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## Combined Cycle Power Plants



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## 1. Executive Summary

This IMIA paper examines the most significant risks associated with the construction (including conversion) and the operation of combined cycle power plants (CCPP). The paper presents different technologies used in a CCPP, highlighting the main differences with simple cycle power plants and emphasizing the benefits of the new combined cycle technology.

The paper also lists some of the most relevant risks that exist during the construction and operation of the CCPP. This includes commissioning and testing risks as well as material failure and equipment breakdown risks.

A special section is dedicated to the underwriting perspective of insuring a combined cycle power plant. It provides the details and issues to consider when underwriting a combined cycle power plant.

The paper also provides special sections with contribution from a CCPP operator providing clients perspective especially with regard to risk profile and how regulations and standards impact the risk profile of a CCPP. Though this perspective is mostly focused on the UK, it does lend itself very well to the operation of CCPP's in multiple locations worldwide.

The paper is not intended to provide an in-depth discussion of the technologies used in various CCPP's of different configurations. Instead, the reader is encouraged to reference a number of previously published IMIA work papers on different technical topics.

Though a tremendous effort was made to describe and discuss the technology of boilers used in a CCPP, we were unable to dedicate a special section on the topic of boilers (superheated or otherwise) due to limitation of resources and time. Instead, it is the recommendation of this working group that the topic of boilers be the subject of an independent working group in the near future.

## 2. Introduction

The additions of modern CCPP's have allowed for the retirement of less efficient and higher air polluting oil and coal fired fossil power plants. CCPP's are the most efficient method of adding electrical capacity to areas with an abundance of natural gas, due to:

- A. Low capital cost, compared to conventional fossil power plants
- B. Shorter construction time compared to conventional fossil power plants: Combined cycle plants are manufactured as a standard reference plant with pre-engineered packages designed to plug together, minimizing onsite installation construction time. The major equipment such as the gas turbine (GT), steam turbine (ST) and generator step up (GSU) transformers are shipped to the site assembled and factory tested. The Heat Recovery Steam Generators (HRSG) are shipped in factory manufactured modularized sections designed for easy tube welding and assembly. Modular construction with factory plug and play auxiliaries enable faster construction times with less human error vs, the traditional method of pulling cables and hardwiring auxiliaries in the field. This minimizes the installation time, cost and schedule risk. The typical erection time of a combined cycle power plant is as short as 2 – 2 1/2 years.
- C. Low fuel cost, due to higher cycle efficiency (lower cost per kilowatt) than conventional fossil power plants
- D. Lower emissions compared to conventional fossil power plants
- E. High efficiency and high power density: A CCPP has a higher thermal efficiency than any other type of conventional power plants. The energy efficiency of modern combined cycle power plants is in the range of 50 – 62%.

The term combined cycle refers to the two thermodynamic cycles that are combined for maximum efficiency. The Brayton combustion turbine topping cycle<sup>1</sup> and the Rankine steam turbine bottoming cycle<sup>2</sup>.

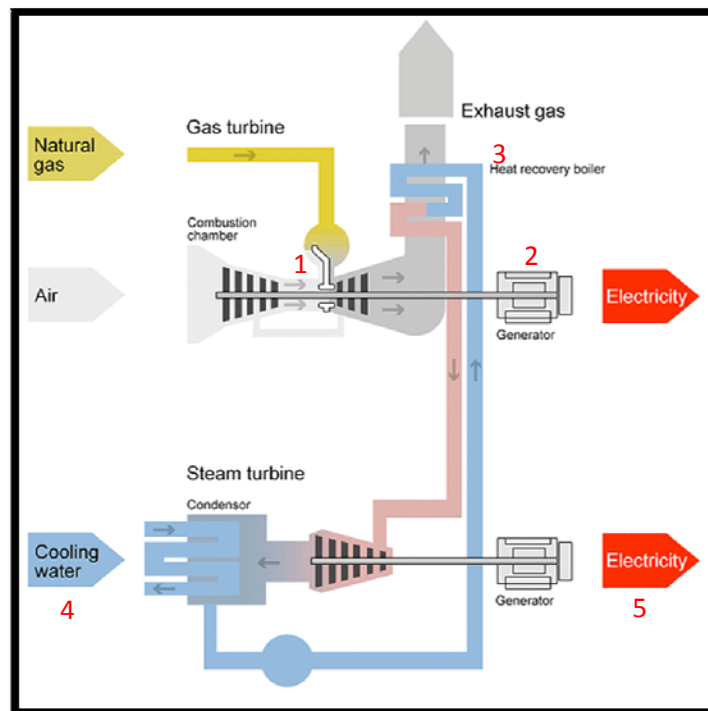


Diagram 1: The basic principles of operation of a typical CCPP

<sup>1</sup> Brayton topping cycle

<sup>2</sup> Rankine bottoming cycle

Natural gas or liquid fuel is burned in the combustion turbine (1) creating a constant pressure which spins a generator (2) producing electricity. The combustion turbine exhaust waste heat and mass flow is captured in a heat recovery steam generator (3) that creates superheated steam to drive a steam turbine (4) that spins another generator (5).

Capturing the heat from the combustion turbine in a HRSG and steam turbine generator, produces approximately 50% more electricity from the natural gas than using the combustion turbine generator in simple cycle mode alone.

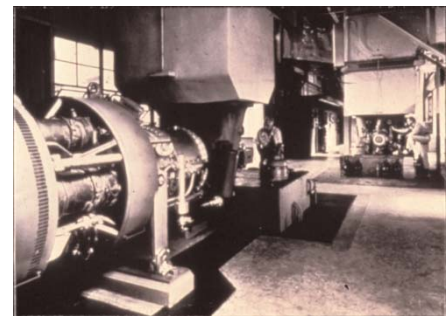
For insurer's the main pieces of capital equipment, that in the event of a loss can exceed the policy deductible, are the combustion turbine, the steam turbine, generator, HRSG, and Generator Step Up (GSU) transformer.

The most common type of combined cycle power plant utilizes gas turbines and is called a combined cycle gas turbine (CCGT) plant. Because gas turbines have low efficiency in simple cycle operation, the output produced by the steam turbine accounts for about half of the CCGT plant output.

There are many different configurations for CCGT power plants, but typically each GT has its own associated HRSG, and multiple HRSGs supply steam to one or more steam turbines. For example, at a plant in a 2x1 configuration, two GT/HRSG trains supply to one steam turbine; likewise there can be 1x1, 3x1 or 4x1 arrangements. The steam turbine is sized to the number and capacity of supplying GTs/HRSGs.

### 3. Development, Features and Future forecast

The commercial development of steam and gas turbine combined cycles has proceeded in parallel with gas turbine development. The first gas turbine installed in an electric utility in the United States was applied in a combined cycle. This was a 3.5 MW gas turbine that used the energy from the exhaust gas to heat feedwater for a 35-MW conventional steam unit. This system entered service in June 1949 in the Oklahoma Gas and Electric Company Belle Isle Station, and a similar system was added to this station in 1952<sup>3</sup>.



*Photograph 1: Gas turbine used in early Combined Cycle System*

Most combined cycle power generation systems installed in the 1950s and 1960s included conventional, fully-fired boilers. These systems were basically adaptations of conventional steam plants with the gas turbine exhaust gas serving as combustion air for the boiler. The efficiency of this type of combined cycle was approximately 5% to 6% higher than that of a similar conventional steam plant. These systems could economically utilize bare tubes in the boiler because of the high mean temperature difference between the combustion products and the water/steam.

Equipment to economically weld continuous spiral fins to tubes was introduced to the boiler manufacturers in 1958. Heat recovery combined cycles, which use the sensible heat in the gas turbine exhaust gas, were made feasible by enhanced gas side heat transfer by the use of resistance-welded, finned tubes.

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<sup>3</sup> GE Power Systems, GER-4206 (04/01), David L. Chase

Finned tube boilers entered service in 1959. During the 1960s, the heat recovery type of combined cycle became dominant. Its initial application was in power and heat applications where its power-to-heat ratio was favourable to many chemical and petrochemical processes. A small number of heat recovery-type combined cycles were installed in power generation applications in the 1960s.

When gas turbines over 50 MW in capacity were introduced in the 1970s the heat recovery combined cycle experienced rapid growth in electric utility applications. The 1980s and early



*Photograph 2: The 2,000MW Seoinchon combined-cycle plant is located on the island of Ildo, 40 miles SE of Seoul, Korea.*

1990s have brought a large number of natural gas-fuelled systems, including plants designed for power only and those designed for power and heat (cogeneration) applications (Figure 3). The power-only plants utilize condensing steam turbines with minimum extraction for feed water heating.

