics with all equipment connected under all operating conditions.

2. Where the generator is placed between the steam turbine and gas turbine, the generator must be capable of receiving steam turbine torque from the collector end.

3. A combined lube oil system (gas and steam turbine plus generator) prevents inadvertent operation and attendant machine damage due to an isolated lube oil supply.

Requirements & Constraints

For most Combined Cycle offers, the plant requirements and constraints can be met with the GE single-shaft configuration. The few exceptions are discussed below. In some cases, plant output and peak output demands exceed single-shaft capabilities. Output demand covers
CHAPTER 1.1  CHAPTER 1.2  CHAPTER 1.3  CHAPTER 1.4  CHAPTER 1.5

9HA.01 1x1 SS

Aux Low Bay
Condenser Low Bay
Cooling Water Low Bay
GT, ST & Gen High Bay with Integrated ST-GT-Gen train

9HA.01 1x1 MS

Aux Low Bay
Condenser Low Bay
GT High Bay
GT Gen Low Bay
GT Lube Oil Low Bay

Cooling Water Low Bay
both electrical and process steam. These output limits are typically process steam extraction leaving at least 10% ST exhaust flow, supplemental firing up to 10% of unfired combined cycle output or ST output greater than 300 MW. Consult with engineering specialists when needs are within +/-5% of these levels to see if a single-shaft is still possible. When process steam demand requires all steam to be extracted prior to the condenser, a clutch is applied to allow the low pressure (LP) ST to be shut down. In this case, a multi-shaft configuration will be offered due to the complex interaction of train dynamics and control when the LP section is not spinning (clutch disengaged). When the supplemental firing need exceeds single generator or steam turbine-to-generator connection (clutch and collector end drive) capabilities, a multi-shaft configuration will be offered.

Customers may require the ability to perform major steam turbine service with the GT operational. In these cases, major is defined as any service requiring the opening of the steam turbine pressure boundary. The challenges of isolating lube oil and hydraulic systems, along with performing work in close proximity to operating equipment with hydrogen-cooled generators, effectively prevent this operation on a single-shaft unit. Instead, a multi-shaft configuration with a bypass stack between the GT exhaust and Heat Recovery Steam Generator (HRSG) is offered. A blanking plate is installed to ensure isolation of the HRSG steam cycle from the exhaust. The location of the steam turbine and its generator in a separate area with a dedicated lube oil and hydraulic system allow major steam turbine maintenance while the gas turbine continues to run.

Customers may require early gas turbine installation to generate power while the bottoming cycle is still under construction or part of a longer range add-on. This is known as phased installation. Single-shaft units typically require hydrogen generators due to their high output. Many phases of bottoming cycle construction call for either the hydrogen generator to be shut down or effectively isolated from construction work to allow hot work near hydrogen systems. Also, the lower lube oil system demand during gas turbine-only operation must be accommodated. Significant gas turbine downtime is needed to finish construction of integrated systems such as lube oil. Due to these issues, multi-shafts are generally specified for phased installations.

From a schedule perspective, both single-shaft and multi-shaft side exhaust configurations are capable of a 24-month Notice To Proceed (NTP) to Commercial Operation Date (COD) schedule. However, the MS activity detail between over-the-bolts major equipment like the GT, ST and generator(s) installation to first fire is different due to the two shaft lines and accessory details.
System Interactions & Engineering Requirements

In power generation applications, 25 of the 96 Systems (26%) are impacted in some way when comparing Single-Shaft to Multi-Shaft. The comparison table below highlights the significant cost drivers.

### Major Quantities Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>1x1 9HA.01 SS</th>
<th>1x1 9HA.01 MS</th>
<th>Delta (MS-SS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>1 – 600MW</td>
<td>1 – 400MW, 1 – 200MW</td>
<td>+1 Generator &amp; related accessories</td>
</tr>
<tr>
<td>General Station Unit Transformer</td>
<td>1 – 750MVA</td>
<td>1 – 500MVA, 1 – 250MVA</td>
<td>+1 GSUT</td>
</tr>
<tr>
<td>Bus Duct Length</td>
<td>3x58m=174m</td>
<td>GT: 3x60m ST: 3x51m = 333m</td>
<td>+159m (91%)</td>
</tr>
<tr>
<td>Lube Oil Tanks</td>
<td>1</td>
<td>2 total, 1 for GT and 1 for ST</td>
<td>+1 Lube oil tank</td>
</tr>
<tr>
<td>Steam Pipe &amp; Rack</td>
<td>Base</td>
<td>+10 m each HP, HRH, CRH &amp; LP Steam X Tons</td>
<td></td>
</tr>
<tr>
<td>High Bay Buildings</td>
<td>57.5x26.5x20.2(m) Vol: 30,780m³</td>
<td>GT: 28.75x13x19(m) Vol: 7,100m³ ST: 26.5x24x19(m) Vol: 12,080m³</td>
<td>-11,600m³ (-38%)</td>
</tr>
<tr>
<td>Generator Low Bays</td>
<td>Generator in high bay</td>
<td>ST Gen: 22x15x19(m) Vol: 6,270m³</td>
<td>+1,420m³</td>
</tr>
<tr>
<td>Condenser Low Bay</td>
<td>26.3x11.7x19(m) Vol: 5,850m³</td>
<td>26.5x11.7x19(m) Vol: 5,890m³</td>
<td>+40m³ (1%)</td>
</tr>
<tr>
<td>Aux Low Bay</td>
<td>26.3x7.65x5(m) Vol: 1,010m³</td>
<td>GT LO: 19.1x7.75x7.8(m) Condenser aux: 26.5x7.3x5(m) Vol: 1,150m³</td>
<td>+1110m³ (1%)</td>
</tr>
<tr>
<td>Cooling Water Low Bay</td>
<td>17.7x15.7x5(m) Vol: 1,390m³</td>
<td>24x7.2x 7(m) Vol: 1,210m³</td>
<td>-180m³ (14%)</td>
</tr>
<tr>
<td>Power Island Footprint</td>
<td>143x91m=13,013m³</td>
<td>172x91m=15,652m³</td>
<td>+2639m² (20%)</td>
</tr>
<tr>
<td>Excitation (Ex) Compartments &amp; Transformers</td>
<td>1</td>
<td>1 LC/Ex compartment &amp; transformer for GT 1 Ex compartment &amp; 1 transformer for ST</td>
<td>+1 Excitation compartment</td>
</tr>
</tbody>
</table>
There are numerous differences across the plant systems. The table below describes the impacts to each system.

<table>
<thead>
<tr>
<th>System</th>
<th>SS</th>
<th>1x1 MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>T50 GT Inlet</td>
<td>Side inlet</td>
<td>Located up and over generator</td>
</tr>
<tr>
<td>B31 ST Unit</td>
<td>Integrated with GT and Generator, Clutch between ST and Generator</td>
<td>Separate unit</td>
</tr>
<tr>
<td>E11 Generator</td>
<td>Single generator sized for combined output of GT and ST, hydrogen cooled, larger units water cooled</td>
<td>Two separate generators. Hydrogen or air cooled (size limited)</td>
</tr>
<tr>
<td>E12 (Generator) Gas Cooling</td>
<td>Hydrogen</td>
<td>Air (size limited) or hydrogen</td>
</tr>
<tr>
<td>E13 Excitation</td>
<td>One system</td>
<td>Two systems, one for each generator</td>
</tr>
<tr>
<td>E14 (Generator) Protection</td>
<td>One system</td>
<td>Two systems, one for each generator</td>
</tr>
<tr>
<td>E20 Electrical Evacuation</td>
<td>Generator step up (GSU) transformer rated for single-shaft combined generator size. Iso-phase bus duct for one generator</td>
<td>Separate GSU transformer for each generator for a total of two. No circuit breaker for ST generator. Iso-phase bus ducts for two generators.</td>
</tr>
<tr>
<td>E21 Voltage Conversion</td>
<td>One step up transformer</td>
<td>Two step-up transformers, one per generator</td>
</tr>
<tr>
<td>E22 High Voltage</td>
<td>High side connections to one step up transformer</td>
<td>High side connections to two step-up transformers</td>
</tr>
<tr>
<td>E322 Low Voltage</td>
<td>Cabling and switchgear to single lube oil and hydraulic system</td>
<td>Cabling and switchgear to two lube oil and sometime two hydraulic systems (when GT has hydraulics)</td>
</tr>
<tr>
<td>P11 GT Control</td>
<td>No lube oil &amp; generator control. Lube oil &amp; generator control by P12 ST control system</td>
<td>Lube oil &amp; GT generator control.</td>
</tr>
<tr>
<td>P12 ST Control</td>
<td>Lube oil &amp; generator control for GT and ST</td>
<td>Lube oil &amp; generator control for ST</td>
</tr>
<tr>
<td>P13 Power Island Control</td>
<td>Logic and controls for integrated shaft line &amp; system starting, operation and shutdown.</td>
<td>Logic and controls for separate shaft line &amp; system starting, operation and shutdown</td>
</tr>
<tr>
<td>P31 Hydraulic Oil/ Lift</td>
<td>Integrated system for ST and GT</td>
<td>Separate systems for GT and ST</td>
</tr>
<tr>
<td>P32 Seal Oil</td>
<td>One system</td>
<td>If two hydrogen cooled generators, two systems. No seal oil for air cooled Generator(s)</td>
</tr>
<tr>
<td>P33 Lube Oil</td>
<td>Combined GT, ST, gen lube oil system. Lube oil supplied to clutch.</td>
<td>Separate systems for GT-gen and ST-gen units. Clutch lube oil needed only on clutched LP designs</td>
</tr>
<tr>
<td>P41 H₂, CO₂, N₂ Storage and Distribution</td>
<td>Single connection for E12 gas cooling system for H₂ and CO₂</td>
<td>Each hydrogen cooled generator (up to two) connects to S E12 gas cooling system for H₂ and CO₂. No connections for air cooled generators.</td>
</tr>
<tr>
<td>P70 HVAC</td>
<td>Shared HVAC for main building</td>
<td>Separate building for GT and ST need separate HVAC systems</td>
</tr>
<tr>
<td>P81 Service Air</td>
<td>Shared service for main building</td>
<td>Separate building for GT and ST need separate Service air systems</td>
</tr>
<tr>
<td>P82 Instrument Air</td>
<td>Single-shaft configuration equipment locations &amp; tubing runs</td>
<td>Multi-shaft configuration equipment locations &amp; tubing runs</td>
</tr>
<tr>
<td>P91 Foundations</td>
<td>Combined GT, ST, gen foundation, combined building foundation, combined lube oil and hydraulic foundation</td>
<td>Separate foundations for GT-gen and ST-gen, their building and lube oil and hydraulic systems</td>
</tr>
<tr>
<td>P92 Buildings</td>
<td>Combined GT, ST, gen building for indoor units</td>
<td>Separate building for GT-gen and ST-gen when indoors</td>
</tr>
<tr>
<td>P93 Cranes</td>
<td>Shared high capacity crane for GT, ST, gen capable of lifting ST rotor, generator rotor, GT rotor</td>
<td>When equipment located indoors, separate high capacity cranes for GT-gen and ST-gen capable of lifting GT rotor and ST rotor respectively. Generator rotors not accessible by building crane.</td>
</tr>
<tr>
<td>P94 Duct Banks</td>
<td>Compatible to single-shaft layout</td>
<td>Compatible with MS layout</td>
</tr>
<tr>
<td>P95 Roads</td>
<td>Compatible to single-shaft layout</td>
<td>Compatible with MS layout</td>
</tr>
</tbody>
</table>
Physical Implementation

For power generation applications, the following table summarizes the physical implementation attribute differences between single-shaft and 1x1 multi-shaft (MS) configurations. Overall, 15 of 35 (43%) of the attributes are affected.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>SS</th>
<th>1x1 MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Single train</td>
<td>Two separate power trains, side by side parallel shaft lines</td>
</tr>
<tr>
<td>(Construction) Interfaces</td>
<td>Common lube oil, seal oil and hydraulic system. Lube oil supplied to clutch.</td>
<td>Separate lube oil, seal oil (hydrogen cooled generators) and hydraulic systems. Clutch lube oil needed only on clutched LP designs</td>
</tr>
<tr>
<td>(Construction) Interferences</td>
<td>Layout specific (example air inlet duct must be maneuvered side-ways into building)</td>
<td>Layout specific (example: congestion occurs when installing GT air inlet over generator while in parallel installing generator and gas turbine installation)</td>
</tr>
<tr>
<td>Modularity</td>
<td>Modular GT compartment engineered for single-shaft. Single lube oil, seal oil and hydraulic module</td>
<td>Modular GT compartment engineered for multi-shaft. Two separate lube oil, seal oil and hydraulic modules</td>
</tr>
<tr>
<td>Cranes</td>
<td>Indoor, single high capacity crane capable of lifting ST rotor, generator rotor, GT rotor. High capacity mobile crane required for HRSG erection</td>
<td>Each unit located indoors (ST and/or GT) have separate high capacity cranes capable of removing ST rotor and GT rotor respectively. Generator rotors not accessible by building crane. High capacity mobile crane required for HRSG erection and outdoor GT &amp; ST unit erection</td>
</tr>
<tr>
<td>Gantry</td>
<td>Construction heavy lift gantry needed for GT and generator, optional for ST LP turbine</td>
<td>Construction heavy lift gantry needed for GT and generators, optional for ST LP turbine. Must be moved between GT and ST unit buildings</td>
</tr>
<tr>
<td>(Construction) Laydown</td>
<td>Single-shaft layout specific</td>
<td>Multi-shaft layout specific</td>
</tr>
<tr>
<td>Cleaning</td>
<td>Single lube oil system</td>
<td>Two lube oil systems</td>
</tr>
<tr>
<td>System Tuning</td>
<td>Single generator systems</td>
<td>Two set of generator systems</td>
</tr>
<tr>
<td>(Construction) Spares</td>
<td>Single generator, lube oil, seal oil &amp; hydraulic and step-up transformer spares. Clutch spares</td>
<td>Two sets of generator, lube oil, seal oil (if present) hydraulic (if present on GT) system spares</td>
</tr>
<tr>
<td>Maintenance</td>
<td>One generator to maintain. Clutch to maintain</td>
<td>Two generators to maintain</td>
</tr>
<tr>
<td>(Maintenance) Spares</td>
<td>Single generator, lube oil, seal oil &amp; hydraulic and step-up transformer spares. Clutch spares</td>
<td>Two sets of generator, lube oil, seal oil (if present) hydraulic (if present on GT) system spares</td>
</tr>
<tr>
<td>(Maintenance) Laydown</td>
<td>Single-shaft layout specific. See layout discussion for detail</td>
<td>Multi-shaft layout specific. See layout discussion for detail.</td>
</tr>
<tr>
<td>(Maintenance) Lifting Needs/Availability</td>
<td>Single generator, lube oil, seal oil &amp; hydraulic systems. Generator rotor pulled with building crane. Clutch</td>
<td>Two different size/models generator, lube oil, seal oil (if present) hydraulic (if present on GT) systems. Generator pull of GT and ST generators with temporary equipment.</td>
</tr>
<tr>
<td>(Maintenance) Assembly Disassembly</td>
<td>Generator disconnected from ST and GT, slide sideways to pull rotor</td>
<td>Generator rotor pulled without moving generator</td>
</tr>
</tbody>
</table>
Combined Cycle Power Plant Best Practices 2015

1.4  Preferred Steam Turbine Exhaust Direction (When to Bid Down vs. Single Side vs. Axial)

What It Is

Two-flow low pressure steam turbines can exhaust to condensers either in the down direction or to the side. Side exhaust steam turbines can exhaust to one side (single side) or both sides. Axial flow low pressure steam turbines can exhaust to a condenser either in the down or axial direction. Four flow low pressure configurations exhaust to condensers only in the down direction.