One recent trendsetting power-only plant is at the Korea Electric Power Company Seoinchon site where eight advanced gas turbines are configured with dry low NO<sub>x</sub> combustion systems and a reheat steam cycle. This 1,886 MW plant is the most efficient operating to date at 55% (LHV) gross efficiency.

## 4. Advances in Modern Combined Cycle Power Plants

***Today's advanced combined cycle plants operate alongside increasing levels of wind turbine and solar energy power plants***

When the 45 – 50% efficient E-Class combustion turbine combined cycle plants entered the market in the early 1980's, they were designed for base load operation and in some cases to supply steam to a steam host. The main components were pulled from the original equipment manufacturer (OEM) parts bins and integrated to meet the needs of the marketplace.

In the early 1990's, the 50 - 55% LHV efficiency F-Class combustion turbine combined cycle plants were the first time that OEM's purposefully developed the main components to operate in concert for optimized efficiency at base load operation.

Today's 58 – 62% LHV efficiency next generation of advanced combined cycle power plants were developed to meet the market requirements for fast start-up, rapid load cycling and minimum load turndown, while maintaining good part load emissions. They can reach full plant load in less than 30 minutes, have 100 MW per minute ramp rates and maintain emissions down to 14% of plant base load. In comparison a simple cycle industrial combustion turbine operating as a peaking plant without a HRSG or steam turbine has an LHV efficiency of approximately 38 – 40%.

Today's advanced combined cycle plants operate alongside increasing levels of wind turbine and solar energy power plants, and are subjected to daily start up peaking operation and load following to smooth out fluctuations in renewable solar and wind generation. Advanced combined cycle plants have been designed with features to support this new trend for increased cyclic operation and turndown capability.

- Air-cooled combustion turbines without the complexity of being linked to the steam cycle (away from steam cooled hot gas path components), with optimized active clearance control to prevent blade rubs during rapid start ups
- Exhaust stack dampers that close to retain the heat in the combustion turbine and HRSG, to permit a rapid start with less thermal shock.
- High capacity de-superheaters, that can maintain steam conditions during rapid starts and cyclic operation
- Optimized combustion turbine control that integrates the start-up ramp rate of the CT with steam turbine thermal stress control
- Standby heating systems for the HRSG and condensate polishers to reach steam purity specifications more quickly
- The addition of an auxiliary boiler to maintain condenser vacuum during shuts downs.
- The integration of the combustion turbine dry low NO<sub>x</sub> combustion system and the selective catalytic reduction system located in the HRSG, resulting in improved emissions during start up and cyclic operation
- HRSG drums with lower thickness to accommodate rapid heating and cooling.
- Double casing high and intermediate pressure steam turbines for improved clearance control and higher ramp rates during fast starts and cyclic operation.

## 5. CCP Technology

### Main Components

In this section, we describe the main components of a CCP. We first describe the technology and provide information about each component, and then discuss in some detail failure modes and different loss scenarios.

### Combustion Turbine

In basic terms, the combustion turbine consists of three main engine sections: The compressor, the combustor and the turbine sections.

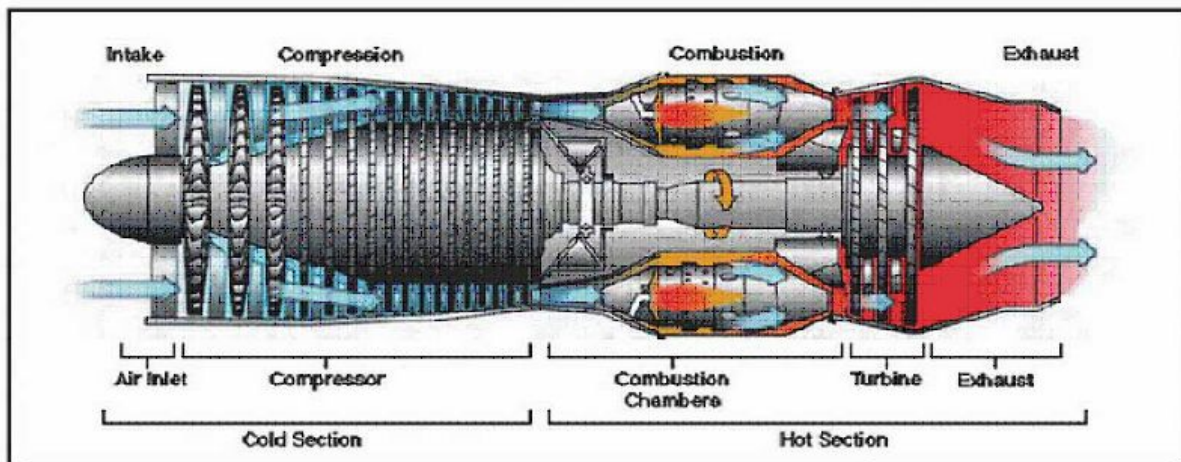


Diagram 2: Main sections of combustion turbine<sup>4</sup>

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<sup>4</sup> The Importance of Hot Corrosion and Its Effective Prevention for Enhanced Efficiency of Gas Turbines



The filtered air enters the compressor section which compresses air and moves it to the combustion chamber. In the combustor, fuel is added to the compressed air and ignited in a continuous high pressure combustion process.

Next, the continuous high pressure combustion gasses are directed into the turbine section where the hot gasses expand through the turbine blades to create torque that provides a portion of the power to drive the compressor section and to turn the generator to generate electricity.

After the hot gasses exit the turbine they are directed into the exhaust section and the heat recovery steam generator (HRSG) boiler to produce steam to be used in the steam turbine generator.

Heavy duty industrial combustion turbines can range in output from 25 – 375 MW. Over the years combustion turbines have been classified by their technology and corresponding turbine inlet firing temperature. Examples include:

- **E class combustion turbines** have a firing temperature up to 2,200F or 1200C and are considered proven technology,
- **F class** combustion turbines have a firing temperature up to 2,500F or 1370C and are considered proven technology,
- **G class** combustion turbines have a firing temperature up to 2,700F or 1480C and are considered proven technology
- The latest next generation combustion turbines have a firing temperature up to 2,900F or 1600C. These combustion turbines enter service as prototype technology, and after the fleet leader accumulates over 8,000 equivalent operating hours without any major component exchanges due to durability issues, they can then be classified as proven technology.

For more information on combustion turbine technology and insurance aspects, please reference the following IMIA Publications which are available online at [www.IMIA.com](http://www.IMIA.com) under the “Knowledge” folder, “Type of Technology”, “Combined Cycle Power Plants”

- IMIA WGP 001 (1993) Development of Industrial Gas Turbines – 06-59, this paper covers the transition from E class to the early development of the F Class combustion turbines which were released to the market in 1993.
- IMIA WGP 013 (00) Large Gas Turbines – Written in 2000 during the start of the rapid deployment of F Class combustion turbines, it focuses on the rapid evolution of the 50 Hz F Class examples.
- IMIA WGP 064 (09) Combustion Turbine Critical Losses and Trends, Written in 2009, the paper covers developments, loss prevention, service, spare parts and interesting claims.

An *emerging issue* for combined cycle power plants is **ageing equipment**. For example ageing E and F Class combustion turbines pose an increased risk of loss due to:

- Changes in duty cycle from base load to peaking. More frequent starting and stopping of a combustion turbine imparts more thermal cycles to the parts which can lead to thermal mechanical fatigue cracking.

***Non-destructive testing, finite element analysis and fracture mechanics models are utilized to determine the remaining operating hours and starts of the rotor components.***

- Lower capacity factor and lower revenue often results in lower maintenance budgets and extended maintenance intervals between combustion turbine overhauls.
- Control system obsolescence may lead to lower functionality and response due to difficulty acquiring replacement components and expertise.
- Excessive turning gear time and blade rock wear at the rotor to blade attachment
- Improper layup during extended periods of down time can lead to moisture related humidity and condensation pitting and corrosion on turbine blades, bearing pedestals and associated generators, fans, pumps and motors.
- Over time, combustion turbine inlet and exhaust duct deterioration (such as rust) can allow ferric oxide particle to erode the compressor parts and allow unfiltered air into the combustion turbine. Exhaust duct and expansion joint deterioration can allow hot gasses to escape causing a personnel safety concern and damage or fire to adjacent equipment.
- Rotor Remaining Life Planning – E and F Class combustion turbine rotors require a rotor inspection at every major inspection interval. Depending on the manufacturer, As rotors approach 100,000 to 200,000 operating hours or 2,000 to 5,000 starts a rotor remaining life requalification inspection should be performed by the OEM or a qualified third party. Non-destructive testing, finite element analysis and fracture mechanics models are utilized to determine the remaining operating hours and starts of the rotor components. Components that are found to have life limiting conditions can often be repaired or replaced to extend the rotor life for another operating interval. The goal is to repair or replace the rotor prior to a catastrophic rotor burst failure which can cause personnel injury, maximum property damage and extended business interruption loss.

*Next generation advanced combustion turbines* are highly efficient, and operationally flexible, while maintaining low stack emissions. The next generation advanced combustion turbine technology has greater power density, megawatt (MW) output, higher business interruption (BI) exposure, and greater property damage (PD) values.

The major improvements in CCGT efficiency has been due to more efficient compressor technology and the increase in combustion turbine firing temperature due to advances in materials, cooling designs, and coatings in the hot gas path. In general modern advanced next generation combustion turbines have the following features

- They can begin producing power in as little as 10 minutes and can reach maximum base load power levels under 1 hour. Combustion turbines can put electrical load on the grid quickly and can cycle the load rapidly in response to sudden shifts in wind or solar resources.
- Next generation advanced combustion turbine combined cycle plants are the cleanest available fossil fuelled power plant technology, with less than 10 parts-per-million (ppm) carbon monoxide (CO) emissions and less than 2.0 ppm nitrogen oxide (NOx) emissions.
- New technology enables these plants to turndown to very low load levels while still maintaining permitted emissions levels.
- Greater than 60% combined cycle efficiency
- Fully air-cooled engines that are not constrained by the bottoming cycle. The majority of advanced next generation combustion turbines have moved away from closed loop steam

***Insurers prefer an evolutionary design approach with previously proven concepts, rather than a revolutionary design`***

cooled combustors and turbine blade and vanes segments which require more time to reach steam quality conditions before being admitted into the combustion turbine.

- Wide Wobble index fuel capability and operation Sub 9ppm NOx combustion emissions
- Fewer compressor stages and higher compression ratios than the F class combustion turbines
- Rapid start up and load cycling capability due to fully air cooled combustor and turbine components. Fast starting and cyclic load capability allows these modern combustion turbines to respond quickly to smooth out the cyclic nature of wind turbine and solar power.
- 3D aerodynamically optimized 4 stage turbine section with advanced aero derivative air cooling technology, blade alloys and zirconium ceramic thermal barrier coatings
- Enlarged compressor inlets with 3D aerodynamic controlled diffusion arc compressor air foils, variable inlet guide vanes (VIGV) and several stages of fast acting variable guide vanes (VGV) to improve part load efficiency, rapid load changes, and turndown capability while maintaining low emissions.
- VIGV and VGV to maintain high efficiency at part load operation by reducing compressor airflow and simultaneously maintaining steady exhaust temperature and bottoming cycle steam conditions to maximize steam turbine efficiency.
- Active rotating to stationary component clearance control to increase clearances during start and stop transient operation, and to reduce clearances for maximum efficiency when at steady state operation.

When manufacturers release a new combustion turbine to the market, Insurers prefer an evolutionary design approach with previously proven concepts, rather than a revolutionary design with first of kind designs with no prior operating history. Manufacturers test their new prototype combustion turbines in factory test stands to validate expected design performance, rotor dynamics, combustion stability, emissions, temperatures, flow, pressures, and strains.

***... the majority of insurance losses occur after the warranty period has expired***

Combustion turbine manufacturers have invested heavily into component level (blade and vane components), system level (compressor and combustor sections) and complete engine full speed, temperature, pressure and load testing in factory test stands or power plants. In these tests the design models and assumptions can be verified by the engine test data. The benefit is that minor tweaking to component cooling, clearances, material or coatings can be adjusted before the combustion turbine is released for commercial production.

This longer factory testing phase which has been instituted prior to series production of the next generation advanced combustion turbines has proven very valuable, as it has resulted in little to no initial loss experience when compared to the release of the first F class combustion turbines in the early 1990's.

For insurers its reassuring that OEMs have undergone this more rigorous approach to validating the combustion turbines prior to commercial release, but the majority of insurance losses occur after the warranty period has expired, and are primarily due to the effects of accumulated operating hours, starts and stops and load cycling. These longer term

***For insurers; it's reassuring that OEMs undergo rigorous validation of combustion turbines prior to commercial release***

damage mechanisms manifest themselves in the form of component oxidation, creep, high cycle fatigue (HCF) vibratory damage and thermal mechanical fatigue (TMF) damage.

As the technology and turbine inlet firing temperature has increased, so has the cost to repair or replace the combustion turbine components. For example the first stage turbine blades which operate in the extremely high temperature environment of the hot gas stream have increased in technology, materials, coatings and internal cooling design. For example the replacement cost for a first stage turbine blade - “E Class” Equiax Cast = \$500,000 USD /set, “F Class” Directionally Solidified (DS)= \$1M USD/set, “G, H, J Class” Single Crystal (SXL) = \$2M + USD/set. G, H- and J-class turbine blades (and several F-class blades) can only be purchased from the respective OEMs. Therefore price levels and delivery times (often co- related) can be critically high.

#### *Combustion Turbine Losses:*

The following section discusses the frequent causes of loss for combustion turbines.

**Compressor high cycle fatigue air foil cracking** can lead to liberated pieces of air foil causing consequential damage to the downstream parts. Compressor air foil cracking can be identified without disassembly of the casings, by performing at a minimum an annual or preferably a bi-annual high resolution fibre-optic borescope inspection of the flow path. For example, a borescope inspection can identify internal component cracks, missing pieces, migrated parts, rubbing, oxidation, foreign or domestic object damage and missing coatings.



*Photograph 3: Crack visible at the trailing edge of a 50 vane in the lower half of a compressor. Courtesy – CCJ Online*

Another method of avoiding compressor air foil cracking is to follow the OEM recommendations by complying with Technical Information Letters (TILs), Technical Advisories (TAs), and Service Bulletins (SBs). These documents are used by the OEM's to communicate known areas of distress, and to provide recommendations on inspection regimens to avoid damage. In addition the OEMs and select third party manufacturers offer upgrades with improved re-engineered components that can be purchased to replace the affected parts with more durable upgraded components. However, there have also been third party manufacturers who have delivered “sub-

OEM” quality, which resulted in damage and insurance claims.

**Loss of lube oil supply during operation**, results in journal bearing damage, and compressor and turbine blade tip casing rub damage. Typically the combustion turbine will require shop repairs to the rotor, journal bearings, blades, diaphragms and vane segments. Loss of lube oil damage can be averted by following the OEM recommendation for emergency lube oil pump pressure drop and cascade testing. Some modern combustion turbine control systems will automatically test the DC emergency lube oil pump every time the unit is started.

On other units the DC pump test can be accomplished during a shutdown sequence by simulating a drop in lube oil header pressure, which cascades the oil pressure supply from the primary AC lube oil pump to the backup AC lube oil pump, and in the event that the AC power supply is lost, the combustion turbine will trip off line and the emergency DC lube oil pump will supply oil pressure from battery power until the rotors can roll down to turning gear speed. The

roll down time for a typical combustion turbine is 30 minutes, followed by at least 6 hours of turning gear cool down time.

**Oxidation and low cycle thermal fatigue cracking** of combustor and turbine hot gas path section components can lead to liberated pieces of air foil which cause consequential damage to the downstream parts. Adherence to the OEM maintenance intervals for the combustion turbine will allow the replacement of distressed hot gas path components before they result in a failure and consequential damage.

For example the failure of several forth stage turbine blades will provide a severe rotor imbalance and extreme vibration which has led to catastrophic failure of the internal components of the combustion turbine, generator, foundations, and broken lube oil supply and drain piping resulting in a fire following.

**Rotor overspeed damage** can be caused by a failure of the turbine controls or protective devices and sequential trip scheme. Routine inspection, testing and maintenance of the controls, and protective devices can avert a catastrophic overspeed loss.