Why It Matters

Choosing the right steam turbine exhaust direction for two-flow and axial-flow pressure steam turbine configurations provides significant plant cost savings. An axial or single side exhaust steam turbine (ST) retains the performance of a down exhaust steam turbine (of the same capacity) in a smaller building volume. As shown in the figures below, lowering the centerline from ~12-13 meters to ~5.5-6.5 meters for both single-shaft and multi-shaft configurations generally requires less concrete and a less expensive building.

Additionally, the use of a low bay configuration over the ST generator and condenser in a multi-shaft configuration means that the building columns for this part of the structure only need to be engineered for environmental conditions, not to handle the crane loads associated with steam turbine maintenance.

The figures below elaborate on the major benefits of a side exhaust. In a typical installation, balance of plant savings are approximately $7.1M for single-shaft and $6.3M for multi-shaft configurations.

<table>
<thead>
<tr>
<th>Quantity Comparison – Indoor with ST building</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7HA SS</strong></td>
</tr>
<tr>
<td>Concrete* (yds³)</td>
</tr>
<tr>
<td>7,777 (Down)</td>
</tr>
<tr>
<td>6,336 (Side)</td>
</tr>
<tr>
<td>-1,441 (-15%)</td>
</tr>
<tr>
<td>Steel (MT)</td>
</tr>
<tr>
<td>950 (Down)</td>
</tr>
<tr>
<td>725 (Side)</td>
</tr>
<tr>
<td>-221 (-24%)</td>
</tr>
<tr>
<td><strong>9HA 2x1 MS</strong></td>
</tr>
<tr>
<td>Concrete* (yds³)</td>
</tr>
<tr>
<td>5,692 (Down)</td>
</tr>
<tr>
<td>4,694 (Side)</td>
</tr>
<tr>
<td>-998 (18%)</td>
</tr>
<tr>
<td>Steel (MT)</td>
</tr>
<tr>
<td>951 (Down)</td>
</tr>
<tr>
<td>860 (Side)</td>
</tr>
<tr>
<td>-291 (-31%)</td>
</tr>
</tbody>
</table>

*Equipment + Building Foundation
Key Enablers

A side exhaust steam turbine requires a semi-rigid connection between the low pressure (LP) hood and condenser to allow differential settlement of the major foundation structures without overstressing the LP hood or impacting clearance control inside the steam turbine. The semi-rigid connection also allows support of the condenser from the bottom of the structure, not at the level of the turbine centerline (5.5 m), reducing the complexity of the condenser foundation.

In multi-shaft configurations, hydraulic jacks are used to remove the generator rotor from the stator. This eliminates the need for a heavy lift crane over the generator, permitting a low bay structure in this area. In a single-shaft plant where the generator does not have a “free end,” hydraulic equipment is used to first pull the entire generator out of the shaft centerline. But since it is still located inside the crane rails used for GT and ST maintenance, the crane is used to remove the rotor from the stator.

A leads up generator on single-shaft units allows the generator to be pulled sideways to clear the shaft centerline for rotor removal. In the case of a multi-shaft unit, a leads up generator simplifies constructability and minimizes the length of isophase bus duct from the generator to the step-up transformer.

Requirements & Constraints

Site conditions combined with water supply capabilities and grid connection electrical output capacity will drive the selection of the gas and steam turbine configuration. The resulting steam production and condenser pressure will determine the volume of steam leaving the steam turbine. When the volume flow of steam is appropriate for a single flow (axial exhaust) or double flow (single side exhaust) steam turbine a low centerline configuration can be used. In situations where the volume flow of steam requires two double flow low pressure (LP) sections (also known as a four-flow low pressure section), a more traditional down flow, high centerline configuration can be used. In situations where the high centerline construction is preferred. Most commonly this would be when acreage is limited. For example, in a repowering scenario it may be necessary to use a down exhaust to fit into structures at an existing power station.

Legacy Practice

Drive Through Bay for Service

State-of-the-Art

Crane for Service

Quantity Comparison – Indoor with ST building

<table>
<thead>
<tr>
<th>9HA 2x1</th>
<th>Legacy</th>
<th>State-of-the-Art</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (yds³)</td>
<td>4,694</td>
<td>4,219</td>
<td>-475 (-10%)</td>
</tr>
<tr>
<td>Steel (MT)</td>
<td>660</td>
<td>580</td>
<td>-80T (-12%)</td>
</tr>
</tbody>
</table>
System Interactions & Engineering Requirements

P93 Crane
For a low centerline multi-shaft plant, the crane rails for maintenance of the steam turbine are oriented transverse to the shaft centerline minimizing the amount of building steel sized to support these loads.

P92 Buildings
The ST building features a P95 access road alongside the P91 steam turbine foundation to minimize the transit of heavy equipment lifts both during initial construction and maintenance.

P91 Foundation, B34 Bypasses, B41 Condensing Steam, H10 Circulating Water
The foundation (and piping systems) connected to both side and axial exhaust condensers must be engineered to facilitate sliding movement of the condenser. This accommodates thermal growth during transient events and the deflections associated with vacuum loads on the structure.

B35 ST Drains, P30 Oil Systems, P66 Plant Drains
Application of a low centerline foundation results in less vertical drop available for gravity driven piping systems. Attention must be paid to the routing of these lines to ensure adequate service.

Physical Implementation
Gantry structures used for installation of turbine sections are much simpler in a low centerline foundation when compared to lifting to a higher centerline structure. An additional advantage of the low centerline foundation is the ability to use the roadway through the building to stage heavy gantry lifts. Because the centerline components can be lifted in from the side, the erection sequence can be adapted to suit the site-specific delivery schedule and construction conditions more easily. In other words, the assembly of the LP section can proceed independent of loading the HP/IP section since the HP/IP does not need to be lifted through the area where the LP is located. Since the areas where lifting is performed (like a road) will never have piping systems running through them, there is no conflict with waiting on turbine delivery prior to starting construction of the piping systems that will serve it.

In single-shaft configurations, special tooling is needed to pull the generator stator sideways from the centerline for rotor maintenance. This tooling is pre-engineered and pre-staged at strategic locations around the world to support maintenance operations. Specialty subcontractors, already trained in the use of this equipment are brought in to perform this work. In previous configurations, the stator was not pulled to the side, but was jacked vertically until the rotor could be removed by pulling it out of the generator directly over the steam turbine.

In multi-shaft low centerline units, the generator rotor can be pulled out of the stator directly, since the generator is at the end of the unit. Because of the low centerline, rotor removal is possible with a specially engineered rail system supported off the ground level instead of the more traditional approach of using the steam turbine maintenance crane. This system is currently in use with generators coupled to gas turbines and has been demonstrated to be a safe and effective method of pulling the rotor.
CHAPTER 1.5

**Compact Gas Turbine Building for Multi-Shaft Configurations**

**What It Is**
For multi-shaft combined cycle plants, gas turbines (GT) and their generators are usually outdoor units. If environmental requirements such as noise, temperature and precipitation or other customer requirements warrant an indoor solution, the GT is installed in a building.

**Why It Matters**
Buildings, when required, add substantial capital cost to a combined cycle plant. For a typical 2x1 9HA.01 configuration, the cost is ~$7-10 MM ($6-8/kW) depending on GT design needs. Key cost drivers are the building footprint and height requirements.

The GE building concept facilitates construction and maintenance within a compact building configuration. Compared to legacy configurations, building volume is reduced by 34% and steel by 19% (86 metric tonnes) for a typical 2x1 9HA configuration. In a typical installation, the savings is expected to be $2M (~$1.7/kW). Similar savings are achieved for other GT models.

**Key Enablers**
By angling the GT air inlet as shown in the figure at right, the building height and width are significantly reduced. Adding a low-drop telescopic crane to the main crane rail allows installation and removal of the air inlet panels for GT maintenance activities such as rotor removal.

---

*GT Building Elevation*  
*Legacy Design*  
*Compact Design*
Requirements & Constraints

Far-field noise requirements can dictate a need for a GT building. When the noise limit is 58dbA at 122m (400 ft.) or less, GE acoustic engineering specialists should be consulted to determine if a building is needed.

The GE GT and generator package can tolerate most site atmospheric temperature ranges and rain/snow frequency and quantities. However, in extreme cold or snow (e.g., Russia) or rain (e.g., Bangladesh) conditions, GE recommends a GT building for maintenance and constructability. Typically, conditions that warrant further discussion between the end user and plant constructor are:

- Ambient temperature extremes colder than -30°C (-20°F)
- Snow amounts > 1m (40 inches) /year
- Rain amounts > 1.5m (60 inches)/year

In these situations, the GE application team will meet with the customer and contractor to discuss applying a GT building and to determine the final offering. Customers usually request indoor GTs under these circumstances.

System Interactions & Engineering Requirements

Building

Building height will be determined by the lifting requirements to remove the GT rotor for servicing. The building must be capable of supporting a crane that can lift the GT rotor.

The addition of a GT building system (GE Function P92 Buildings) affects the following other GE functions:

P91 Foundations

A suitable foundation is needed for the building that considers the site soil conditions, rain and snow loads plus the crane lifting (GE Function P93) capacity.

P93 Cranes

A single main-building crane of sufficient capacity to lift the GT rotor is necessary. The capacity of this crane must be considered in the engineering of building structure (P92) and foundation (P91). In addition, a smaller capacity low-drop telescopic crane capable of lifting the GT inlet panels must be provided as shown in the figure above.

P95 Roads

The addition of a building requires the roadway between gas turbines for multiple GT configurations.

P74 HVAC of Plant Aux

The addition of a building requires HVAC systems suitable to maintain interior conditions based on internal and external heat loads.

T50 GT Inlet

The smaller building requires the GT inlet to have a sloped duct to clear the building crane.

E32 Low Voltage

Additional building lighting, HVAC and crane are powered by this system. They need to be added to the plant electrical load list, single line diagram, cable list, installation drawings and bill of quantities as appropriate. Outdoor lighting in the GT building area must also be adapted for the presence of a structure.
Physical Implementation

The addition of a building affects the physical implementation attributes as compared to an outdoor GT plant.

Layout Interfaces

The typical GE plant 2x1 MS layout will accommodate the GT building without change to equipment and accessory arrangement.

Lifting Capability/Availability Cranes

Placement of the GT will be accomplished by a constructor-provided gantry crane system, regardless of whether the GTs are indoors or outdoors. The building crane will be used in lieu of an outdoor crane for inside building GT accessory, compartment and external component assembly.

Construction Laydown

Laydown space typically provided between the GTs for outdoor units is now inside the building.

Maintenance Laydown Requirements

Laydown space provided between the GTs is now inside the building.

Maintenance Lifting Needs/Availability

Building crane provides for typical GT maintenance including rotor removal. An outdoor crane is not needed for this servicing.

Maintenance Assembly/Disassembly

With a single heavy capacity crane, heavy work on multiple GTs at the same time is not possible. However, since GT maintenance is typically performed sequentially, this does not normally impact servicing outage duration. Note that for added cost, a second heavy-capacity crane can be installed at customer request to provide for simultaneous usage on multiple GTs.

Other

The critical path schedule for the plant is unchanged by the addition of a building. However, the presence of a building does impact the amount of parallel work that can be accomplished with two or more GTs in the multi-shaft configuration. Because of limited unit access, there is limited construction benefit to two heavy-lift capacity cranes. Because of this, the GE standard practice provides one main building crane for indoor units. Outdoor units typically employ two outdoor mobile cranes to support GT accessory and compartment erection.
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2.0 Schedule

A critical factor affecting the Total Installed Cost (TIC) of a new power plant is the amount of time required for plant construction and commissioning. The typical standard for measuring this duration is the time from when the customer issues the official Notice to Proceed (NTP), until the plant is capable of generating full revenue at the plant Commercial Operation Date (COD). OEMs and Engineering, Procurement & Construction (EPC) contractors, strive to cost effectively reduce this NTP-COD schedule in order to reduce plant TIC and provide a more competitive equipment/plant offering and win more orders. For a 1,000 MW combined cycle power plant, the interest charged on the money the typical customer borrows to build the plant averages $2.3 million per month. Shortening the NTP-COD schedule means the customer can generate revenue earlier, pay off their construction loans faster and be more profitable. Plant and equipment offerings with reduced NTP to COD schedules are therefore the most competitive.

NTP-COD schedules can be shortened in a number of ways. Providing the EPC with accurate drawings and information early in the plant bidding and design process allows plant engineering to proceed and be completed more quickly. Such engineering is critical to competitive bidding for sales opportunities as well as timely and smooth plant construction.

Another method for attaining a shorter, more predictable NTP-COD schedule is the reduction in the total volume and complexity of installation work required for GE equipment. The following features all reduce the labor and time required to install/commission GE turbine/generators.

- Modularized gas turbine compartment
- Steam Turbine Installation and Constructability Features
- Lube Oil System Flush Features
- Flanged Steam Turbine Valve Connections

By incorporating the above features and by supplying accurate drawings/information to the EPC, GE enables a faster and more predictable NTP-COD schedule. This results in GE’s equipment being more competitive and also enhances the competitiveness of EPCs that bid for projects with GE equipment.

2.1 Project Schedules for Single-Shaft and Multi-Shaft Plants
2.2 Modularized Gas Turbine Enclosure
2.3 Steam Turbine Installation and Constructability Features
2.4 Lube Oil System Flush Features
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2.1 Project Schedules for Single-Shaft and Multi-Shaft Plants

The project schedule is a comprehensive view of all the elements of bidding and building a power plant. Understanding the key elements of a project schedule is important when determining critical path of the power plant cycle. The schedule or total cycle is usually expressed in months from Notice to Proceed (NTP) to Commercial Operation Date (COD). Several levels of project schedule are used and a Level One (L1) schedule is often included in the contract with the customer.

Different elements of the schedule are owned and controlled by different parties, yet the total project schedule is very important to the economics and competitiveness of a power plant. Without a good and reasonable project schedule, it is possible for an OEM to have the most efficient power generation equipment in the world and still lose a bid because it will take too long to install the power plant. In general, GE’s power generation equipment will be one critical path from NTP to the delivery of the GT, ST and Generator(s). Once delivered, the EPC is typically the critical path for installation and commissioning up to COD.

Single-Shaft – 24 Month Schedule at a Glance

- Parallel Erection of GT/ST/Gen/HRSG
- GT/ST/Gen Flexible Installation Sequence
- Separated Mechanical and Electrical
- Roadway Through Turbine Building
- Low Centerline
- Mechanical Steam Pipe Cleaning
- E-Room Electrical Compartment

Equipment Enablers
- Modularized GT Compartment, Piping and Accessories
- ST Constructability Features
- Side or Axial Exhaust ST, Side Inlet GT

Assumptions
Site access 90 days prior to NTP for Geo-Tech survey, greenfield site, no pilings required, liquid fuel commissioning after COD, customer reliability run requirements add to schedule duration.
The schedule of a CC power plant can range from 24 to 36 months or more, depending on such variables as where it is installed, the climate of that region, the labor force who build the plant, logistics of the project site, etc. GE and the EPC share the critical path of these schedules. Shorter equipment engineering and manufacturing cycles support earlier construction. In addition, there is value in a configuration that is conducive to easy and timely installation. During the bidding phase of a project, the customer puts a value of the schedule and it is factored into their evaluation of the power plant. For recent international projects, the value of one month of the schedule was worth over ~$10.7M of Net Present Value (NPV).

Project schedules for SS and MS differ slightly due to the configuration and layout of the plant. The target for a SS plant is 24 months and for a MS it is 30 months. The primary difference between the durations of SS and MS is the added volume of labor for multiple shaft lines and generators (for a 2x1 that is three shaftlines compared to one in a 1x1) that require more integration and labor to coordinate the commissioning of the power plant.
2.2 Modularized Gas Turbine Enclosure

What It Is
Modularization is used to meet the objectives of high quality, low cost and short lead times. In this case, a modularized gas turbine (GT) enclosure can reduce site installation labor, improves overall quality and maintainability.

Why It Matters
By modularizing the GT enclosure, the gas turbine critical path installation cycle is shortened by 8 weeks and labor reduced up to ~10,000 hours. Packaging piping and valves into modules that stack together to form the enclosure virtually eliminates the need to install them in the field. They arrive at the site fully commissioned and tested, leading to better quality control and less time spent troubleshooting. GE has also extended the scope of modularization to include instrument air and all drain piping within the GT enclosure resulting in more critical maintenance space and easier access. A clean roof configuration is incorporated with no electrical or mechanical equipment located on the roof panels. These panels are engineered with quick removal features for faster GT inspections.

Key Enablers
The enclosure modules have been packaged together to allow for a simplified installation. The modules ship to site with all piping, valves, instrumentation tubing, cable tray and insulation already installed and commissioned in the factory. Instrumentation is mounted to the exterior of the modules and is simply connected to the home-run cable back to the control panel at the site.
The equipment package allows for a construction schedule that is more flexible and enables parallel paths of construction. Once the modules are set in place, work can begin simultaneously to install on-base piping to the gas turbine while crews work separately to join instrumentation to the control system with interconnect cables.

**Modularization Comparison... Cooling and Sealing Air**

**7F.03 Cooling and Sealing Air**
1. Install modules
2. Install piping between GT and modules
3. Insulate field installed piping

<table>
<thead>
<tr>
<th>Results</th>
<th>7F.03</th>
<th>7HA</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install Hours</td>
<td>1,641</td>
<td>850</td>
<td>48%</td>
</tr>
<tr>
<td>Field Welds</td>
<td>74</td>
<td>35</td>
<td>52%</td>
</tr>
<tr>
<td>Field Install Valves</td>
<td>6</td>
<td>0</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Requirements & Constraints**
This feature has been engineered as the standard offering for the 7HA and 9HA configurations. There are no constraints to application.

**System Interactions & Engineering Requirements**
This configuration impacts the gas turbine piping for all of the sub-systems which are packaged inside the gas turbine enclosure. Cooling and sealing air and fuel systems are integrated with the enclosure structure as modularized sections.

**T10 Gas Turbine Unit**
Base piping systems are integrated with the modularized sections of the GT enclosure.
T12 Cooling and Sealing Air
Piping systems are integrated into the modularized sections of the GT enclosure.

T20, 30 Gas Fuel, Liquid Fuel Delivery
Fuel skids are integrated into the modularized sections of the GT enclosure.

P91 Foundation
The foundation needs to account for the modularized GT enclosure.

Physical Implementation
This has a significant impact on the packaging of the GT unit and enclosure.

Layout Location and Interfaces
The layout is not impacted by the modularized enclosure, but interfaces are adjusted to accommodate standardized locations.

Packaging Modularity
Liquid fuel and gas systems now arrive packaged within the GT enclosure structure vs. separate skids.

Construction Connections
Significantly less flanges and welding are required to install modularized sections.

Plant Critical Path
Schedule is improved utilizing a modularized configuration including parallel work paths.
CHAPTER 2.3 Steam Turbine Installation and Constructability Features

What It Is
This is the sequential mechanical erection, oil flush and electrical/controls connection of the steam turbine components and assemblies. Its completion is marked by the ST achieving turning gear status.

Why It Matters
The duration of the steam turbine installation cycle is a primary driver of the total time required to construct a combined cycle power plant. Historical construction installation durations for the D400 have ranged from 8 to 10 months. For GE’s new line of D600 and D650 turbines construction cycles have been reduced to ~5.5 to 6.5 months, depending on the specific model. At the same time, man hours required for turbine installation have been reduced by ~35%. A series (A200, A450 and A650) also include features to reduce installation cycles by 4 to 6.5 months, depending on the configuration. These enhancements allow more ST installation work to be conducted in parallel, resulting in installation times that are faster and less variable. For the customer, that means plant construction costs are lower and more predictable.

Reduction of Construction Cycle

<table>
<thead>
<tr>
<th>&quot;Construct-Ability&quot; Enabling Approach/Feature</th>
<th>Benefit</th>
<th>Cycle Reduction Estimate (Weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards, LP Stationary Parts &amp; Build Stand Arrives Six Weeks Before HP-IP</td>
<td>Set and grout standards early. LP hood &amp; inner casing build parallel path activities</td>
<td>3</td>
</tr>
<tr>
<td>No-Tops-On/Tops-Off Alignment</td>
<td>Removes activities from critical path</td>
<td>4</td>
</tr>
<tr>
<td>&quot;Boltless&quot; LP Diaphragm Support Bars</td>
<td>Once LP rotor is set - no need to lift to adjust steam path components</td>
<td>1</td>
</tr>
<tr>
<td>Steam Pipes Flanged</td>
<td>Reduces the critical path cycle for piping attachment</td>
<td>3</td>
</tr>
<tr>
<td>Oil Flushing Boxes</td>
<td>Removes oil flush from critical path activities</td>
<td>3+</td>
</tr>
<tr>
<td>Shimmable Keys</td>
<td>No waiting for final machining of solid keys when finishing turbine construction</td>
<td>2</td>
</tr>
<tr>
<td>Three Piece Cross-Over</td>
<td>Ease of install &amp; maneuvering. Small “lay down” space footprint</td>
<td>1</td>
</tr>
<tr>
<td>Ship IP/LP Assembled</td>
<td>No IP-LP build at site</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Examples of Key Constructability Features

D600ST

Key Enablers
Features implemented in the equipment combined with improved foundation and plant layouts are key to achieving this reduced cycle. Shown below are just a few of the enablers.

Requirements & Constraints
The selection/implementation of the constructability features is application specific.

Some code types will have “ship assembled” options depending primarily on factory capacity and logistics, followed by various considerations of the customer/EPC.

System Interactions & Engineering Requirements

For example, lubrication oil features are included that put the oil flush on an independent and parallel path to the main centerline construction. Lubrication oil piping will be “dry” guard unless the customer or local regulations and standards require “wet” guard. Regardless, the benefits for schedule remain intact.

B31 Steam Turbine Unit
New features are incorporated into the equipment as specified in Chapter 2.3.
P91 Foundation

Foundation arrangement needs to suit the features below and should be reflected in the GE customer foundation interface drawings.

- Close coupled valves
- Lube oil flush features. Incorporate flush box features into plant layout and lube oil system drawings
- Height of A series LP hood supports
- Access under D series side exhaust

Physical Implementation

Construction Methods

The features are sufficiently independent and will be implemented into all new applicable steam turbines going forward. The plant critical path schedule is shortened due to the constructability features.
2.4 Lube Oil System Flush Features

What It Is

By incorporating flush boxes on its turbine standards, GE reduces the time required to prepare for and recover from oil flush. It also enables the performance of lubrication oil flush in parallel with other critical path installation and maintenance activities to shorten the overall schedule.

Why It Matters

Turbine lubrication oil flush has historically been an activity that directly affected installation and maintenance durations because it had to be performed in sequence with other critical construction and maintenance activities. Also, the duration of the lubrication oil flush has been highly variable due to site-to-site variations in equipment and workmanship. The time required to prepare for, execute and recover from oil flush typically ranges from 3 to 6 weeks for steam turbine (ST) new unit installations. Eliminating lubrication oil flushing from “critical path” installation and maintenance work effectively removes the time required to do flush work from installation and maintenance durations.

Without this highly variable and time-consuming activity in the installation and maintenance cycles, the total installed cost of GE’s equipment goes down and overall life cycle costs are reduced. The use of flush boxes reduces cycle time by 3 to 6 weeks.

Key Enablers

Dedicated flush boxes installed at the turbine standards are the key features required to perform oil flush in parallel with other turbine activities. Flush boxes provide

the means for the oil feed piping and the oil itself to be isolated from the standards during flush. This allows coupling alignment, instrumentation installation and other critical activities to continue within the turbine standards while oil flush occurs in parallel.

The lubrication oil feed piping must be flanged between the flush boxes and the bearing that is served by the feed piping. This allows the piping that is not flushed to be removed and cleaned by hand. After cleaning, this short section of piping can also be easily inspected and verified as being free of contaminants.

Requirements & Constraints

Adequate space to install the flush boxes must be provided at the turbine standards. They are not to be installed remotely from the standards as this will increase the amount of unflushed piping requiring hand cleaning and inspection. Also, the use of separate feed and drain piping is highly recommended in order to reduce the work required to install this piping and make the system easier to flush. Note, the use of guards around the feed piping is required in locations where pressurized oil could spray on hot turbine components.
System Interactions & Engineering Requirements

There are few system interactions affected by the use of lubrication oil flush boxes.

P30 Oil System

Oil supply piping needs to incorporate spool pieces to interface to the flush boxes. Flush boxes will need to be added to the scope of the piping system and scope of supply.

Physical Implementation

Layout Location

Flush boxes will not impact lube oil tank location, but boxes need to be located within the interconnecting piping between the lube oil tank and turbine.

Methods Cleaning

Implementation of flush boxes will lower the cycle time required to flush the lube oil system.

Construction Connections

The flush boxes will be shipped separately from the turbine standards. They are to be installed during the turbine erection process. The assembly will include typical bolting hardware and gaskets to assemble the flush boxes and piping in a leak free condition. The absence of external leaks is to be verified during the commissioning of the lubrication oil system.
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3.0 Simplification

Several new electrical and mechanical accessory system features are available that provide for a simplified system design and faster implementation in the field. The first feature, electric Inlet Guide Vane (IGV) and Variable Stator Vane (VSV) actuators, replace the hydraulic system for vane actuation. The second feature is the pressure atomized liquid fuel system which provides significant improvements in reliability, availability and maintainability (RAM) as well as greatly reduced number of components and piping. The third feature is factory commissioned skids which essentially commissions the skid in a vendor facility vs. in the field. The fourth feature is the consolidated electrical room bringing significant improvements in integrated electrical system packaging and factory checkout. The fifth feature is the water mist fire protection system which replaces the legacy CO₂ system.

3.1 Electric Inlet Guide Vane and Variable Stator Vane Actuators
3.2 Pressure Atomized Liquid Fuel System
3.3 Factory Commissioning of Accessory Skids
3.4 Consolidated Plant Electrical Room
3.5 Water Mist Fire Protection
CHAPTER 3.1 Electric Inlet Guide Vane and Variable Stator Vane Actuators

What It Is

Electromechanical actuators can be used in place of traditional hydraulically-driven actuators on and around the gas turbine to offer many operational advantages.

Why It Matters

Historically, Gas Turbine Inlet Guide Vane (IGV) and Variable Stator Vane (VSV) actuators have been hydraulically controlled. There are a lot of complexities with a hydraulically controlled system that can be simplified by going to a different form of actuation.

Electromechanical linear actuators are GE’s preferred method to eliminate high pressure hydraulics inside the gas turbine (GT) enclosure.

Electric actuators only require cable trays and cable routing for installation at site. This eliminates field routing of hydraulic tubing and piping, removing the risk of leaks and removing costs associated with installation and flushing the piping.

By using electric IGV/VSV actuators, we eliminate all of the hydraulics on the gas turbine along with redundant hydraulic pumps and AC motors, accumulators, filters, tubing/piping, instrumentation and servos. This greatly reduces the number of components that require maintenance and commissioning. Although it is difficult to place a value on it, plant insurers typically view the removal of hydraulics favorably.

The actuators are located on the gas turbine and provide the linear actuation that drives the movement of the IGV and VSV vanes. The controller for the actuators is called the Digital Vane Positioner (DVP). The DVP converts commands from the Mark*VIe, reports back positioner feedback/fault information and controls the position of the actuators.

Key Enablers

The electric actuators are located in the same position on the GT as the hydraulic actuators and are supported by:

- 220v DC battery back-up system (typically supplied by GE)
- Two Can-bus network cables back to the Mark*VIe Power-Constrained Noise Optimizer (PCNO)
- Digital Positioner cabinet located outside of gas turbine enclosure (typically supplied by GE)
- Instrument air for digital positioner cabinet cooling
Requirements & Constraints

When the gas turbine enclosure is supplied by GE, the digital positioner cabinet is located inside the Inlet Plenum Acoustical Enclosure. Cable length limits will set the location constraints for the E-Room. If the customer supplies the GT enclosure and locates the digital positioner cabinet (not typical), the cable lengths to the actuators will also be required to meet specific functional requirements for the configuration.

Greasing of the actuators once a year or after 8,000 hours of operation is the required maintenance. Also, actuators are to be sent back to the supplier for overhaul at the major 50,000 hour outages. GE provides removable platforms to allow walk-up access to the actuators.

System Interactions & Engineering Requirements

**T10 Gas Turbine**

Electrical actuators mount to support brackets located on the compressor casing. Mechanical actuation is through linkages to the compressor IGV and VSV actuation rings.

**P10 Control System**

Most system interactions are between the Mark*VIe and the Digital Positioners.

**P82 Instrument Air**

The Digital Positioner will use instrument air for cooling the cabinet. Sizing of the instrument air system needs to account for this cooling requirement.

**E30 Auxiliary Power Distribution**

PEECC and digital positioner cabinet distance requirements need to be taken into account when placing equipment in the plant layout. Cabling requirements to actuator need to be determined.

**P31 Hydraulic System**

The overall hydraulic system requirements are reduced which will enable a smaller hydraulic system and the elimination of piping supply and return for the IGV/VSV actuator.

Physical Implementation

**Methods**

With electrical actuation, system calibration methods are revised for electronic vs. hydraulic means.

**Maintenance Lifting Needs/Availability**

At major rotor outages, the building crane used for typical GT maintenance will be needed to pull the actuators off the gas turbine. An outdoor crane is not needed for this servicing.
3.2 Pressure Atomized Liquid Fuel System

What It Is
The pressure atomized liquid fuel system eliminates fuel coking by flushing residual fuel with high pressure water instead of air or nitrogen purging. It provides a more reliable fuel delivery system with less complexity compared to prior configurations.

Why It Matters
Reliable starting and transfers are critical for a back-up fuel system. System reliability is intrinsically improved by the removal of several components: atomizing air, flow divider, fuel heating, fuel forwarding and fuel recirculation. System installation and maintenance durations are also inherently reduced (installation reduced ~3,500 hours) by an order of magnitude as a result of the simplifications to the system. The arrangement of valves in the system provides a National Fire Protection Association (NFPA) purge credit-ready configuration. This system also utilizes 30% less water for NOₓ control.
Key Enablers
The combustor utilizes a combination of both high pressure fuel delivery and passive air flow within the unit to atomize fuel, thereby eliminating the need for an atomizing air system.

The combustor requirements for fuel viscosity are less stringent, and do not require a fuel heating system. Nor is a fuel recirculation system required.

Higher pressure drop across combustion nozzles overcomes the effects of elevation/gravity head on fuel distribution. This, in combination with water flushing, allows removal of the flow divider.

Hydraulically coupled, the pressure-atomized system mixes water with fuel prior to entering the combustor. This enables the existing water injection system to be used to flush the fuel system; downstream through the combustors as well as upstream into the fuel supply manifolds, greatly reducing the possibility of fuel coking. Water purge has proven superior to air purge in testing over many fuel cycles, as illustrated by the fuel nozzles below.

A single, multi-stage, single-speed, centrifugal fuel pump delivers liquid fuel across all operating ranges. The single centrifugal pump replaces both the fuel forwarding system and the positive displacement pump which were used in prior configurations.