The OEM recommendations for performing simulated electronic and full functional sequential trip testing should be performed on an annual basis, or after any maintenance has been performed on areas where these components may have been disturbed.

As combustion turbines approach the end of their useful lives, major items such as the rotor will require a rotor requalification inspection. This is typically required after 200,000 operating hours or 5,000 starts have been accumulated.

The rotor requalification inspection involves the disassembly of all the rotor components and non-destructive testing such as hardness checks, phased array ultrasonic inspection, eddy current inspection and X-ray inspection to detect the presence of subsurface crack or inclusion defects which could reach a critical flaw size, resulting in a catastrophic rotor burst. Rotor requalification and remaining life assessments are available from the combustion turbine OEM, or qualified vendors with expertise in non-destructive testing, metallurgy, finite element analysis and fracture mechanics modelling.

The **Maximum Foreseeable Loss (MFL)** for a combustion turbine is defined as a catastrophic overspeed with a lube oil fire following, to the combustion turbine, generator and adjacent auxiliary systems like the cooling air, lube oil, gas fuel, inlet duct and exhaust duct systems.

It requires demolition and removal of damaged equipment, possible foundation, inlet/exhaust ducts, enclosure and piping repairs, replacement or repair of the turbine, and generator, and associated auxiliary systems.

The estimated maximum downtime is 18 to 24 months. In the event that there are other combustion turbines constructed alongside the failed unit, then the damage and costs to adjacent combustion turbines increases if the separation between units is 30'– 60' (10 – 20m) – add 25% to the cost, and if the separation is < 30' (10m) separation add 50% to the cost.

### Steam Turbine

Steam turbines used in E-Class combined cycle plants were typically existing models designed to run constantly for industrial applications. In the early 1990's with the advent of F-Class combustion turbines and the ever increasing pursuit of higher efficiency, lower heat rate and greater power density, manufacturers designed purpose-built steam turbines to meet these ever increasing demands. The F-Class steam turbines were typically single case axial or side exhaust designs with lower capital cost and installation costs.

Advanced next generation CCPP steam turbines typically have increased steam temperature and pressure triple pressure reheat designs with 2400 PSI (165 bar) high pressure steam outputs, and 1,112 degree Fahrenheit (600 degree Centigrade) steam temperatures. In order to extract the maximum energy captured by the HRSG, steam is admitted into the steam turbine at high pressure, intermediate pressure and low pressure levels.

Some of the features of new steam turbines are

- Improved aerodynamics and sealing for increased performance
- Double casing high and intermediate pressure steam turbines for improved clearance control and to allow higher ramp rates during fast starts and cyclic operation.
- Fully 3-dimensional high performance variable reaction blading
- Integral cover buckets and nozzles for improved performance
- Design and controls for increased cycling and fast transients
- Spring backed seal technology for easy replacement
- 41% shaft efficiency, Start up in less than 10 minutes, for full plant start up in 30 minutes, and turndown to 14% baseload
- Double flow low pressure turbines

For a single shaft combined cycle configuration, the steam turbine, a shared generator and combustion turbine are all coupled together on the same shaft. The single shaft layouts provide a benefit of lower initial plant capital cost over the traditional multi-shaft combined cycle plant layout (each gas turbine and each steam turbine has its own generator).

Manufacturers have improved their steam turbines by adding features to improve their cycling capability. During start up, fast ramp rates, and rapid load swings, generous clearances between the rotor and stationary parts are required to allow for differential expansion of the stationary and rotating steam turbine parts.

In order to accommodate the fast ramp rates of modern combustion turbines, combined cycle plants must be designed with a method of dumping any steam produced until the steam pressures, temperatures and moisture content meets the steam turbine quality requirements. Full steam bypass systems that would allow one or more combustion turbines to run in simple cycle mode if the steam turbine were damaged are rarely found in modern CCPPs due to their higher capital cost and complexity.

Modern Steam turbine models can be configured with different internal blade flow paths and can have an additional low pressure turbine added to match the steam conditions of the topping cycle if it is a 1x1, 2x1, or 3x1 CCPP.

#### *Steam Turbine Losses*

Because of the cyclic operational duty of advanced next generation CCPP steam turbines, there is a higher tendency for the phase transition zone to shift from the condenser, upstream into the last stages of the low pressure turbine blading.

*Manufacturers  
have improved their  
steam turbines by  
adding features to  
improve their  
cycling capability*

The **phase transition zone** is where the steam is condensing into a mixture of steam and moisture droplets. The moisture droplets travelling at high velocity can cause moisture erosion on the low pressure turbine blades and vanes. If left undetected the moisture erosion on the blade and vane air foils can progress to the point that the erosion pits form a stress concentration and crack initiation site.



*Photograph 4: Rotating blades in a low pressure turbine at first condensation. The areas with oxide deposits are dry, and the blank metal zone is wet during turbine operation.*

These cracks can propagate due to the thermal stress of starting and stopping the turbine (Thermal Mechanical fatigue TMF) or due to the vibration effects of operation at higher loads (High Cycle fatigue HCF), or vibration induced by steam flow, which is referred to as aero-elastic instability.

**Phonograph courtesy:** Investigations into the Composition of the Water Phase in Steam Turbines Robert Svoboda\* and Maurice Bodmer Materials Department, Alstom, Brown Boveri Strasse 7, CH-5401 Baden, Switzerland

To combat the effects of moisture erosion, protection measures such as the blade air foil fatigue strength can be increased by laser shock peening which increases the compressive strength of the air foils, by application of stellate moisture shields, or with materials and coatings with improved corrosion and erosion resistance.

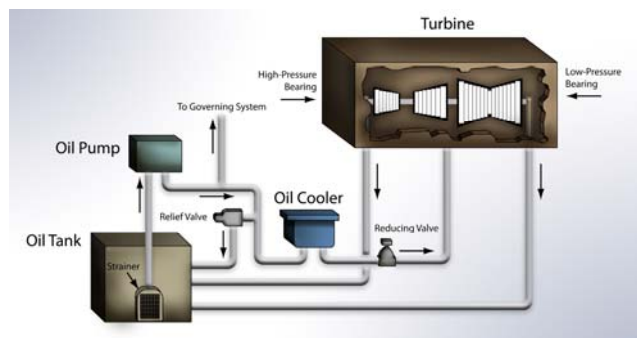
In order to increase the L-0 blade lengths, to lower the kinetic energy losses, stronger and lighter materials are needed. In the 1990s last stage low pressure blades have been manufactured from Titanium to enable longer air foils to capture more thermal energy, and to provide lower stresses at the blade to rotor root attachment area.

The benefit of longer last stage turbine blades is their ability to capture as much kinetic energy as possible from steam, the lower the discharged kinetic energy, the higher the steam turbines efficiency. Last stage blades up to 60” are now being offered by the major steam turbine manufacturers. Titanium L-0 blades are costly to manufacture, and several manufacturers have experienced some issues with cracking at the blade root attachment area to the rotor on their F-Class CCPP steam turbine technology. Some manufacturers have returned to using high strength stainless steel L-0 blades for their new low pressure turbines instead of Titanium.

### Steam Turbine Auxiliary Systems

#### Steam Turbine Lubrication Oil and Hydraulic Fluid Systems

Aside from turbine blade failures, the most common turbine reliability issues are bearing and control system failures, which often can be traced back to lubrication-related issues.. Therefore, a turbine lubrication reliability program should be an integral part of any power plant maintenance program.



*Diagram 3: Typical steam turbine lubrication system*

#### Hydraulic Power Unit

The hydraulic power unit supplies hydraulic fluid, under pressure, to the power actuators that position the main stop and control valves, and the LP admission valves.

## Shaft Sealing System

A shaft sealing system is required to keep high pressure steam inside the turbine from leaking into the turbine room, as well as to keep air from leaking into the vacuum and sub atmospheric areas inside the turbine.

## Steam Turbine Bypass

To facilitate start-up of the combined cycle plant, and to improve operational flexibility, for example, during rapid load changes, steam bypass lines for HP and LP steam is installed to deliver the steam generated by each HRSG to the condenser. Each bypass line is designed to handle the maximum steam flow corresponding to the combination of maximum steam flow and specific volume.

## Heat Recovery Steam Generation System

The HRSG is basically a heat exchanger, or rather a series of heat exchangers. It is also called a boiler, as it creates steam for the steam turbine by passing the hot exhaust gas flow from a gas turbine or combustion engine through banks of heat exchanger tubes. The HRSG can rely on natural circulation or utilize forced circulation using pumps. As the hot exhaust gases flow past the heat exchanger tubes in which hot water circulates, heat is absorbed causing the creation of steam in the tubes. The tubes are arranged in sections, or modules, each serving a different function in the production of dry superheated steam. These modules are referred to as economizers, evaporators, superheaters/ reheaters and preheaters.

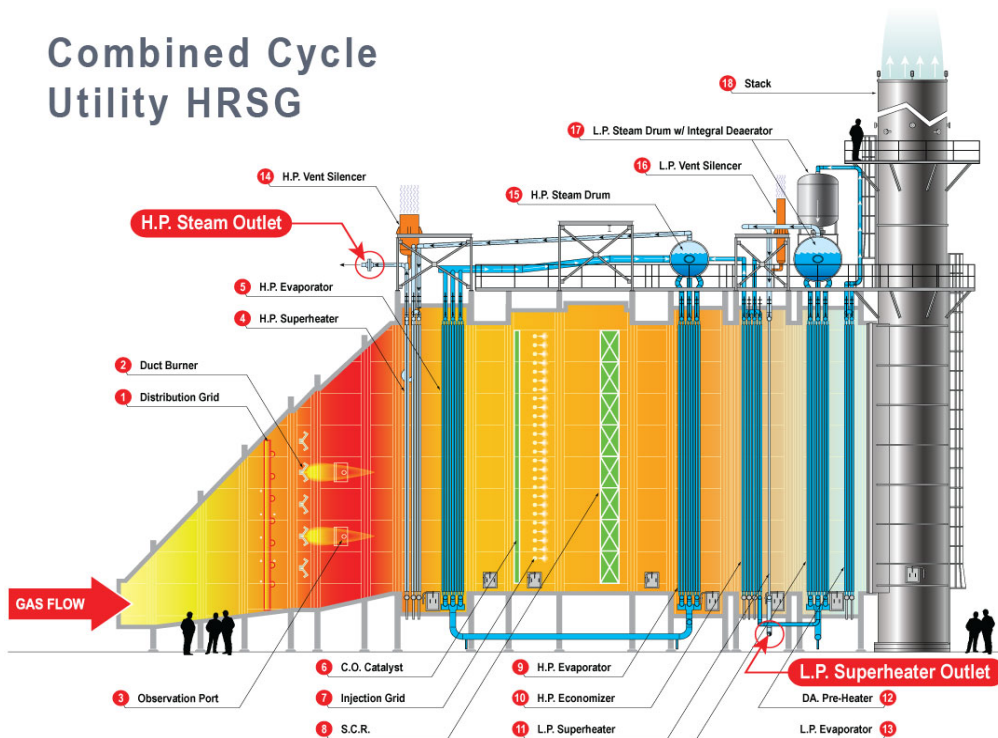


Diagram 4: sections of HRSG<sup>5</sup>

**Principles of Operation:** The **economizer** is a heat exchanger that preheats the water to approach the saturation temperature (boiling point), which is supplied to a thick-walled **steam drum**.

<sup>5</sup> Victory Energy Operations, LLC



The drum is located adjacent to **finned evaporator** tubes that circulate heated water. As the hot exhaust gases flow past the evaporator tubes, heat is absorbed causing the creation of steam in the tubes. The steam-water mixture in the tubes enters the steam drum where steam is separated from the hot water using moisture separators and cyclones. The separated water is recirculated to the evaporator tubes. Steam drums also serve storage and water treatment functions.

An alternative design to steam drums is a once-through HRSG, which replaces the steam drum with thin-walled components that are better suited to handle changes in exhaust gas temperatures and steam pressures during frequent starts and stops.

This provides the following attributes:

- Maintains vertical tube module arrangement in horizontal gas path as proven in drum-type boilers.
- Replaces HP drum with thin-walled components (separator), which improves operational flexibility.
- Maintains natural circulation flow characteristics and therefore assures flow stability and even heat distribution.
- Requires no changes in HP economizer and HP superheater.
- Retains proven low pressure and intermediate pressure drums.

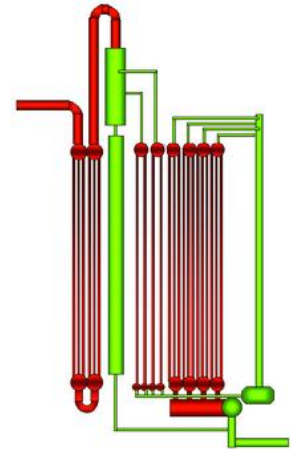


Diagram 5: Benson once-through HRSG

In some designs, duct burners are used to add heat to the exhaust gas stream and boost steam production; they can be used to produce steam even if there is insufficient exhaust gas flow.

Saturated steam from the steam drums or once-through system is sent to the superheater to produce dry steam, which is required for the steam turbine. Preheaters are located at the coolest end of the HRSG gas path and absorb energy to preheat heat exchanger liquids, such as water/glycol mixtures, thus extracting the most economically viable amount of heat from exhaust gases.



Photograph 5: Drum heaters used to increase temperature in the HRSG

The superheated steam produced by the HRSG is supplied to the steam turbine where it expands through the turbine blades, imparting rotation to the turbine shaft. The energy delivered to the generator drive shaft is converted into electricity. After exiting the steam turbine, the steam is sent to a condenser which routes the condensed water back to the HRSG

The Heat Recovery Steam Generator and accessories comprise mainly the following:

- **Economizer:** The Economizer sections raise the boiler feedwater to a suitable approach temperature.
- **Steam Drum:** Connections are provided on the steam drums for steam outlet, feed inlet, riser and down comer, venting, safety valve, surface blowdown, feed water regulators, water columns, chemical feed and nitrogen blanketing.
- **Evaporator:** The HP and LP evaporator systems are of natural circulation. Each pressure evaporator section consists of evaporator heat transfer section, steam drum, downcomers, and risers. The heat transfer section consists of multiple rows of finned tubes. Lower and upper headers, manifolds, vents and drains are included.

- **Superheater:** The superheater section is designed to increase the steam temperature to the temperature stated in heat balance. Superheated steam has a high energy content and is free of moisture. Required crossover tubes, vents, drains and safety valves are included.
- **Attemperator:** The HP superheater steam temperature will be varied at final superheater outlet depending on the gas turbine operating condition. In order to control the steam temperature within a predetermined value (at MCR) an attemperator is provided downstream of the HP superheater outlet. Demineralised Injection water is tapped from the feedwater pump discharge line upstream of the HP economizer.
- **Steam safety valve and silencer:** Safety valves for steam drum and superheater of design and capacity are provided in accordance with the requirements laid down in the ASME code. The silencers are combined for several safety valves for drum and superheater, and designed to reduce the noise level not to exceed 105 dB(A) at 1 meter distance from the equipment.
- **Exhaust gas inlet duct:** The ductwork is properly stiffened, reinforced and complete with expansion joint and necessary doors.
- **HRSG heat exchanger chamber:** The HRSG heat exchanger chamber is constructed of carbon steel casing externally reinforced with structural steel. All structural steel are seal welded to the casing to prevent corrosion behind the structural.
- **Thermal insulation:** Thermal insulation is applied to piping, valve, tank and equipment having an operating temperature in excess of 60 deg. C.
- **Stack:** Typically, the HRSG stacks are of self-supporting and constructed of carbon steel.
- The HRSG is equipped with an **access door** located for convenient access in the base section, drains, connecting ductwork with expansion joint, access platforms and vertical ladders with enclosing safety cage to the platform level.
- **Aviation warning lights** is provided to each stack of HRSG. At the mouth of stack, a deflector ring of stainless steel of adequate external diameter is arranged to prevent down flow of gases on the outside of the stack at extreme low loads.
- **Blowdown and drain system:** piping and valves are provided for each HRSG to collect blowdown water, drum overflow water and steam drains. Each HRSG is fitted with two blowdown facilities, one may be designed to operate on a continuous and the other one on an intermittent basis. Both are led to the blowdown flash vessel. The same applies for the drum overflow (Emergency blow down).
- An **intermittent blowdown connection** is located on each of HP and LP evaporator. This blowdown is used to reduce the solids collected in the evaporator. It is usually operated intermittently, once a shift or shortly after the HRSG is shut down and still pressurised. Also, this blowdown is used to lower the drum level in case of abnormal high level during operation.
- The **continuous blowdown connection** is used during normal operation, in conjunction with the chemical feed system, to maintain proper steam drum water quality.
- **Nitrogen blanketing system:** The nitrogen blanketing system is used to protect the internal surfaces of the heat recovery steam generator with wet condition during short unit shutdown. When extended unit shutdown is anticipated, HRSG should be drained and dried for nitrogen conservation.