With the aforementioned reduction in systems and components in the liquid fuel system, the piping is significantly simplified with 70% fewer combustion can connections. Consequently, the potential for leakage at joints is also significantly reduced. Piping installation and system maintenance are reduced by an order of magnitude, further facilitated by the ability to remove the top half of the manifold assembly in one piece.
Requirements & Constraints

Fine filtration for fuel and water is required immediately upstream of the gas turbine (GT) compartment to protect the downstream control valves and fuel nozzles from particulates. Standard filtration considers liquid fuel as a backup. Continuous liquid fuel use as a primary fuel would necessitate filtration upgrades. Centrifugal pumps require only a strainer at the inlet, no fine filtration is required.

Water is used while running on natural gas to pressurize the manifolds as an additional measure to ensure no gases from the GT can enter. A small positive displacement pump is provided for this purpose.

System Interactions & Engineering Requirements

**P91 Foundations**

A suitable foundation is needed for the demineralized water tanks, fuel tanks and pumps that considers the site soil conditions, rain and snow loads and crane lifting (GE Function P93) capacity.

**P93 Cranes**

A single crane of sufficient capacity to lift the fuel and water pumps is necessary upon installation, as well as for any unplanned maintenance or pump replacement.

**E31 Medium Voltage**

The liquid fuel and water injection pumps need to be added to the plant electrical load list, single line diagram, cable list, installation drawings and bill of quantities as appropriate.

**P22 Liquid Oil Conditions**

A length of fuel piping immediately outside the GT must be maintained above a minimum temperature for viscosity purposes. Typically, this requirement is met when fuel piping is installed underground, below the frost line. Otherwise, some customer-provided heat tracing would be required.

**P61 DI Water System**

Demineralized water is required for the water injection system while running on liquid fuel.

**P82 Instrument Air**

Instrument air supply is required for the fuel and water pumps, filtration module, and within the GT compartment.

**T30 Liquid Fuel Delivery**

Delivery system to meet requirements for pressure atomized fuel and water supply.

Physical Implementation

The fuel delivery requires placement of both the water injection and fuel pumps in close proximity to the supply tanks. This reduces pressure losses on the pump inlet and the effects of any fluid transients on the pump casing. Spare pump inlet strainers should be maintained for water and fuel.

Piping between the pumps and the filtration module should be provided with low point drains and high point vents. Water piping requires freeze protection.

The filtration module should be located as close to the GT compartment as practical. This improves filtration of the supply piping upstream and facilitates drainage of fuel from filters and bleed valves to the false start drain tank. Spare filters should be maintained for both water and fuel.

Cable for FOUNDATION™ Fieldbus protocol is required for the water and fuel pumps.
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3.3 Factory Commissioning of Accessory Skids

What It Is
Factory commissioning of accessory systems moves the commissioning steps that would normally be completed in the field to the manufacturer, thereby minimizing the field labor and schedule impacts to conduct this work.

Why It Matters
Factory commissioning of accessory skids benefits both the EPC and end user by reducing field installation and commissioning time. Running the skid at or near operating conditions at the factory allows the vendor to verify that the skid meets basic operating requirements. It also enables activities like equipment calibration, leak check, loop check and other corrective actions needed to be performed prior to shipment to the field. Skids arrive fully tested, flushed and cleaned, as close to a ‘plug and play’ installation as possible. It is ~80% faster to commission a skid in the factory instead of the field. Depending on the type of issue, if problems are detected during commissioning and are caught at the factory instead of the field, savings to the schedule can be anywhere from days to weeks. With factory commissioning, delays in getting vendor technical or field support, diagnosing problems, waiting for shipment of replacement parts, and rework by site personnel are eliminated.

Key Enablers
Utilizing FOUNDATION™ Fieldbus devices provides the ability to calibrate these devices in the factory, eliminating the need to complete or repeat calibration in the field. A Mark*Vle Suitcase Controller is connected to the skid during testing to calibrate instrumentation. This suitcase controller allows full simulation of the unit control, including settings and protectives. Teams from engineering, sourcing and the vendor are then able to collaborate and execute on an optimum test plan to reduce commissioning activities in the field.

Requirements & Constraints
Factory commissioning of skids mitigates risks caused by lack of skilled labor availability in the field. It also improves schedule predictability and enhancement to maximize efficiency and reduce cost.
System Interactions & Engineering Requirements

Skid Test Requirements
Systems currently factory commissioned on the 9HA platform:
- T20 Fuel Gas
- P33 Lube Oil
- P32 Seal Oil
- P31 Hydraulic and Lift Oil
- H22 Generator Stator Cooling Water
- B37 Steam Seal

Physical Implementation

Packaging
Factory commissioning provides for a pre-commissioned and functionally tested skid to be delivered to the field.

Commissioning
System is commissioned in the vendor’s facility which reduces field commissioning activities. The skid arrives in the field with a detailed list of completed testing and calibration.

Methods and Work Force Planning
Reduces labor required to set-up, commission and functionally test systems in the field.
CHAPTER 3.4 Consolidated Plant Electrical Room

What It Is

The Electrical Rooms (E-Rooms) contain all of the electrical and control equipment necessary for a power plant to operate properly. They are a fully integrated alternative to having multiple electrical and control equipment enclosures at various plant locations. The E-Room enclosure(s) contain as much state-of-the-art GE equipment as possible to address site layout constraints and project-specific customer requirements.

Why It Matters

There are many benefits to providing a pre-engineered and pre-tested E-Room for the total plant controls and battery placement. Consolidated power and controls E-rooms at optimal locations in the plant vs. various scattered containers reduces complexity and project risk (schedule, safety and cost), while lowering the total installed cost of controls and electrical systems. In addition to lower installation labor, the entire system of integrated components is factory tested before shipment to reduce quality risk and commissioning time at site.
**Key Enablers**

GE is a major supplier of all required equipment needed in the E-Rooms, including breakers, controls and VFDs. Early definition of the E-Room scope ensures a high quality delivered product and enhances the customer AE design information. The need for lower plant TIC drives a more consolidated deliverable to reduce interfaces and site labor, which the E-Rooms deliver.

Inside the E-Room, a logical layout is utilized to consider Medium Voltage (MV) from Low Voltage (LV) separation, serviceability and plant operability. Modularized construction allows a scalable, repeatable configuration for various plant configurations.

**Requirements & Constraints**

The controls for plant components are either integrated in skids or packaged in electrical and electronic control containers (PEECC). This provides shelter from the elements for both operators and sensitive controls.

The E-Room consolidates controls and electrical distribution into one location as opposed to various functional units throughout the plant. Space for the E-Room location has to be considered in the plant layout. In some cases space constraints within the plant could limit the opportunity for its application.

**System Interactions & Engineering Requirements**

The E-Room is engineered in modules, each containing MV, LV, protection or control cabinet lineups. The overall size of the E-Room will depend on the amount of controls for the power plant and the customer/GE scope agreement.

The utilization of the E-Room concept (P90 Structures) affects/benefits other GE functions. The functions and impacts are:

**P91 Foundations**

A suitable foundation for the E-Room consisting of footers for the building piers is needed. Concrete piers located to GE’s specifications can be used as well. The foundation engineering will also consider seismic requirements for the specific area of the plant as well as soil conditions.
P95 Layout
Optimization of E-Room scope and location will vary with overall plant configuration.

Systems that can be integrated into the E-Rooms:
- P11 – GT Controls
- P12 – ST Controls
- P14 – Plant Controls
- P51 – GT Fire Protection
- E13 – Excitation
- E14 – Generator Protection
- E31 – Medium Voltage
- E32 – Low Voltage
- E41 – LCI
- B20 – HRSG Controls

Physical Implementation
The E-Room presents the following physical implementation attributes as compared to single PEECC and stand-alone silo controls configuration.

Layout Location
The E-Room enhances the plant layout by centralizing control and MV/LV systems in optimized locations.

Layout Interfaces
The E-Rooms present centralized locations for wiring of devices and loads. Wire runs should be considered in the plant layout.

Packaging Modularity
The E-Room is made up of sections or modules. Its modular construction allows for quick assembly upon delivery.

Packaging Preservation
Packaging for shipment is needed for over-the-road travel as it will have one or two open sides for modular assembly.

Construction
Lifting of the E-Room modules for off-loading is accomplished with an onsite crane.

Connections
Connections from plant equipment to the E-Room to join the various components to the MV, LV, MCCs and control cabinets and power panels can be done immediately after the E-Room is set on the foundation.

Commissioning
This is limited to offloading, mechanically tying the modules together and re-landing electrical interconnections. The systems are otherwise pre-installed and checked prior to shipment. Operations, testing of equipment, data access and automation can be done as required. Access to the E-Room is provided via metal doorways equipped with panic bars and door hardware to meet all NFPA and OSHA standards. Prefabricated stairways with platforms made to OSHA standards are supplied at each point of access to the E-Room. All controls and distribution equipment arrives to site pre-installed and tested.

Maintenance
Maintenance of the structure is expected to be minimal, limited to exterior paint. There is no additional impact in the maintenance and update of control systems.

Maintenance Access Requirements
The equipment contained within the E-Room can be accessed by engineers or qualified technicians for maintenance, operations and updates in a climate controlled environment. Physical access to panels and cabinets is provided via ample aisle ways that meet or exceed NFPA 70-110.

Maintenance Laydown Area
Clear access is recommended in the direction of the entry doors for eventual removal of MCC components, or removal/addition of a full MCC cabinet.
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3.5 Water Mist Fire Protection

What It Is
A fire protection scheme based on the use of water mist as a suppressant that meets the requirements for gas turbine and other protective enclosures.

Why It Matters
Insurers require equipment protection in the event of a fire. Water mist offers many benefits compared to CO₂ fire protection.

• Eliminates the potential asphyxiation risk associated with CO₂. Water mist is safe for personnel in the compartment during discharge
• Less costly to install and maintain/operate
• Does not require a highly sealed enclosure for the system to be effective
• Does not require a 30-second discharge delay to allow personnel to exit compartments

Key Enablers
The water mist system is a twin fluid type, employing water as the suppressant and compressed air as the atomizing medium. Immediately upon activation, water mist is discharged into the compartment, filling it with a fine water mist that extinguishes fires by:

• Cooling by evaporation and wetting by water mist droplets
• Reduction of local oxygen concentration by water vapor
• Blocking of radiant heat by water mist droplets

Requirements & Constraints
The water mist system is configured per National Fire Protection Association (NFPA) 750 which is a widely accepted standard. The fire protection system is engineered based on the site configuration (gas only or dual fuel) and customer requirements.

The plant operator is responsible for keeping the compressed air cylinders and water tank filled. The skid contains a fill and drain connection for the water tank. Power to the skid is required for the control panel, heater and other components.

The skid minimum operating temperature is 39°F, and the skid is provided with heater(s). The customer can choose to install the system in a temperature-controlled building and remove the water mist skid enclosure. The system has been tested with piping and nozzles at -40°F during discharge with no issues. Heat tracing is recommended in low temperature environments for post discharge blow down.
System Interactions & Engineering Requirements

NFPA 750 requires the water mist system to have the capacity to provide protection to the largest group of hazards. The water mist skid exceeds this requirement by containing enough water and compressed air to discharge to the two largest zones.

The water mist system protects the turbine compartment, #2 bearing tunnel, and accessory compartment. Other compartments can be protected based on site configuration. Each protected compartment contains the water mist tubing, detectors and strobes/horns. During a discharge, the fire protection control panel sends a signal to the turbine control panel to trip the turbine and shut ventilation.

Testing was completed on turbines to compare the thermal shock of the casing between turbine shut down with compartment ventilation versus turbine shut down with water mist discharge. The conclusion was water mist does not increase thermal shock on the turbine casing. Other testing proved CO₂ has a larger effect on thermal shock.

P41 H₂, CO₂, N₂ Storage and Distribution
CO₂ is replaced with the water mist system, totally eliminating CO₂ from the plant.

P10 Control System
Control system modifications necessary to set up and control water mist system.

The following items are key components for this important safety system:

Gas Pump Unit (GPU)
Mechanical, piston-type pump powered by the pressurized gas cylinders.

Gas Cylinders
Two banks of high pressure gas cylinders provide compressed air to power the GPU.

Water Storage Tanks
Contains enough water to discharge to the two largest zones.

Control Panel
Listed electrical fire alarm control, monitoring and signaling panel (FACP).

Tubing & Nozzles
Stainless steel distribution tubing and spray nozzles for discharging the water mist.

Detectors
Bi-metallic temperature switches that are mounted in pairs in protected enclosures.

Annunciation
Strobes and horns provide visible and audible annunciation.

Physical Implementation

Skid
The water mist skid is located based on customer preference. The skid can be easily lifted to the desired location during installation.

Tubing
Tubing is provided for each protected compartment. Installation of the turbine compartment and bearing tunnel tubing is normally in the EPC contractors scope, as is providing and installing the interconnect tubing between the water mist skid and protected enclosures. Heat tracing may be necessary on the interconnect tubing as described in the Requirements & Constraints section.

Wiring
The detectors and strobes/horns must be wired to the fire protection control panel. The panel needs wiring to the turbine control panel.
Commissioning
A discharge test should be completed to ensure the system functions properly.

Maintenance
The fire protection control panel should be inspected periodically or whenever the turbine control panel receives an alarm. Post discharge, the following must be completed:
- Inspect nozzles, piping and blow down tubing
- Fill water tank
- Empty and refill gas cylinders
- Reset system
- Update records

Tubing Disconnection During Outage
During an outage, fire protection tubing must be disconnected to facilitate roof removal. Tubing must be reconnected and tested for leaks before start up.
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4.0 Performance

This section describes in detail several new features that either improve performance (efficiency & heat rate) or maintain the same performance at lower cost.

Heat Recovery Steam Generator (HRSG) designs with bent serrated fins is a GE technology that improves heat transfer performance over the typical serrated fin tubes. HRSGs with enhanced fin design allow for a smaller unit with equivalent performance compared to configurations with traditional serrated fins. Plant configurations that support ~600°C (1112°F) main steam and reheat steam temperature enable the most efficient utilization of the GT exhaust energy. Fuel heating to 226°C (440°F) utilizing low temperature energy from the bottoming cycle results in an overall gain in combined cycle efficiency. Typically the intermediate pressure economizer discharge water is used to heat fuel in a three-pressure reheat cycle. In power plants with four-flow low pressure section steam turbines, a steam condenser that operates at two different vacuum (pressure) levels improves efficiency of the entire combined cycle.

Serious consideration should be given to all these performance enhancing features.

4.1 Heat Recovery Steam Generator Enhancements
4.2 600°C (1112°F) Main Steam and Reheat Steam Temperatures
4.3 Fuel Heating to 226°C (440°F)
4.4 Two-Pressure Condenser for Steam Turbines with 4-Flow Low Pressure Sections
4.1 Heat Recovery Steam Generator Enhancements

What It Is

Heat Recovery Steam Generators (HRSG) utilize various heat exchangers to convert exhaust energy from the gas turbine into steam for the bottoming cycle. These heat exchangers are comprised of helically wound finned tubes. The modern HRSG utilizes a serrated fin for clean exhaust applications. The enhanced fin configuration (bent serrated fin) is a GE technology that improves heat transfer performance over the typical serrated fin.

Why It Matters

HRSGs with enhanced fin features allow for a smaller unit with equivalent performance over configurations with traditional serrated fins. This benefits the plant with a lower capital equipment cost and a reduced foundation footprint and size.

For a typical 7HA.01 HRSG the total surface area is reduced by ~5%. The reduction in foundation length is ~300mm (12") as compared to an HRSG with conventional serrated fins resulting in a savings of ~8.4 cubic meters (11 cubic yards) of concrete.

Key Enablers

- HRSG OEM capability to produce the enhanced fin configuration.
- Advanced collaboration with the prospective HRSG suppliers to assure they have received the GE technical data/details on the technology.
- GE Quality team coordination with the HRSG OEM finning contractors to validate the process implementation to produce the product to GE defined tolerances.