The nitrogen gas from the system is also used for preserve the deaerator and feedwater storage tank during extended unit shutdown.

## CCPP Auxiliary Components

### DIVERTER DAMPER AND BYPASS STACK SYSTEM

The function of the diverter damper and bypass stack system is to conduct exhaust gas from the GT exhaust to either the HRSG inlet or to the atmosphere. The main equipment which is responsible for the direction of the exhaust gas is diverter damper. Many CCPP cannot operate in simple cycle mode through the bypass stack because the combustion turbine emissions will exceed the plant's air permit limits. In normal operation the exhaust gasses must pass through the selective catalytic reduction (SCR) located in the HRSG which reduces the carbon monoxide (CO) and Nitrogen Oxide (NOx) emissions below the plant's air permit levels. Many CCPP choose not to run in simple cycle mode through the bypass stack because it is not economical without the efficiency benefit of the steam turbine bottoming cycle. The system consists of sub-systems with the following functions:

- Diverter damper to divert the exhaust gas pass.
- Bypass stack with silencer to conducts exhaust gas to the atmosphere.
- Seal air unit to seal the diverter damper
- Guillotine damper and shut-off the exhaust gas to HRSG

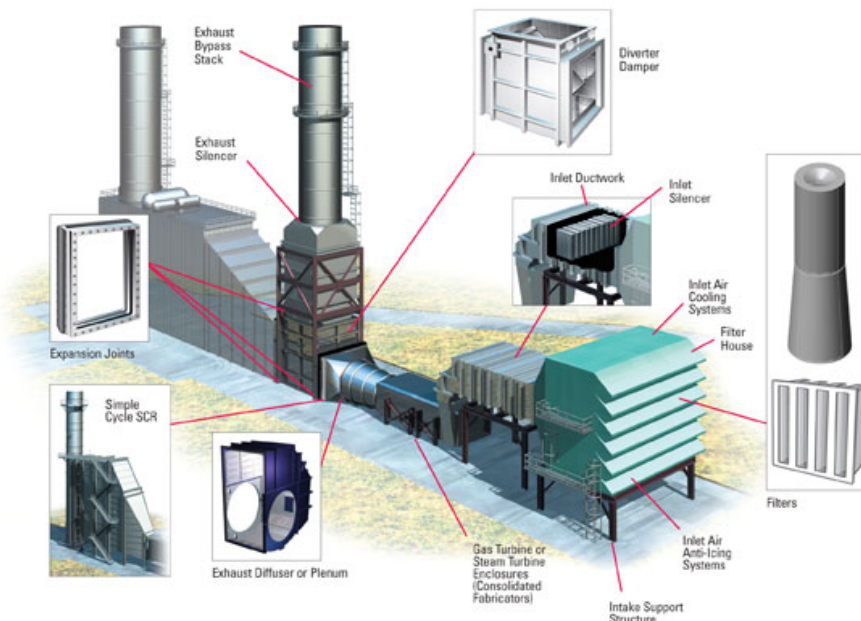


Diagram 6: Exhaust dampers

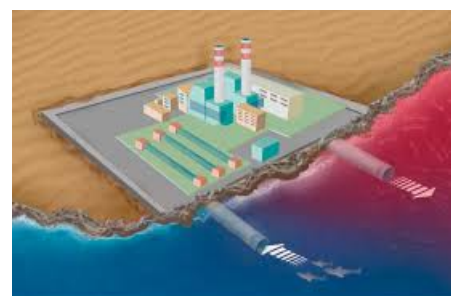
Courtesy BRADEN MANUFACTURING, Subsidiary of Global Power Equipment Group, Inc.

### Plant cooling

Once steam has passed through a turbine, it must be cooled back into water before it can be reused to produce more electricity. Colder water cools the steam more effectively and allows more efficient electricity generation.

#### Types of Cooling

**Direct or Once-through systems** take water from nearby sources (e.g., rivers, lakes, aquifers, or the ocean), circulate it through pipes to absorb heat from the steam in the condensers, and discharge the now warmer water to the local source. Once-through systems were initially the most popular because of their simplicity, low cost, and the

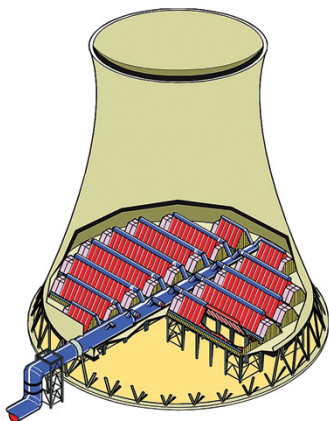


possibility of siting power plants in places with abundant supplies of cooling water. This type of system is currently widespread in the eastern U.S. Very few new power plants use once-through cooling, however, because of the disruptions such systems cause to local ecosystems from the significant water withdrawals involved and because of the increased difficulty in siting power plants near available water sources.



*Photograph 6: Inshore Intake at Kilroot, Carrickfergus*

**Indirect or Wet-recirculating or closed-loop systems** reuse cooling water in a second cycle rather than immediately discharging it back to the original water source. Most commonly, wet-recirculating systems use cooling towers to expose water to ambient air. Some of the water evaporates; the rest is then sent back to the condenser in the power plant. Because wet-recirculating systems only withdraw water to replace any water that is lost through evaporation in the cooling tower, these systems have much lower water withdrawals than once-through systems, but tend to have appreciably higher water consumption. In the western U.S., wet-recirculating systems are predominant.



**Dry-cooling systems** use air instead of water to cool the steam exiting a turbine. Dry-cooled systems use no water and can decrease total power plant water consumption by more than 90 percent. These can use Natural draught towers or mechanical draught towers which as the name suggests, use mechanical devices to move air through. The tradeoffs to these water savings are higher costs and lower efficiencies. In power plants, lower efficiencies mean more fuel is needed per unit of electricity, which can in turn lead to higher air pollution and environmental impacts from mining, processing, and transporting the fuel. In 2000, most U.S. dry-cooling installations were in smaller power plants, most commonly in natural gas combined-cycle power plants.

Type of cooling is decided based on multiple issues, most importantly:

**Siting (Location):** The geographic location of power plants has a huge impact on cooling technology options, water availability, type of water used for cooling, and environmental impacts. Solar and geothermal power plants, for example, must be sited in areas with high solar radiation and geothermal energy, respectively—locations that may be arid and far from conventional water resources. In these situations, dry cooling may be an option, or alternative water sources may be available, but such choices can affect power plant performance and local environments.

**Water type:** Although many power plants use freshwater for cooling, waste water and salt water are other possibilities with advantages and disadvantages. Salt water is an obvious and abundant option for coastal power plants, for example, but such plants face similar challenges as inland plants with regard to damaging the local aquatic ecosystems through excessive withdrawals or thermal pollution (from discharges of hot cooling water).

### CHEMICAL DOSING SYSTEM

Typically, the chemical dosing system in a power plant consists of:

- Ammonia dosing units:
- Oxygen scavenger dosing units,
- Phosphate dosing units,
- Corrosion inhibitor dosing unit,
- Associated piping, valves, instruments, etc.



*Photograph 7: Skid dosing system. Courtesy ProMinent*

Ammonia (NH<sub>3</sub>) is dosed into the condensate system and feedwater system to avoid corrosion problems and to adjust pH-value. The amount of chemicals will be determined by the condensate and feedwater flow and by the pH-values actually measured.

The final oxygen removal of the feed water should be done by the injection of Oxygen scavenger. The amount of chemicals will be determined by the condensate and feedwater flow and by the residual O<sub>2</sub> values actually measured. The dosing quantities of Oxygen scavenger are typically manually regulated as per results of the water sample analyses.

The sodiumphosphate is added to avoid deposits of hardness in the boiler(HRSG) tube system and to increase pH value in the drum. The injection point for the sodiumphosphate solution is at the HP/LP drum. The amount of chemical is determined from the phosphate actually measured at boiler blow-down. The dosing quantities of sodiumphosphate are manually regulated as per results of the water sample analyses.

To avoid corrosion problem and to adjust the pH-value in the closed circuit of cooling water system, corrosion inhibitor is added. The dosing quantities of corrosion inhibitor are manually regulated as per results of the water sample analyses.

### WATER TREATMENT SYSTEM

When the power plant uses freshwater or seawater for cooling, a desalination plant is used

- Produce the distillate water for demineralisation feedwater
- Produce the distillate water for service water and firefighting water
- Provide demineralised water to condensate and feedwater system
- Provide demineralised water to the closed cooling water system
- Provide potable water to the plant

## SANITARY AND WASTEWATER TREATMENT SYSTEM

The function of wastewater treatment system is

- Adjust the pH of equipment drains.
- Treat oily wastewater.
- Treat sanitary wastewater

The wastewater treatment system treats all the wastewater including oily wastewater, chemical wastewater, and sanitary wastewater and discharge treated water via surface water outfall, seawater outfall, sewage lagoon and etc.

## ELECTROCHLORINATION SYSTEM

The electro chlorination plant is designed to produce sodium hypochlorite.

## SAMPLING SYSTEM

A dedicated instrumentation panel used to facilitate chemical monitoring of the steam/water cycle of the plant. All necessary steam and water samples are provided for safe and efficient operation of the plant and shall include as a minimum samples taken from the following locations;

1. Condensate extraction pump discharge
2. Condensate after chemical addition
3. Condenser hot-well (collection tank)
4. Outlet deaerator
5. Boiler drum water (from each boiler drum)
6. Saturated steam (from each boiler drum)
7. Superheated steam (from each superheater)

The sample panel shall be located in a dedicated air conditioned analysis room/enclosure. The room shall be equipped with facilities for checking the instruments and storage of any reagents etc.

## SHUTDOWN DIESEL GENERATOR

The function of shutdown diesel generator is to supply electric power to the most critical items of Plant during a complete blackout.

## FIRE PROTECTION SYSTEM

The function of fire protection system is to provide the life safety from fire hazard and to provide the property protection from fire hazard. Additionally, the fire protection system must be able to provide early warning and suppression of fire. Fire protection systems are designed in accordance with the requirements of NFPA and other standards.

The fire protection system components may include:

- Fire pump system I
- Underground fire service main I
- Hydrants and hose cabinets I
- Standpipe and hose systems I
- Sprinkler system I
- Water spray fixed systems I
- Foam-water spray systems I
- Fixed low expansion foam systems I
- Tank shell cooling systems I

- Mobile and portable fire extinguishers I
- Fire alarm & detection system

Examples of fire protection system devices in different BUILDING/AREA/EQUIPMENT TO BE PROTECTED are listed as follows (it should be noted that these systems and equipment vary considerably depending on the design of the different plants)

Steam and gas turbine buildings require combined foam/water indoor hydrants and manual fire alarm stations. Steam turbine oil system can use automatic water spray fixed system while the steam turbine/generator bearings uses drypowder extinguisher.

Fuel oil storage tanks typically use low expansion foam heat detectors in the tanks and tank shell cooling systems and fuel forwarding pump stations use automatic foam/water spray fixed systems.

Gas receiving stations require explosion proof gas detectors and explosion proof manual fire alarm stations for outdoor area in addition to smoke detectors and manual fire alarm stations for indoor areas.

All oil filled transformers use Automatic water spray fixed systems, Heat detectors and Buchholz-relays. All other buildings and areas require indoor/outdoor hydrants and hose cabinets in addition to fire alarm stations.

#### VENTILATION AND AIR CONDITIONING SYSTEM

The function of HVAC system is to achieve the following:

- To control environmental conditions within buildings for the comfort of operation and maintenance personnel.
- To control environmental conditions in buildings within limits for proper operation and protection of equipment and systems.
- To air-pressurise the buildings to prevent the ingress of untreated air.
- To provide air pressurisation for smoke control in protected personnel escape routes.
- To remove hazardous gases and fumes.
- To control the spread of fire hot gases and smoke.

#### CONTINUOUS EMISSION MONITORING SYSTEM (CEMS)

Continuous emission monitoring (CEMS) equipment are provided to monitor the stack emissions of each HRSG unit in the plant, including CO (Carbon Monoxide), NO<sub>x</sub> (Mono Nitrogen Oxides), CO<sub>2</sub> (Carbon Dioxide), O<sub>2</sub> (Oxygen) and any other measurements such as SO<sub>2</sub> (Sulphur dioxide), Moisture Concentration, Opacity and Volumetric Flow considered necessary by the local Environment Agency.

The CEMS is typically an integrated system and includes in-stack flow measurement devices, such as flow traverse probes connected to control and data recording systems which are installed in control rooms and connected to the main control system.

#### Electrical connections

*Generator Busducts* (IPB= Isolated Phase Busduct) have the following main functions:

- Link between generator and unit transformer including generator circuit breaker, disconnections and earth switches
- Connections to power station services, excitation transformer, neutral point and current/voltage transformers

- Govern the generated heat in enclosures and conductors, protection and maintenance earth facilities, magnetic shielding and protection against environmental conditions

*Unit transformer.* The main categories used as auxiliary transformers:

- **Dry type transformers** (e.g. RESIBLOC type) which are characterized by extremely high mechanical resistance of the winding because of the fibre-glass-reinforced resin insulation and a very high resistance to fluctuation in temperature.
- **Oil immersed transformers** where core and winding are contained in mineral oil which are used as large auxiliary transformers.
- **Special transformers**, as converter transformer or excitation transformer are available. The standard cooling is natural air convection (AN). Air forced cooling (AF) or combinations (AN/AF) in case of loading or seasonal hot ambient temperature can be offered.

## 6. Underwriters Perspective & Challenges:

### Surveys

Engineering risk assessment surveys, also known as loss control surveys, provide location specific risk information and are a great benefit to the insurance underwriter. Combined cycle power plants (CCPP) are categorized as a highly engineered risk where it's important for underwriters to gain some transparency into the account risk quality. Survey reports provide specific location equipment, natural catastrophe (Nat Cat) and fire (FLEXA) risk exposures. An engineering risk assessment survey of the location should be requested on 100% of all new submissions and 100% of updated renewal information to gain an understanding of the risk exposures of the account. A survey should be requested whenever there is prototypical equipment, high Nat Cat exposure, changes in values, unfamiliar processes or occupancies, or abnormal loss history frequency or severity.

*A survey should  
be requested  
whenever there  
is prototypical  
equipment*

Included in the survey is the development of loss event scenarios which assists the underwriter in developing the adequacy of the account pricing, sublimits, conditions, line size/ limits and deductibles.

One of the most important element of this evaluation is estimation of the maximum foreseeable loss (MFL) (some insurers use the term (MPL) Maximum Possible Loss, (EML) Estimated Maximum Loss, or (PML) Probable Maximum Loss).

These events apply to property damage and business interruption. It is defined as a catastrophic event (machinery break down, explosion or fire) which requires the demolition and replacement with new equipment, adjacent auxiliary systems and structures.

For a combined cycle plant, a combustion or steam turbine catastrophic overspeed, or rotor blade failure with lube oil fire following, resulting in a total loss of the unit, with additional losses to surrounding units and property. It also includes business interruption revenue from lost electricity payments, capacity payments, steam sales, bonus payments or other contractual obligations. Deducted from the revenues are materials and supplies, consumed directly in



producing the end product or services, such as fuel, service charges, transportation charges, wheeling / transmission charges, and ordinary payroll.

Examples of a combined cycle power plant MFL is the catastrophic overspeed and destruction of a combustion turbine and generator, a steam turbine and generator, a HRSG internal explosion, or a severe flood event.

There are three types of surveys:

1. **Property survey** which focuses on the fire and natural catastrophe exposures,
2. **Machinery breakdown survey** which focuses on the equipment, operations, and maintenance exposures,
3. **All-risk survey** which is a combination of the property and machinery breakdown survey.

Surveys are performed by engineering professionals who are familiar with all aspects of combined cycle power plants. During the survey the Survey Engineer will:

- Interview the management,
- Review the loss control programs,
- Review the previous year's inspection, testing and maintenance reports,
- Tour the facility to assess the overall condition,
- Document their findings in a professional report.

Machinery and property survey reports contain general facility information and configuration, an overall location risk opinion, recommendations to reduce the potential for losses, review of management loss control programs, estimates for normal loss event (NLE), probable maximum loss (PML), and maximum foreseeable (MFL or MPL) costs and scenarios, and Business interruption evaluations.