Requirements & Constraints

Fuels – Enhanced fin technology has unrestricted applicability for the HRSGs in gaseous fuel applications in the GT and/or duct burner.

Enhanced fin technology can be applied in HRSGs for distillate and heavy fuel oil applications provided they are backup fuels with utilization of less than 200 hours/year.

Enhanced fin is not applicable for HRSGs where distillate and heavy fuel oil are the primary fuel.
System Interactions & Engineering Requirements

**B20 HRSG, B21 HP Steam, B22 IP Steam, B23 LP Steam**

An HRSG with the enhanced fin provides for a smaller cross section for the HRSG heat exchanger sections. This equates to reduction in casing and interconnecting piping as well.

**P91 Foundations**

The resulting HRSG will have a reduced foundation footprint and a reduced weight. This positively impacts the sizing of the concrete foundations below the HRSG.

**B10 Feedwater**

Small reduction in feedwater piping that interfaces to the HRSG may be realized due to the reduced HRSG length.

**B32 Steam Admission**

Small reduction in LP steam piping that interfaces to the HRSG may be realized due to the reduced HRSG length.

**B40 Condensate**

Small reduction in condensate system piping that interfaces to the HRSG may be realized due to the reduced HRSG length.

Physical Implementation

As compared to typical serrated fin configurations:

- Will have no impact on the modularity of the heat exchangers. HRSG modularity remains a project specific evaluation based on logistics and site limitations.
- Implementation of enhanced fin has no impact on the cranes, laydown area or craft labor required for HRSG assembly.
- It will slightly reduce foundation excavation/forming and concrete work due to the reduced length of the HRSG.
- No impact on commissioning or operations.
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4.2 600°C (1112°F) Main Steam and Reheat Steam Temperatures

What It Is
Increasing high pressure (HP) and reheat (RH) steam turbine inlet temperatures increase bottoming cycle electrical output and overall combined cycle efficiency.

Why It Matters
Advanced F and H class gas turbines (GT), have high exhaust temperatures. In many cases, the exhaust temperatures are high enough to support increasing bottoming cycle HP and RH steam temperatures from 565°C/565°C (1050°F/1050°F) to 600°C/600°C (1112°F/1112°F). This improves combined cycle efficiency by approximately 0.2%.

Key Enablers
To achieve an ~600°C (1112°F) steam temperature there must be adequate gas turbine exhaust temperature. The typical Heat Recovery Steam Generator (HRSG) superheater minimum approach temperature (the difference between the incoming gas temperature and the exit steam temperature) is approximately +22°C (40°F). This means that the exhaust gas would need to be at least 622°C (1152°F) to attain a steam temperature of ~600°C (1112°F). This target/threshold may be reduced but it requires more HRSG heat transfer surface area. The extra area typically costs more than the value it brings in efficiency.

The steam turbine (ST) and its valves must be capable of accepting this temperature. The HRSG and steam piping must also be engineered to accommodate these temperatures and may require material modifications beyond that of a traditional 565°C (1050°F) cycle. These bottoming cycle aspects add significant cost, and in order to justify the increase, the performance value must outweigh the cost. The performance value is strongly driven by the number of operating hours per year and fuel price.

Requirements & Constraints
The performance value of an ~600°C/600°C (1112°F/1112°F) bottoming cycle will determine whether this option is selected. It depends heavily upon the operating regime of the plant, particularly the number of operating hours per year. Another important parameter affecting performance value is the fuel price.

System Interactions & Engineering Requirements
The implementation of an 600°C (1112°F) steam cycle impacts the following GE functions:

B21 HP Steam, B22 IP Steam
Austenitic stainless steel tubing and header alloys must be used in the highest temperature HP and RH superheater HRSG heat exchangers. This is a change from the ferritic steel T91/P91 materials used at 565°C (1050°F). Total superheater surface area must also be increased to heat the steam to higher temperatures.
B31 Steam Turbine Unit
The steam turbine and its valves need to be engineered to accommodate ~600°C (1112°F) steam temperature for both the HP and intermediate pressure (IP) turbine inlets. Materials and turbine cooling schemes need modification from a traditional 565°C (1050°F) configuration.

B32 Steam Admission
Steam piping for both the HP and reheat (RH) systems need to be engineered to accommodate ~600°C (1112°F) steam temperature. This will require thicker piping compared to 565°C (1050°F) configurations. GE studies have shown P91 ferritic steel alloy is still applicable for current combined cycle plants up to 600°C (1112°F) steam temperature. Pipe routing should also be examined to allow proper features to handle piping stress and additional expansion due to the higher steam temperature. A study performed on a 2x1 7HA.01 multi-shaft plant estimated HP steam combined piping wall thickness would increase by 18-23mm (0.7-0.9 inches) depending on specific pipe run. Similarly RH steam piping wall thickness would increase by 10-12 mm (0.4 to 0.5 inches).

B10 Feedwater
Increasing steam temperature results in less steam production from the HRSG and slightly reduces the flow of the feedwater pumps and associated piping.

B40 Condensate
Increasing steam temperature results in less steam production from the HRSG and slightly reduces the flow of the condensate pump and associated piping.

B41 Condensing Steam
Increasing steam temperature results in less steam production from the HRSG and slightly reduces the overall duty to the condensing system.

H10 Circulating Water
Increasing steam temperature results in less steam production from the HRSG and slightly reduces the overall duty to the condensing system. Thus, slightly less water flow is required.

Physical Implementation
Implementing a ~600°C (1112°F) steam cycle affects the following physical implementation attributes as compared to a traditional 565°C (1050°F) steam cycle:

Connections, Flanges & Welding
The use of higher grade alloys in the HRSG will require proper connection to steam piping systems which may be dissimilar metals. The use of austenitic stainless steel in the HRSG has different post weld heat treatment and non-destructive testing requirements. The steam piping welds take additional time due to increased pipe wall thickness. Austenitic stainless steel in the HRSG metallurgy may impose additional requirements on the installing contractors for weld procedure preparation/qualification.

Layout
HRSG heat exchangers expand at startup as their temperature increases from ambient temperature to rated steam temperature. This expansion increases at higher steam temperature. Austenitic stainless steel heat exchangers expand about 50% more than ferritic steel. The vertical expansion increases from 225 to 330 mm (9 to 13 inches) for high temperature heat exchangers. Drains connected to these heat exchangers will also see this amount of movement. HRSG engineering and pipe routing shall accommodate this expansion at acceptable stress levels for the life of the plant.
4.3 Fuel Heating to 226°C (440°F)

What It Is

Utilizing low temperature energy from the bottoming cycle to heat the fuel results in an overall gain in combined cycle efficiency.

Why It Matters

Increasing gas turbine inlet fuel temperature from 185°C (365°F) to 226°C (440°F) improves the combined cycle efficiency by approximately 0.1% pts. Heated fuel reduces the amount of fuel flow needed to meet the required gas turbine firing temperature.

Key Enablers

In order to achieve 226°C (440°F) fuel temperature there should be adequate feedwater temperature available from the Heat Recovery Steam Generator (HRSG). Typically the intermediate pressure economizer discharge water is used to heat fuel in a three-pressure reheat cycle. GE guidance for the fuel heater recommends a hot end approach no less than 14°C (25°F). That means to achieve 226°C (440°F) fuel temperature, a minimum of 241°C (465°F) water temperature is required.

The water temperature at the IP economizer discharge is dependent upon the evaporator pressure and evaporator subcool. Subcool is the difference between the IP economizer discharge temperature and the IP evaporator saturation temperature. GE guidance for the IP subcool is 8°C (15°F), which means the evaporator pressure must be at least 39.3 bara (570 psia) to achieve the required economizer discharge water temperature. The evaporator pressure is determined by adding the IP turbine inlet pressure to the associated reheat system pressure drop.

The fuel heating system must be engineered to accept the specified temperature and its heat exchanger is sized accordingly to provide the heating duty required. The gas turbine (GT) fuel nozzles must also be engineered to accept the Modified Wobbe Index resulting from the fuel temperature increase.

Requirements & Constraints

The performance value of 227°C (440°F) fuel will determine whether this option would be selected. Its value depends heavily upon the operating regime of the plant, particularly the number of operating hours per year. The other important parameter that affects performance value is the fuel price. GE experience has shown that the cost of raising fuel temperature to 227°C (440°F) is minimal and in almost all scenarios proves to be a worthy trade.

System Interactions & Engineering Requirements

The implementation of a 227°C (440°F) fuel heating cycle impacts the following GE functions:

T20 Gas Fuel Delivery

Gas turbine fuel nozzles must be engineered to accommodate the Modified Wobbe Index of the fuel at 227°C (440°F). This customization is completed on a project specific basis since fuel compositions and supply temperature varies. This process does not change for fuel heating to 227°C (440°F).
B10 Feedwater
Increasing the level of fuel heating increases the IP feedwater flow required. The feedwater pump will be engineered accordingly.

B21 HP Steam
Increasing the IP system pressure to accommodate fuel heating to 226°C (440°F) will result in an increase in HP steam production from the HRSG and should be engineered accordingly.

B22 IP Steam
Increasing the IP system pressure to accommodate fuel heating to 226°C (440°F) will require the IP drum to be sized accordingly.

B23 LP Steam
Increasing the fuel heating temperature slightly decreases the LP steam production from the HRSG and shall be engineered accordingly.

B30 Steam Turbine Unit
Increasing the IP system pressure to accommodate fuel heating to 226°C (440°F) requires a decrease of the IP turbine inlet nozzle area.

B32 Steam Admission
Increasing the IP system pressure to accommodate fuel heating to 226°C (440°F) requires the reheat system steam piping to be engineered for the higher steam pressures needed to support this temperature. The increase in HP steam production shall be considered when engineering the HP steam piping. The slight decrease in LP steam production should be considered when engineering the LP steam piping.

B40 Condensate
Increasing the fuel heating temperature slightly decreases the LP steam production from the HRSG and the condensate pump shall be engineered accordingly.

B41 Condensing Steam
Increasing the fuel heating temperature slightly decreases the LP steam production from the HRSG and slightly reduces the overall duty to the condensing system.

H10 Circulating Water
Increasing the level of fuel heating slightly decreases the LP steam production from the HRSG and slightly reduces the overall duty to the condensing system resulting in less cooling water flow rate required.

P21 Gas Conditioning
Increasing the level of fuel heating requires additional surface area in the fuel heater. An example from a study performed on the 7HA.01 predicted a heat transfer surface increase of 30% resulting in a cost impact of approximately $400K.

Physical Implementation
The implementation of a 226°C (440°F) fuel heating cycle impacts the following physical implementation attributes as compared to a traditional 185°C (365°F) fuel temperature:

Layout
The increased size of the fuel heater and associated piping shall be considered when configuring the plant layout and gas fuel skid.
What It Is
This steam condenser, attached to a steam turbine (ST), operates at two different vacuum (pressure) levels. It is configured to interface with a four-flow ST.

Why It Matters
Site conditions and plant performance optimization sometimes require a four-flow steam turbine to enhance the electrical output from the ST generator. The typical application is in a multi-shaft configuration with multiple gas turbines. The four-flow steam turbine has two low-pressure shells, and each exhausts to a separate condenser shell. The two condenser shells can be engineered at the same pressure or different pressure levels, but configuring for two different pressure levels provides significantly better value to the customer. As an example, consider a 7HA.01 2x1 MS with a cooling tower at 15°C (59°F) and 60% relative humidity and 90 thousand fuel hours (fuel hours are the product of the fuel price in $/MMBtu and annual operating hours). A two-pressure condenser provides $2MM more customer value due to higher ST output [440 kW (.05%)] than a single-pressure condenser at approximately the same plant cost.

Key Enablers
The figure below compares cooling water circuits with a one-pressure condenser vs. a two-pressure condenser. The coldest cooling water enters only one condenser shell in the two-pressure configuration. This technique allows the shell to operate at a significantly lower condenser pressure (or vacuum) compared with the shells in the one-pressure case. By this method, the two low-pressure steam turbine sections connected to this condenser shell produce additional power due to their lower exhaust pressure.

Because the two condenser shells must operate at different pressures, the steam bypass system configuration is different. The high-energy bypass streams – high pressure (HP) and hot reheat (HRH) – from each heat recovery steam generator (HRSG) are split evenly to each condenser shell. Bypass valves are provided at the inlet to each condenser shell to prevent a direct connection through the piping within the shell. Direct connection would cause the shells to operate at the same condenser pressure and eliminate the benefit of this system.
Requirements & Constraints

The operating regime, product application, site atmospheric condition and fuel costs for the plant affect the final system configuration. The combined cycle application engineers should use this input, along with the reference models and combined cycle cooling system optimization tools to determine the optimum configuration.

System Interactions & Engineering Requirements

The two-pressure condenser configuration primarily affects the plant’s heat rejection and bottoming cycle functions. The impacts to each system are enumerated below.

The differential pressure between the two condenser shells should not exceed 2.0 in Hg.

H10 Circulating Water

GE Application Engineers vary parameters such as the cooling water flow, cooling tower approach, condenser terminal temperature difference (TTD), etc. to select the optimal configuration by balancing the total installed cost of the system with the incremental performance value. Configurations vary depending on customer fuel price and operating hours.

The total installed cost includes the cooling tower, circulating water pumps, condenser and circulating water piping. The performance impact includes the incremental ST output, cooling tower fan power and circulating water pump power.

B41 Condensing Steam

The two-pressure condenser shall be once-through one-pass for each condenser shell. In addition, each condenser shall have connections for bypasses from each HRSG for HP and HRH steam, whichever is applicable. The lower pressure condenser shall also include provisions, such as a false bottom, to allow the condensate to drain to the higher pressure condenser.
B34 Bypass

With two condenser shells operating at different pressures, each HRSG requires two (2x50%) HP-to-condenser (if applicable) and two (2x50%) HRH-to-condenser bypass valves. Each bypass is connected to one condenser shell. This balances the thermal load on each condenser shell while the unit is operating on steam bypass – avoiding high differential pressure in the two condenser shells, which could cause the ST to roll off the turning gear.

Changes to the heat rejection and bottoming cycle system also affect these GE functions:

E31 Medium Voltage
The circulating water pumps typically have medium voltage motors. The medium voltage system will support the circulating water pump power needs.

E32 Low Voltage
The cooling tower fans typically have low voltage motors. The low voltage system will support the cooling tower fan power needs.

P91 Foundations
The cooling tower cell size, fan size and number of fans affect the cooling tower basin/foundation. The condenser configuration details drive the condenser foundation engineering.

Physical Implementation
The two-pressure condenser affects the following physical implementation attributes as compared with a single-pressure condenser for a four-flow ST:

Layout Interfaces
The cooling tower and circulating water pumps are similar in two-pressure and single-pressure condensers. The size of the cooling tower will be enhanced and may impact the plot plan size. The 2x50% bypass configuration for each HRSG increases the number of high energy bypass valves (by a factor of 2) and the space requirement to route the bypass piping.
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5.0 Operability

Several new operability features are available. The first is plant hot starts in 30 minutes or less. This feature is also known as Rapid Response. It requires additional balance of plant equipment to achieve the short start time. Thus, it is incorporated in the plant design when needed to meet customer requirements. The second feature is achieving purge credit during plant and gas turbine shutdown (as compared to after plant shutdown, but prior to next startup). The third feature is a SSS clutch located between the generator and steam turbine on single-shaft applications.

5.1 Plant Hot Starts in 30 Minutes or Less
5.2 Plant Shutdown Purge Credit
5.3 SSS Clutch for Single-Shaft Applications
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5.1 Plant Hot Starts in 30 Minutes or Less

What It Is
The ability to start the combined cycle power plant in hot condition (up to 8 hours after shutdown) in 30 minutes or less. The expected startup time begins when the gas turbine rolls off turning gear and ends when the gas turbine achieves base load and the steam turbine bypass valves are closed. At that time overall plant load is at about 95%. The remaining load is achieved when steam temperature reaches its normal operating level.

Why It Matters
The current power generation spectrum across the world includes heavy penetration of renewable energy sources such as wind and solar. The amount and availability of these sources can be highly unpredictable, bringing vulnerability to the electrical grid. To overcome this issue, the Gas Turbine (GT)/Combined Cycle Power Plants (CCPP) are often used for ancillary service, providing fast and reliable output in a cyclic operating profile that requires hot start times ≤ 30 minutes. In addition to cutting hot start times by half, this feature also reduces emissions up to 89% compared to conventional combined cycle plants.

Requirements & Constraints
The requirements and constraints that drive this feature are operations related. Things like start times, starts per year, hours per start and environmental-related demands such as air permits all come in to play.

System Interactions & Engineering Requirements

T10 Gas Turbine
The gas turbine must have the capability to reach baseload within 20 minutes from turning gear operating mode. The fast start GT capability of 10 minutes from turning gear to baseload will reduce plant hot start time by approximately 5 minutes.

T20 Gas Fuel Delivery
The gas fuel delivery system must include the fuel isolation functionality according to purge credit compliance requirements.
B10 Feedwater
The HRSG boiler feedwater system must be sized for additional attemperation required for HRSG terminal attemperators, high pressure (HP) bypass systems or HRSG interstage attemperation systems. The application team must also consider utilizing the redundant pump in the system during startup only.

B20 HRSG
The HRSG and particularly the critical stress components like water and steam headers must accommodate the simple cycle GT startup rates.

B21/22/23 HP/IP/LP Steam
Steam piping must include necessary warming features such as additional drains with increased sizing to minimize the duration of steam conditioning prior to steam turbine start.

B28 HRSG Supplemental Firing
All supplemental firing systems must include the gas fuel isolation functionality as per purge credit compliance requirements.

B31 Steam Turbine Stress/Life Consumption
The steam turbine must have a fast acceleration time of 2-3 minutes from turning gear to Full Speed No Load (FSNL) and fast loading of 4 to 5 minutes from FSNL to approximately 80% ST load capability. The design team must ensure that the ST allows fast startup capability within the hot start expected life consumption, based on the defined plant mission. If this is not possible, floating life consumption via scheduling the steam turbine start can be considered for hot starts only.

B34 Steam Bypass
The Rapid Response plant requires an HP Hybrid Bypass system consisting of an additional bypass directly connected to the condenser. This is due to additional steam flow at gas turbine baseload operating conditions. This additional bypass system cost is estimated to be approximately $1MM/HRSG for a typical installation including hardware and installation costs.

B40 Condensate System
The condenser and condensate pumps system must consider the additional steam generation and attemperation for the Rapid Response startup. Typical designs utilize the redundant condensate pump during startup only to provide additional water flow. The condenser duty during full load GT operation with ST bypassed must be part of system sizing definition.

B50 Auxiliary Steam
When the gas turbine requires heated fuel to reach base load, a steam-to-water heat exchanger startup fuel heating system is required. The auxiliary boiler must be sized for additional auxiliary steam flow in order to heat the gas turbine fuel. The larger sized auxiliary boiler is estimated to cost approximately $1.4MM for a typical 9HA.01 single-shaft combined cycle power plant.

H10 Circulating Water System
The Rapid Response condensing duty during startup must be considered in the system sizing definition.

E41 Load Commutating Inverter (LCI)
The LCI sizing must be determined based on the gas turbine start requirements and capability. In a plant with multiple GT/HRSG units feeding steam to a single steam turbine, each GT needs a dedicated LCI for shortest possible start time.
P11 Gas Turbine Control
The control software must provide LCI pre-connect, purge credit, fire-on-the-fly and fast synchronization features in addition to traditional control functionality. For fast start GT applications, the fast acceleration and fast loading must be included in the package.

P12 Steam Turbine Control
In addition to traditional control functionality, the control software must provide model-based acceleration and loading (ATOS) along with HP steam turbine discharge moisture control features.

P13 Power Island Control
The control software must include HP system hybrid bypass control, feed-forward control for HP and Hot Reheat bypass, and terminal attemperator control in addition to traditional control functionality.

P14 Plant Control
In addition to traditional control functionality, control software must include automatic operation capability to achieve the best HRSG bottle-up conditions, both during shutdown and to execute the Rapid Response start sequence.

P21 Gas Conditioning
When the gas turbine requires heated fuel to reach base load, the gas fuel delivery system must include fuel heating independent from the HRSG for startup. Fuel heating to ensure there are no holds on transfer to emissions compliance combustion mode during GT startup. The startup fuel heating typically consists of a steam-to-water heat exchanger located upstream of the performance heater that is fed by steam from an auxiliary boiler. Startup fuel heating must be sized for gas turbine baseload fuel flow at rated fuel temperature sufficient to cover the Modified Wobbe Index range. The additional startup fuel heating heat exchanger cost is estimated to be approximately $300K for a typical 9HA.01 single-shaft combined cycle power plant.

Physical Implementation
In order to minimize steam conditioning time prior to steam turbine start, steam bypass valves must be located as close as possible to the steam turbine inlet.
5.2 Plant Shutdown Purge Credit

What It Is
Establishment of a purge credit after shutdown is a way to provide faster dispatch availability for start requests on single and multiple units.

Why It Matters
Conventional starts (i.e., without shutdown purge credit) require a system purge during start-up that results in a longer startup time. For example, the 7F.04 with a conventional start is approximately 15 to 20 minutes longer than a plant with shutdown purge credit. Additionally, completing a shutdown purge credit using the unfired airflow of the gas turbine during coast-down reduces the thermal impact on the Heat Recovery Steam Generator (HRSG). Lowering the thermal impact on the HRSG is especially valuable to customers with plants that have cyclic operations involving daily starts and stops because the life of the HRSG is extended.

Key Enablers

Fuel Systems Design for Purge Credit
The National Fire Protection Association (NFPA) 85 or later revisions require GT and HRSG supplemental burner (if present) fuel systems to meet the requirements listed in the code. The NFPA fuel system requirements include hardware, software, operations and protective actions related to the fuel system.

Gas Turbine-based Purging Methods
The gas turbine (GT) compressor rotation is the source of clean air for purge in both startup and shutdown. Purge time is adjusted as needed based upon the HRSG size and configuration.

Power Plant Operations Philosophy and Controls
Plant designs should include the coordination of multiple fuel system and interlocking requirements as defined in NFPA 85. The plant operating philosophy defines the integration of the gas turbine with the other plant components and controls, resulting in an operable cost effective design. The plant philosophy is also the framework for the scope split between the multiple sources of engineering and controls.

Requirements & Constraints
Identification of all plant elements potentially involved in the purge credit is required for a complete design including:
- Gas turbine fuel systems (liquid, gas, other)
- HRSG Supplemental (a.k.a. Duct) burning systems
- Selective Catalytic Reduction (SCR) systems
- Compression Ratio (CR) systems
- Bypass dampers

The HA plant products utilize a “typical” max case horizontal HRSG to qualify the gas turbine coast-down air volume is sufficient to meet purge requirements. HRSG solutions (including vertical HRSGs or other variations) are evaluated during the proposal phase is required to confirm the volume flow is sufficient.

A supply of compressed air and demineralized water for GE and other vendor-supplied purge credit systems must be present to successfully integrate purge credit into a plant.
System Interactions & Engineering Requirements

T10 Gas Turbine
The fuel isolation speed of the gas turbine is determined by the size of the HRSG.

T14 Starting Means
Units with non-GE starting means must consider actions to integrate new startup and shutdown operations related to purge credit. The starting means must be capable of accelerating the gas turbine to firing speed for a conventional purge credit start and purge in case of a fault in the purge credit system.

T20 Gas Fuel
The gas fuel systems of GE gas turbines utilize an NFPA 85 System 2 configuration consisting of a triple block and double vent system with a pressurized pipe section. The gas fuel system utilizes a connection of compressed air supplied by the plant to connect to the gas fuel system. Adequate supply air at specified conditions is required to execute the purge credit sequence correctly.

T30 Liquid Fuel
The liquid fuel systems of GE HA gas turbines utilize NFPA 85 System 3 requirements and are configured to accommodate a shutdown purge credit by isolating the liquid fuel system on normal shutdowns. These liquid fuel systems have a tie-to-plan demineralized water requirement that must be integrated into the fuel system purge credit sequences.

T41 Bypass Stack
Purge credit with a bypass stack includes the need for the stack damper to be positioned to the appropriate flow path for both purge and credit. The damper controls must be integrated into the plant master purge credit interlock by the designer of the plant.

B20 HRSG
The volume and configuration of the HRSG must be evaluated to determine the full scope of the purge credit. Additionally, operating sequences of the GT in purge credits (starts and shutdowns) must be communicated to the HRSG vendor in the proposal to ensure the configuration supports operability requirements.

B28 Supplemental Firing
If a plant has supplemental firing, then the system configuration must conform to one of the designated NFPA 85 system types and participate in the plant interlock for formation of a plant level purge credit.

The duct burner integration must be completed by the designer of the plant, which includes Input/Output (I/O) between the Distributed Control System (DCS) and burner programmable logic control (PLC).

B25 SCR/Ammonia
NFPA 85 considers the SCR ammonia systems a potential risk in a purge credit that must be factored into the engineering of the ammonia skid and blower systems. The SCR integration must be completed by the designer of the plant, which includes I/O between the DCS and burner PLC.

E41 LCI
The Load Commutator Inverter (LCI) or static starting system must be capable of meeting and sustaining a purge of the GT exhaust and HRSG at or above the NFPA 85 defined purge rate of ~8% or the full load rated airflow.
P11 GT Control
The gas turbine controller manages the gas turbine fuel credit components (fuel systems) and will execute purging sequences. The gas turbine is one component in an integrated plant and requires inputs from the plant master control to inform it when specific plant level coordinated operations are occurring. The overall purge protective interlock related to fuel isolation is now managed by the plant level interlock and not just the gas turbine.

P14 Plant Control
The designer of the plant is responsible for configuration requirements, identification of scope split between the sub components, operational philosophy and supervisory control methods associated with a plant level purge credit. When GE engineers the plant controls, the operations philosophy for the purge credit will be included in the Plant Operating Philosophy T210 system.

P20 Fuel Systems
All plant fuel and combustible systems are required to meet NFPA 85 guidance for purge credit.

P31 Hydraulic
The gas turbine control methods for shutdown purge credit must include the management of fuel cutoff and potential restoration of hydraulics to complete the fuel system sequences forming a purge credit.

P60 Cooling Systems
Considerations for cooling systems need to be factored into plant configurations for purge credit because multiple auxiliary systems may be on-line to support purge credit operations. This can include water systems to support liquid fuel, compressed air, hydraulic and other systems requiring water or other mediums used for cooling.

P80 Compressed Air
The GE gas turbine fuel system utilizes plant compressed air for displacement of remaining fuel from gas manifolds and to form the pressurized pipe section. Each gas fuel system and sequence has different air demand mainly due to physical differences in piping. The plant designer is responsible for evaluation of air supplies and potential unit to unit interactions due to purge credit needs.

Physical Implementation
Sufficient supply of compressed air shall be included in the plant. Air receivers dedicated to each independent unit provide the most robust plant solution with each receiver sized to meet the needs of the unit.

Arrangement and containment for liquid fuel drainage associated with purge credit must be considered for dual fuel plants.

Physical communication between plant components must be factored into the division of responsibility and scope for each component. Direct communications are rare between the gas turbine and sub components within the DCS or PLC connected to the DCS.

I/O requirements for each component participating in a purge credit will contribute to the arrangement of the skids, I/O panel arrangements, and cabling schedules for each system. Delays in this information can result in rework and/or unexpected costly add-ons to the project.
5.3 SSS Clutch for Single-Shaft Applications

What It Is

The synchro-self-shifting (SSS) clutch enhances operational flexibility and availability of a combined cycle single-shaft power plant by enabling the disengagement of the steam turbine from the gas turbine/generator. With SSS action, the clutch teeth are phased and then automatically shifted axially into engagement when rotating at precisely the same speed. The clutch disengages as soon as the input speed slows down relative to the output speed.

Why It Matters

On a single shaft power train without a clutch, the steam turbine accelerates to full speed with the gas turbine before the HRSG produces steam. At full speed, the steam turbine requires substantial amounts of cooling steam to maintain components within temperature limits. This steam is typically supplied by an auxiliary boiler. With a clutch, the ST is disconnected during the GT acceleration process and cooling steam is eliminated.

A clutch with an automatic overrunning feature allows the gas turbine/generator to accelerate while the ST remains near turning gear speed. Later, steam produced by the heat recovery steam generator (HRSG) accelerates and loads the steam turbine while maintaining components within temperature limits. The elimination of cooling steam significantly reduces the auxiliary boiler size and cost (approximately a $1.7M savings for a typical 9HA.01 plant).

In addition, the clutch allows access to the gas turbine for maintenance and inspection much sooner than conventional non-clutched single-shafts (access in 12 hours vs. 72 hours).
The SSS Clutch is located in the Steam Turbine front standard which allows for rapid GT startup to baseload without the ST.

**Key Enablers**

Single-shaft power-train with the generator in the middle. The gas turbine and steam turbine drive the generator from opposite ends. Each turbine incorporates a thrust bearing.

**Requirements & Constraints**

The single-shaft line incorporates into the steam turbine front standard. Lube oil is provided from the combined lube oil system adjacent to the shaft line. Rotor connections on both ends of the clutch are integrated into the flanges for the steam turbine and generator.

At startup, the clutch enables the gas turbine to accelerate to Full Speed No Load (FSNL) without the steam turbine in operation. Later, HRSG steam accelerates the steam turbine. The clutch engages once the steam turbine speed matches the speed of the gas turbine.

The clutch meets the following criteria:

- Transmits steady state torque to the steam turbine
- Sustains torque from fault conditions
- Tolerates torque from minor transients
- Accommodates relative axial flange motion of the connected rotors
- Tolerates small angular or radial misalignment

Among the operational benefits, the clutch:

- Engages smoothly when the steam turbine speed matches the generator speed
- Disengages smoothly when the steam turbine speed falls below the generator speed

**P91 Foundations**

In addition to the normal ST needs, the centerline foundation must provide adequate length, support and stiffness for the SSS clutch. This ensures the clutch gear teeth remain in alignment and transmit the required torque. Consult the ST Design Practices for detailed guidelines.

**P92 Building**

Compared to a direct coupled single-shaft train, the building length is longer by the length of the clutch.

**B31 Steam Turbine**

The SSS clutch-enabled steam turbine is configured with two support bearings.

**P10 Controls**

The acceleration of the steam turbine shaft is controlled to meet the clutch engagement requirement for smooth operation.

**T11 GT Thrust**

The gas turbine thrust bearing takes into account the rotor thrust in the direction of the gas turbine from the steam turbine.

**E10 Generator**

The generator collector end and stub shaft to the clutch are enhanced to meet rotor dynamics and collector brush requirements.

**B50 Aux Steam**

No LP cooling is required with the SSS clutch, reducing auxiliary steam system complexity and cost.

**P33 Lube Oil**

The clutch is supplied with its own oil supply line from the common lube oil system to ensure long life. The system sizing supports the flow and return of oil to the lube oil system.
Physical Implementation
The clutch's location in the main shaft line impacts the rotor train length and thus the foundation and building sizes.

Steam Turbine and Generator Interfaces
Both steam turbine and generator accommodate the clutch through flange connection modifications.

Maintenance Assembly/Disassembly
The clutch weight is approximately 2,300 kg (5,071 lb.) for a 9HA.01 gas turbine, so the building crane can be used with no added laydown space required. Special tools are provided with the clutch for maintenance activities.
Several new Controls and User Experience (UX) features are available to reduce total installed cost, improve reliability, availability and operability, and lower operating and maintenance costs.

The first feature is Digital Bus Technology, which allows several signals to be transmitted over one set of wires, as opposed to traditional technology that uses dedicated sets of wires for each sensor/signal. This provides significant savings in overall plant installed cost by reducing field-run wiring, making wiring checkout easier and speeding system commissioning. Digital Bus Technology also provides additional sensor and actuator health information, enabling enhanced diagnostics and prognostics to improve reliability and reduce maintenance costs.

The second feature is Plant AutoStart, which automates startup by augmenting the traditional plant start from GT turning gear rolloff with elimination of manual operator actions previously needed to establish a ready to start state. Plant AutoStart delivers predictable, improved start times following a normal shutdown, thereby reducing fuel costs and startup emissions, and improving the ability to meet dispatch requirements.

The third feature is a State-of-the-Art Human-Machine Interface (HMI) that is simple, intuitive and efficient; designed to improve both the functionality of the interface and the user experience. This HMI delivers improved situational awareness and anomaly detection and simplified decision making.

The fourth feature is Plant Level Alarm Management & Fault Tolerant Protection. This feature helps improve the availability and operational flexibility of the power plant. The Alarm Management system displays only actionable alarms and pertinent information to the operator, providing visibility into plant issues without causing alarm fatigue. The Fault Tolerant Protection System automatically places the equipment in a safe, but reduced mode of operation following certain failures, rather than tripping the unit.

The fifth feature is Intelligent Dual Control Redundancy (IDCR). Compared to the traditional Triple Modular Redundant (TMR) system, IDCR improves reliability and reduces control cabinet I/O. Safety systems remain TMR, while active in-range fault detection and surrogate sensor modeling allow IDCR to reduce control system hardware and maintenance costs.

6.1 Digital Bus Technology for Instrumentation and Controls
6.2 Plant AutoStart
6.3 State-of-the-Art Human-Machine Interfaces
6.4 Plant Level Alarm Management & Fault Tolerant Protection System
6.5 Intelligent Dual Control Redundancy
6.1 Digital Bus Technology for Instrumentation and Controls

What It Is

Digital Bus Technologies are digital protocols used to communicate information regarding command, control, feedback and monitoring. They are applied to various power plant control input and output (I/O) signals. Digital Bus Technology allows several signals to be transmitted over one set of wires as opposed to traditional, individually wired means (e.g., 4-20 mA current loops). This technology also provides additional functionality in areas such as sensor and actuator health at low or no incremental cost. This ability is not readily available with traditional approaches. There are several Digital Bus protocols available and adopted in GE Power Plant equipment.

Why It Matters

Utilizing Digital Bus Technologies for control I/O signals provides significant savings in overall plant installed cost. They reduce field-run wiring, make wiring checkout easier and speed system commissioning.

The control system for a plant with a single combined cycle block may include as many as 3000 I/O devices such as sensors and actuators to properly control, protect and monitor the equipment. Typically, each of these requires dedicated wiring of 2, 3, or more wires that run from the device to the control panel. Installation and checkout of this field-run wiring requires a considerable amount of material, labor and commissioning time. It also includes significant opportunity for errors during plant construction. Reducing the amount of wiring and providing the means for rapid field checkout saves significant material, time and rework. That translates into a lower total installed cost for the plant equipment. The first 9HA plant outfitted with Digital Bus Technology will save approximately $1M in total installed cost.

Digital Bus Technologies also provide benefits over the life of the plant. Digital Bus sensors and actuators provide more information to the control system, facilitating enhanced fault detection and accommodation, analytics and prognostics. These features support moving what would be unplanned maintenance activities to planned plant outages. That means improved spare parts planning, higher plant operating reliability, availability and lower operating costs.

Key Enablers

Several Digital Bus protocols/standards such as CANopen®, Profibus™ DP and FOUNDATION™ Fieldbus (FFB) are suitable for use in power plant equipment and are both established and maintained by various industry organizations. Also, a significant number of reliable, mature components including sensors, MOVs, motor control centers and segment protectors are available from multiple suppliers for power plant use.
Requirements & Constraints

GE’s approach is to have Digital Bus I/O across the plant.

- Some signals may be required to be hardwired per local codes or standards (e.g., SIL safety systems).
- Balance of Plant (BOP) and other equipment should adopt a similar level of digital bus technologies, but commercial and other preferences may prevent this.
- Some customers, including EPCs, will require GE support to design/integrate Digital Bus Technologies for equipment outside of GE scope. For example, FOUNDATION™ Fieldbus devices need to be qualified to operate with the chosen control system. GE Controls engineering has a process in place to facilitate this.

Other constraints, based on internal technical issues are described in the System Interactions & Engineering Requirements section below.

System Interactions & Engineering Requirements

Implementation of Digital Bus Technologies will impact all plant systems that are connected to the control system, whether for adoption or technical or commercial evaluation of the technologies.

Various Digital Bus Technologies and formats have varying characteristics (e.g., data transmission rates) and different levels of adoption/familiarity in certain areas. For example, Profinbus™ DP for electrical integration with Smart MCCs has a relatively high adoption level. Careful assessment of control requirements including transmission rates and latency is necessary to determine which Digital Bus Technology to apply to which I/O signal. How signals are combined and configured will also depend on plant layout and signal path distances.

Some signals, such as those requiring relatively high voltage or current may not be contenders for digital bus I/O.

Technical considerations are too numerous to describe fully in this document. The majority of signals are FFB but faster loops may require CANopen®. Smart MCCs are typically provided with Profinbus™ DP.

Physical Implementation

The physical interconnection of digital bus signals (e.g., FOUNDATION™ Fieldbus Segment Protector locations) will be determined as part of the electrical and controls design for each system. As indicated in the System Interactions & Engineering Requirements section, plant layout may impact the design.
6.2 Plant AutoStart
(Pre-Start & End State Automation)

What It Is
Plant AutoStart is a feature that automates startup to reduce operator manual action. Legacy plant control automation systems often automated plant start from GT roll-off of turning gear, but still required the operator to take significant pre-start manual actions to achieve the plant ready-to-start state. The addition of automated pre-start control eliminates these actions when restarting from a normal plant shutdown. Additional automation now provides automatic transition to a variety of typical end states such as simple cycle operation and intermediate shutdown states. With appropriate system engineering, the plant control system integrates sequencing and operation of systems and components including the gas turbine (GT), steam turbine (ST), generator, accessories, heat recovery steam generator (HRSG), and BOP auxiliaries required to start and load the plant from a normal shutdown to an operator-selected load.

Why It Matters
Plant AutoStart now delivers predictable, improved pre-start and start times from the ready-to-start condition. This reduces the emissions and cost, and increases the certainty of meeting plant dispatched load in an efficient manner.

Key Enablers
An extended scope GE offering is required, including a Mark*VIe Plant Control System that integrates gas turbine, steam turbine and generator control with control and operation of the HRSG and BOP systems, and HMI screens providing a single plant operator interface.

Group Control
Utilizing a group control approach, control of associated components and systems is combined into sets of plant pre-start building blocks, or groups. The plant control automatically starts the groups in the proper sequence to achieve ready-to-start and plant start.

Requirements & Constraints
Plant AutoStart requires automation of equipment that may be outside of GE’s normal scope of supply and therefore requires interaction with the plant designer to coordinate control of this equipment.

System Interactions & Engineering Requirements
Automation is provided from a normal plant shutdown condition. This means BOP systems such as electrical switchgear and electrical plant systems, instrument air, and demineralized water train and water chemistry systems are operating. Transition from a maintenance shutdown (i.e., where the electrical plant is de-energized) to normal shutdown will still require manual operator action.

P10 Control System
A GE Plant Control System is required. Typical control interfaces of most plant systems are adequate to support Plant AutoStart from a normal shutdown condition.
Physical Implementation

Plant AutoStart is implemented via software and hardware of the GT, ST, Generator and Plant (including HRSG and Electrical) control systems.

Plant AutoStart is implemented within the integrated control system. All systems requiring control, sequencing, operation and/or monitoring must be appropriately enabled and interfaced with the control system. The operator interface HMI screens are located in the control room.
6.3 State-of-the-Art Human-Machine Interfaces (HMI)

What It Is
GE’s latest operator-centered human-machine interface (HMI) is simple, intuitive and efficient; engineered to improve both the functionality of the interface and the user experience.

Why It Matters
Operators experience the plant equipment through the control system, therefore the interface and user experience are important. Research shows that poorly engineered HMIs contribute to operator errors and lost revenue. Through research, engineering and validation with 88 operators in 25 plants and 5 countries, GE’s advanced HMIs conform to a simple principle: with a glance, operators should be able to recognize which information they need to attend to and what it indicates. In the figures below, note the simple display of critical plant parameters in the “after” view. The parameters outside of normal operating levels are much easier to detect via the different color (yellow, orange or red) than the normal parameters shown in blue.

Key Enablers
GE’s HMI is a significant departure from the industry’s status quo. It has been developed in close cooperation with GE customers to drive more consistent and efficient power plant operations. It delivers improved situational awareness and anomaly detection along with simplified decision-making through:

- Conformance to International Society of Automation (ISA) 18.2, The High Performance HMI Handbook (PAS), and other industry guidelines
- Reduced information and cognitive overload
- Less operator fatigue
- 21% usability improvement ratings over past systems
- Efficient maintenance and troubleshooting
Requirements & Constraints

The HMI philosophy remains the same regardless of the various site or plant requirements and constraints. The detailed content is adjusted as needed based on these requirements. For example, if dual fuel capability (natural gas and distillate) is needed, the HMI screens will be adapted to show both sources.

System Interactions & Engineering Requirements

The HMI provides operator interaction and display for all systems except for the P90 Structures function and its sub-functions consisting of P91 Foundations, P92 Buildings, P92 Cranes, P94 Duct Banks, P95 Roads. The HMI is part of the P10 Control Systems function and its sub-functions  P11 GT Control, P12 ST Control, P13 Power Island Control, P14 Plant Control.
An HMI set can comprise 50 to 200 screens for a single-block and single-shaft power plant. Therefore, the systematic categorization of screens improves navigation efficiency and operation efficiency. Some HMI screens are organized by plant topology in which the lower level of screens progressively describes more details of a process and/or assets. Other screens are organized by process or operator task.

By plant topology:
- Level 1: Overall Plant
- Level 2: Major units (GT, ST, HRSG, BOP, Electrical, Generator)
- Level 3: Major systems/sub systems of the respective units
- Level 4: Sub systems/Individual equipment or devices.
- Faceplate: Individual data points.

By process control or operator task:
- Screens that provide a single representation of controlling a process that includes multiple systems
- Screens that support an operator task. (e.g., startup, shut down, etc.)

Alarm visualization is an integral part of the HMI user experience to enhance operator sensitivity to abnormal conditions and improve identification and response effectiveness. The following guidelines are applicable to the HMI:
- Shape, color, and number indicate/differentiate different priorities of alarms. Red Triangle with 1 = Priority 1, Orange Diamond with 2 = Priority 2, and Yellow Pentagon with 3 = Priority 3.
- Visual effects on alarm indicators differentiate the status of alarms (acknowledged, active, normal, etc.). Acknowledged alarms keep shape and number, but change to gray background.
- Seamless navigation is provided between the alarm window and the alarm indicators on HMI screens.
- Colors specified for alarms are not used for other HMI display components.

**Physical Implementation**

As described above, the operator experience, interface and display via the HMI has been improved.
6.4 Plant Level Alarm Management & Fault Tolerant Protection System

What It Is

Alarm Management and the Fault Tolerant Protection System are two separate, but complementary features of a control system that help improve the availability and operational flexibility of the power plant. The purpose of these features is to alert operators to abnormal operating conditions and to also take automatic action when system/equipment operating conditions reach inoperable levels, with the objective of preventing personnel, environmental and equipment damage as well as economic loss. Alarm Management is the process by which alarms are defined, engineered, monitored and managed to provide the highest level of operator effectiveness. The Fault Tolerant Protection System provides the owner/operator with the opportunity to make commercial decisions to extend plant operation in a degraded mode without sacrificing personnel and equipment safety.

Monitoring & Assessment Analysis

Provides guidance for analysis
- Alarm system measurement
- Unauthorized alarm suppression
- Alarm attribute monitoring
- Reporting of alarm system analysis
- Alarm performance metric summary

- Performance metrics
  - Average annunciated alarm rate per operating position
  - Peak annunciated alarm rate per operating position
  - Alarm floods
  - Frequently occurring alarms
  - Stale alarms
  - Annunciated alarm priority distribution
  - Alarm attributes priority distribution
Why It Matters

Operating effectively in the midst of equipment or other plant challenges is a necessity. Alarm Management and the Fault Tolerant Protection System improve plant operations and the ability to keep the power plant up and running. The fundamental purpose of an alarm system is to alert the operator to abnormal operating situations by means of an audible and visible annunciation. A key factor in operator response effectiveness is the speed and ease with which the operator can isolate the root cause of the problem and choose a course of action. Legacy alarm systems flood the operator with data. With the introduction of fully digital control systems, alarms became easy to implement and inexpensive to configure and deploy. The unintended result is that almost anything would be alarmed. The quantity of information displayed by the alarm system was only limited by the size of the monitor. Incidents of misoperation began to increase as a result of having too much data available with too little useful information being presented. In 2009, the ANSI/ISA-18.2 standard was introduced to address this issue. Using ISA-18.2 principles, GE’s Alarm Management system provides visibility into plant issues without causing alarm fatigue by considering human factors in alarm system engineering. With Human Factors Engineering (HFE) techniques such as alarm rationalization coupled with GE control system’s advanced functionality and intuitive Human-Machine Interface (HMI), only actionable alarms and pertinent information are displayed. As a result, compared to legacy alarm systems, the total number of alarms is reduced by 80% and a root cause is easily obtained from the information displayed.

The purpose of GE’s Fault Tolerant Protection System is to take automatic action when system/equipment operating conditions reach inoperable levels. Each failure mode is individually evaluated to determine if a trip or shutdown can be eliminated and replaced with a Fault Tolerant Protection System mode of operation.
Upon entering a Fault Tolerant Protection System mode of operation, appropriate alarms and alerts are passed to the Alarm Management system to alert operators and maintenance personnel of necessary actions, while the equipment is automatically placed into a safe mode of operation. This mode of operation may be one of reduced performance (e.g., reduced output) rather than a trip, if possible, to allow continued operation prior to corrective action.

**Key Enablers**

GE’s Alarm Management system is engineered to address operator alarm fatigue and blindness through key enablers such as conformance to ISA-18.2 guidelines and GE’s Control System Alarm Viewer, ToolboxST and Workstation ST products, that include advanced filtering and intuitive viewing features. Specifically, functions such as alarm “Out of Service,” “Shelving,” and “Parent/ Child Pairing,” enable only the pertinent information to be presented to the operator.

It is not sufficient to use a multiple alarm priority-level system. The solution must be an alarm system that can dynamically filter the alarms based on the current plant operation and conditions so that only the currently significant and important alarms are annunciated. Dynamic alarm management focuses the operator’s attention by eliminating extraneous alarms, providing recognition of critical problems, and informing more accurate operator response.

For the Fault Tolerant Protection System, key enablers are Model Based Control (MBC) and other fault detection software utilizing Kalman filters to determine sensor diagnostic, isolation and accommodation through surrogates and intelligent sensor technology coupled with Input Signal Processing (ISP) technology.

**Requirements & Constraints**

The requirements and constraints that drive this feature are operations-related such as reliability, availability and redundancy requirements.
System Interactions & Engineering Requirements

The alarm management and fault tolerance philosophy remain the same regardless of the various site or plant requirements and constraints. The detailed content of the system is adjusted as needed based on these requirements. For example, if dual fuel capability (natural gas and distillate) is needed, the system will be adapted to cover both fuel sources.

Plant Level Alarm Management and Fault Tolerant Protection Systems are part of the P10 Control Systems function and its sub-functions P11 GT Control, P12 ST Control, P13 Power Island Control, P14 Plant Control. They interact with and cover all plant functions except for the P90 Structures function and its sub-functions consisting of P91 Foundations, P92 Buildings, P93 Cranes, P94 Duct Banks, P95 Roads.

Requirements at the plant level are given below:

- Consistent alarm strategy across the plant functions with a reduced number of meaningful and actionable alarms
- Group alarm methodology developed following industry guidelines as part of a plant-level Alarm Management strategy
- Adaptive alarms including state-based alarm strategies compliant with ISA-18.2
- Guidance to the operator to inform decisions based on the alarms received
- Alarm structure allowing filtering and ordering of the alarms through different criteria
- Intelligent sensor technology and smart Motor Control Center feature
- Fault detection software utilizing Kalman filters to determine surrogates. The Fault Tolerant Protection System has the pre-requisite of having the Model-Based Control and Input Signal Processing software architectures applied

Alarm Management and the Fault Tolerant Protection System can be applied independently based on the above constraints.

Physical Implementation

There are no new physical implementation details. Alarm Management and the Fault Tolerant Protection System are updates to the existing Controls Application Software and HMI software packages which already exist.
6.5 Intelligent Dual Control Redundancy

What It Is

Intelligent Dual Control Redundancy (IDCR) streamlines and simplifies the backup safety configurations of both the Turbine Control Panel CPUs and the instrumentation within the turbine accessory systems in a traditional Triple Modular Redundant (TMR) control architecture. With IDCR, the following updates are applied:

- Control Panel with dual CPUs and dual I/O networks
- Instrumentation redundancy determined on a case-by-case basis to meet reliability targets
- Active in-range fault detection and surrogate modeling to meet reliability targets

For example, all safety systems instrumentation remains triplicated to maintain tripping reliability, but some of the basic process control instrumentation redundancy can be consolidated to improve running reliability, while maintaining tripping reliability with surrogate sensor models.
Why It Matters

Compared to TMR, IDCR enables the following:

- Virtually identical tripping reliability while improving running reliability
- Lower cost solution
  - reduced product cost in control components and gas turbine accessories
- Lower cost to maintain
  - 20+ sensors reduced, 1 CPU, 4 network switches, and 15+ I/O modules reduced on the gas turbine control panel. 1 CPU, 4 network switches reduced on the steam turbine control panel
- I/O density reduction in control panel
  - 15+ I/O modules eliminated resulting in fewer panels required within controller cabinet

The benefits are illustrated in the figures below.

Key Enablers

The following technology features are applied to create an Intelligent Dual Control System:

- Surrogate sensor models – surrogate models acting as a 3rd sensor in voting
- In-range fault detection of previously undetectable faults

Requirements & Constraints

The IDCR philosophy remains the same regardless of the various site or plant requirements and constraints. The detailed content is adjusted as needed based on these requirements. For example, if dual fuel capability (natural gas and distillate) is needed, the IDCR philosophy will be adapted to cover both fuel sources.

System Interactions & Engineering Requirements

P11 GT Control

The configuration of Control Panel components is revised to Intelligent Dual configuration in the figure above. Where surrogate sensor models have been developed, triplex sensors become dual sensors.

P12 ST Control

The configuration of Control Panel components is revised to Intelligent Dual configuration in the figure above. Surrogate sensor models and changes to sensor count are not currently applied.

Physical Implementation

The footprint of the Control Panels remains the same. There are fewer components that need to be mounted within the Control Panel, but the number of reduced components does not currently drive the reduction of a Control cabinet.
Instrumentation Redundancy

Below is an example list of sensors that were removed for a dual fuel 7F.05 gas turbine. Reduction in sensors also results in a reduction in vendor, field and customer wiring and terminations. For pressure instrumentation, this also results in a decrease in tubing lines and pressure taps on piping. In terms of footprint, less total sensors means the instrumentation on the 557T panels can be redistributed and eliminate unnecessary panels by consolidation.

<table>
<thead>
<tr>
<th>MLI</th>
<th>Device</th>
<th>HW MLI</th>
<th>Description</th>
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<td>96TD-1C</td>
<td>A122</td>
<td>Inlet Dew Point Temperature</td>
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<td>96TS3P-1</td>
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Combined Cycle Power Plant Best Practices 2015

Appendix

Appendix A – Requirements and Constraints
Appendix B – Plant Functions
Appendix C – Physical Implementation
Appendix D – Definitions and Acronyms
Appendix E – Document Creation and Revision List
## Appendix A

### Requirements and Constraints

Requirements and constraints capture the plant mission and goals, interface of the plant to infrastructure and location based constraints. These are broken down into six categories:

- Operations
- Site
- Fuel
- Grid
- Environmental
- Schedule

The purpose of this dimension is to capture the requirements and constraints that drive the minimum viable product offer. This is best illustrated by an example. Under the "Grid" category in the figure below, "capacity limit" is shown as a constraint. Assume the constraint for the site is 1000 MW. However, the customer asked for a 500 MW plant. The true constraint is 1000 MW. The customer preference is 500 MW. GE would discuss the situation with the customer and adjust the offer as appropriate. Additional customer special requests or option preferences similar to this, such as paint color, material preferences or sources are captured for specific transaction and are in addition to this list. The figure below elaborates on the attributes for each of these six categories.

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Customer requirements and site specific constraints
Combined Cycle Power Plant Best Practices 2015

Appendix B  Plant Functions

System Interactions & Engineering Requirements

The primary goal of the system interaction section is to describe which functions of the power plant are affected by the feature. The functions of the plant are split into five primary systems. Along with defining the functionality of the power plant, it also provides the common language or system breakdown structure (SBS) for use across GE Power & Water teams when discussing the plant. The functional system design considers physical implementation needs while also supporting the plant requirements and constraints.

The five primary “parent” systems are:

**Topping Cycle**
The gas turbine and its dedicated systems.

**Bottoming Cycle**
The steam turbine, HRSG, condensate, feed water and associated system.

**Heat Rejection**
Systems that reject heat to the environment.

**Electrical**
Systems that export power to the grid or supply power to plant equipment.

**Plant Integration**
Systems that support the main plant equipment in converting fuel to electrical power.
Functions are sometimes split into three major groups

- **Group 1 – What GE Controls** – Equipment, accessories and system definition that GE supplies.
- **Group 2 – What GE Influences** – Customer, partner or EPC systems and equipment that directly support GE supplied systems.
- **Group 3 – Site Specific** – Systems and equipment beyond those in the first two groups that are necessary to meet site requirements and constraints. These systems are engineered by the customer, customer EPC, or GE partner (in case of Turnkey) and complete the plant package. Examples include raw water processing and waste water treatment systems.

These major groupings provide visibility to interactions between GE Equipment, GE Extended scope and Balance of Plant scope of supply. Such views give insight into total plant cost and optimization of functional design and implementation decisions.
# Physical Implementation

Physical Implementation of the plant considers how the plant is built, operated and maintained. The implementation methods also consider the functional needs of the plant and the plant requirements and constraints. The physical implementation of the plant must be adaptable to meet the requirements and constraints of the plant such as manpower availability and logistical constraints.

## Layout
- Location
- Interfaces
- Interferences

## Packaging
- Preservation
- Modularity

## Construction
- Lifting Capability/ Availability
- Cranes
- Gantry
- Material Handling
- Laydown
- Connections
- Flanges
- Welding
- Wiring
- Construction Waste
- Construction Tools
- Methods
- Work Face Planning
- Spares

## Commissioning
- Methods
- Test Requirements
- Cleaning
- System tuning
- Spares

## O&M
- Operations
- Test equipment
- Data Access
- Automation
- Maintenance
- Special Tools
- Access Reqs
- Laydown Reqs
- Spares
- Predictivity
- Lifting Needs/
- Availability
- Assembly/
- Disassembly

---

How the plant is built, operated and maintained
Definitions

**Build to Interface:** Drawings and specifications that define all mechanical, electrical and civil interface points.

**Build-to-Print:** Drawings and specifications include all supplier-specific components, materials, layout, dimensions, tolerances and special construction notes, including applicable codes and standards, required to facilitate the final design and construction of the equipment. The drawings and specifications are such that all mechanical, electrical and civil interface points are specified.

**Architecture:** The core technologies, assembly methods, and classes of materials associated with a given design concept. Gas turbine examples of these respectively include external vs. internal fed bucket cooling supply, bolted rotor vs. welded or curvic/hirth, and steel vs. nickel alloys.

**Rapid Response:** A plant configuration that adds HP and RH Steam terminal attemperation and additional steam bypass capability to allow the GT to operate unrestrained during the starting of the ST. A modified HRSG specification provides a robust HRSG that is capable of handling the new GT operating profile.

**Rapid Response Lite:** A plant configuration that adds HP and RH steam terminal attemperation to allow the GT to operate at loads up to Minimum Emissions Compliance during starting of the ST

**Equipment Only:** Contract scope in which GE provides the GT, ST, & Gen. Included are purchased auxiliary and MSD equipment related to the GE equipment such as Inlet filter house, excitation, controls and fuel systems.

**Engineered Equipment Package:** Contract scope in which GE provides power island equipment, plant construction engineering services, major equipment including HRSG, plant controls, condenser, and CC performance guarantees.

**Turnkey:** Contract scope in which GE provides GT, ST, Gen, HRSG, conceptual plant engineering, plant controls, plant commissioning, and performance CC guarantees and testing. A GE EPC partner generally provides detailed plant engineering, BOP equipment and materials, inland transportation, construction, commissioning labor.

**Reference Plant:** A typical plant design that includes power island layout and accommodation of standard options. The reference plant has sufficient detail to support proposal activities.

**Fieldbus:** An all-digital, serial, two-way industrial control network protocol for real time distributed control. Control signals and power are provided over the same wires. The two predominant standards are Profibus™ and FOUNDATION™ Fieldbus. The protocols are governed by a series of industrial standards.

**Total Installed Cost:** The total cost of a plant from initial order to COD. This includes permitting and insurance, capital carrying (finance), engineering, shipping, equipment, construction, installation, commissioning, taxes, cost of required spare components and project management.

**Life Cycle Cost:** Total cost of the plant owner/operator from purchase to the end of useful life, which is typically specified as 30 years. The current expected customer evaluation term is 20 years and includes the CSA, routine maintenance, major (capital) maintenance, fuel, inspections and operating labor.

**Plant Cold Start:** Plant shutdown ≥ 72 hours

**Plant Warm Start:** Plant shutdown < 72 hours but > 8 hours. Startup curves are made for 48 hours as representative of this range. The start time varies linearly with shutdown hours between 8 and 48 and between 48 and 72. Start time from 0 to 8 hours shutdown is constant as is time after 72 hours.

**Plant Hot Start:** Plant shutdown ≤ 8 hours

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Acronyms

• ACC: Air Cooled Condenser
• ASR: Accident Scenario Review
• ATEX: Atmosphere Explosive
• BIL: Basic Insulation Level
• BOP: Balance of Plant
• B/L: Baseload
• BTI: Build-To-Interface
• BTP: Build-To-Print
• C&Q: Compliance and Quality
• CAPEX: Capital Expenditure
• CEMS: Continuous Emissions Monitoring System
• CC: Combined Cycle
• COD: Commercial Operation Date
• Conv: Conventional (Plant Start Type)
• CSA: Contractual Service Agreement
• CSQ: Coaching Service Quality
• DCS: Distributed Control System
• DD: Device Description
• DFR: Design for Reliability
• DoC: Declaration of Conformity
• DoI: Declaration of Incorporation
• DTC: Design to Cost
• DTM: Detailed Transient Model
• DVP: Digital Vane Positioner
• DWG: Drawing
• EC: European Commission
• EEP: Engineered Equipment Package
• EMFH: Events per Million Fired Hours
• EU: European Union (27 Countries in Europe)
• FFB: Foundation Fieldbus
• F-F: Flange-to-Flange
• FMEA: Failure Mode & Effects Analysis
• FSNL: Full Speed, No Load
• GTA: Gas Turbine Auxiliaries
• GT/G: Gas Turbine/Generator
• HFE: Human Factors Engineering
• HGP: Hot Gas Path
• HMI: Human Machine Interface
• HP: High Pressure (Designation for Steam Turbine or Steam System)
• HRH: Hot Reheat
• HRSG: Heat Recovery Steam Generator
• ICPE: Installation Classes for The Environment
• IDCR: Intelligent Dual Control Redundancy
• IED: Industrial Emission Directive
• IGV: Inlet Guide Vane
• IP: Intermediate Pressure (Designation for Steam Turbine or Steam System)
• IPB: Isolated Phase Bus
• IPPC: International Plant Protection Convention
• IRR: Internal Rate of Return
• ISA: International Society of Automation
• ISO: International Organization for Standardization
• KKS: “Kraftwerk Kennzeichensystem” – A Standardized Power Plant Designation System
• LCB: Life-cycle Control Board
• LCC: Life Cycle Cost
• LCI: Load Commutator Inverter
• LCPM: Life Cycle Product Management
• LHV: Lower Heating Value
• LNG: Liquefied Natural Gas
• LP: Low Pressure (Designation for Steam Turbine or Steam System)
• LSB: Last Stage Bucket
• LSL: Lower Specification Limit
• LTSA: Long Term Service Agreement
• LVRT: Low Voltage Ride Through
• MCW: Main Circulating Water
• MECL: Minimum Emissions Compliance Load
• MF: Maintenance Factor
• MLI: Model List Item
• MS: Multi-Shaft
• MSD: Material Ship Direct
• MTBF: Mean Time Between Failures
• MTBFO: Mean Time Between Forced Outage
• MTBUE: Mean Time Between Unsafe Events
• MTTR: Mean Time to Repair
• NFPA: National Fire Protection Association
• NPV: Net Present Value
• NTI: New Technology Introduction
• NTP: Notice To Proceed
• O&M: Operating and Maintenance Manual
• OSM: On Site Monitoring
• OTB: Once Through Boiler
• P&E: Plant & Equipment
• PBCS: Product Baseline Compliance Specification
• PCNO: Power-Constrained Noise Optimizer
• PDC: Power Distribution Center
• PED: Pressure Equipment Directive
• PEECC: Packaged Electronic/Electrical Control Compartment
• PIIO: Power Island Integration and Optimization
• P/L: Part Load
• PLC: Programmable Logic Control
• QMS: Quality Management System
• RAM: Reliability, Availability and Maintainability
• RDS-PP: Reference Designation Systems for Power Plants ISO/TS 16952-10
• RDSU: Remote Deployable Software Upgrades
• RH: Reheat Steam, Steam at Intermediate Pressure That is Superheated
• RoHS: Restriction of The Use of Certain Hazardous Substances in Electrical and Electronic Equipment
• RR: Rapid Response
• RSG: Remote Service Gateway
• SBS: System Breakdown Structure
• SC: Simple Cycle
• SI: International System of Units
• SIL: Safety Integrity Level
• SS: Single-Shaft
• SST: Smart Start
• TDI: Technical Direction of Information
• TIC: Total Installed Cost
## Appendix E

### Document Creation and Revision List

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### APPENDIX

| A   | Requirements and Constraints                                        | 04/15   |        |                                                                             |
| B   | Plant Functions                                                      | 04/15   |        |                                                                             |
| C   | Physical Implementation                                              | 04/15   |        |                                                                             |
| D   | Definitions and Acronyms                                             | 04/15   |        |                                                                             |
Imagination at work