**Property Surveys** include a natural catastrophe review for earth quake, volcano, tsunami, tropical cyclone, extra-tropical storm, hail, tornado, lightning, flood, storm surge, coastal flooding and the corresponding fixed protection for Nat Cat perils. A property survey also includes a review of the fire protection configuration, fixed fire protection systems, and Inspection, testing and maintenance of fire protection systems.

**Machinery breakdown survey** will focus on major equipment and systems such as the turbines, boilers/HRSGs, generators, and transformers. It will focus on the equipment condition, protective systems, modifications and upgrades, operational history (hours, starts, and trips), maintenance programs, and personnel O&M training and procedures.

When performing a survey of a combined cycle power plant there are certain risk analysis factors which can affect the quality of the risk.

- The equipment should be analysed for upgrades and improvements, unusual loss history, age, and location dependent environmental conditions such as proximity to seashore and corrosive salt air.
- The plant operation and human element analysis includes the plant operating mode such as base load, peaking, swing load / cyclic.
- The presence of OEM plant condition/health monitoring systems that can assist in identifying adverse operational trends before they result in damage and downtime.

- The plant maintenance practices are analysed to determine if there is a preventative maintenance philosophy which follows the proper OEM or industry standard equipment overhaul intervals.
- The presence of an OEM or third party long term service and maintenance agreement is looked upon favourably.
- A computerized major maintenance software system which schedules preventative maintenance tasks and records equipment maintenance history is beneficial.
- A review of critical spare parts such as having generator step up transformer bushings on hand can limit downtime.
- The inspection and testing of machinery protective devices such as turbine overspeed trips, generator breakers and reverse power relays, steam turbine valves, equipment vibration monitoring and trips is essential in preventing damage.
- To reduce the risk of fire damage, alarms systems, equipment automatic protections systems, periodic maintenance and testing of fire pumps reaction valves and sprinkler heads and sprinkler coverage density is important. Fixed protection systems for natural catastrophe exposures such as flood, earth quake, tsunami, tropical / extra tropical storms, lightning, are reviewed.
- Flood protection such as dikes, equipment elevation above base flood elevation, flood control doors and flood contingency plans are reviewed, Construction to applicable earthquake codes is reviewed, and lightning surge protection for transformers and switchyards is inspected.

### **Underwriting information**

In order to assess CCGP projects from underwriting point of view we need the following documents:

- Project schedule;
- Project estimate or CAPEX;
- List of machinery with its value breakdown;
- Layout drawing;
- List of contractors and subcontractors.

If we deal with new power plant construction we require additional data related to the natural conditions of the construction place (geological research, seismic activity research, hydrological research). This data is needed to understand if the likelihood / possibility of natural perils was taken into consideration by the designers. Even projects located in hazardous regions can be insured if their design takes natural hazards into consideration.

When providing coverage of defects (on the basis of LEG 2 or LEG 3) it is a good practice to request **reference lists**<sup>6</sup> of key machinery (turbines, generators, HRSG, transformers) to validate their track record in other locations and avoid having to cover proto-types without proper consideration. Typically we require such document when we realize that some project implies installation of modern, recently designed machines.

Evaluating CCGP projects, underwriters should pay special attention to the following highlights:

- Power capacity of steam and gas turbines;
- Turbine, generator and HRSG location within the power unit;
- Period of major equipment brand marks / models trouble-free operation;

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<sup>6</sup> Reference list is a document describing world-wide experience of machinery / equipment operation at different locations.

- GT first firing date;
- Dates of trial run;
- Initial operations period, i.e. time between end of trial run and documental commissioning;
- Defects liability period.

Basic principles of CAR / EAR coverage for CCPP power plants depend on the following phases of project:

### **Early Works Phase**

This phase consists of works necessary for project site preparation. Quite simple coverage is required. Usually the coverage of works within this period is based on Munich Re Construction All Risks (MRe CAR) wording with minimal number of extensions.

### **Construction phase**

This is a very important project phase as major power plant premises are constructed. The most significant perils are connected with soil conditions, failures of design and possible violence of fire safety regulations.

Coverage of this phase shall include specific clauses regulating fire safety requirements and measures which have to be provided by the designers in order to avoid destructive consequences of inundation, ground subsidence and earthquake.

At this phase insureds need cover of project defects as an extension to standard CAR wording. As it is mentioned above underwriters accompanied by risk-engineers shall carefully analyse and estimate project documentation.

Basic machinery and equipment for the next project stage (a phase of erection) is being supplied to the site at construction phase. Then such machinery and equipment is stored at the site in special premises. So it is very important for the insurer to implement clauses stipulating specific requirements for location of storehouses and for storage conditions within the premises.

### **Erection phase**

This phase includes installation of all machinery and equipment, laying of pipelines and cables. This phase shall be covered by using Erection All Risks (EAR) Wording which provides specific terms and conditions of such works coverage.

### **Hot testing**

It is a phase of the very high risk exposure due to the following reasons:

- Combustible material are inside the equipment;
- Machinery is being put under load and it may be damaged because of installation or testing team failures or because of machinery defects.

The duration of hot testing period is a significant term of the policy. It makes substantial impact on the premium rate. Thus it is very important to define this period correctly.

World practice of underwriting considers GT first firing as the date of hot testing beginning. In general it is correct. Meanwhile such approach involves very long hot testing period stipulation which leads to insurance and reinsurance rate increase. From our point of view it should be more correct to split periods of GT and HRSG and ST hot testing.

### **Trial run**

Actually it is a final stage of hot testing when machinery goes through the peak load. For example, typically in Russia this phase continues for 72 hours.

## **Initial operations**

This phase starts when trial run is finished and when it is necessary to get all necessary approvals of the technical authorities and to sign commissioning documents between principal, contractor and the above mentioned authorities.

There are 2 different points of view to the risk degrees of trial run and of initial operations phases:

- a) Risk exposure of trial run is the highest,
- b) Initial operations period is more risky than trial run phase.

Both points of view have quite reasonable explanations which are as follows:

- a) Prior to trial run phase a project achieves its full contract value: all facilities are built and all machinery is assembled. Meanwhile such machinery has not been commissioned at its full capacity. Thus it is probable that some design or assembly defects appear when machinery is exposed to maximum possible loading. Appearance of the above defects may lead to devastating loss of machinery and to critical damages to constructive facilities.
- b) Nevertheless trial run usually is executed by well-skilled team which is specialized on power machinery testing and commissioning. Employees of such team are aware of possible emergency situations scenarios and of necessary actions in case of these scenarios realization. When a trial run is finished, an appropriate act is signed by Principle and Contractor and it is officially allowed by state authorities to operate with a power unit it testing and commissioning team will leave a construction site. In the meantime a contractor and a principle will need time to adjust variable formalities in order to issue final acceptance certificate. This period of time is called Initial operations phase. While the above-mentioned formalities are being adjusted power unit is being maintained by principal's operational staff, i.e. by people who are not so aware of emergency situations which may happen to newly assembled equipment as testing and commissioning team. That is why there is a probability of emergency situation occurrence which will not be prevented by operational staff and which will lead to substantial collapse.

Erection, hot testing, trial run and initial operation phases require special attention to coverage of defects.

## **Coverage of defects**

The specific issues of such defects coverage within the above phases are as follows: Earlier it was a common underwriting practice to exclude losses resulted from defects.

Then competitive market dictated its new requirements and insurers had to meet such requirements or to be out of market. Firstly insureds insisted on coverage of consequential loss due to defect with an exclusion of defective part or item in itself. The reason for such wish of the insureds was quite understandable: they did not want to retain losses not only of defective items but of surrounding equipment and facilities as well.

The next wave of competitive market influence was to cover even defective part or item in itself but not to cover costs incurred to improve the design of such defective part. The reason of brokers and clients who request for such coverage is as follows: insureds are conscientious purchasers of equipment thus they would not like to pay for some detail defectively designed or produced by manufacturer.

Due to the above evolution modern clauses covering defects look like exclusions with so-called "back-exclusions": it means that basic exclusion of losses related to defects is softened to

exclude only a defective part or item in itself or to exclude improvements of such defective part or item design.

Basically there are following most common clauses in modern EAR insurance practice:

- LEG 1 – total exclusion of loss resulted from defects (even consequential loss)
- LEG 2 or MR 200 – exclusion of defects with back-exclusion of consequential loss
- LEG 3 – exclusion of defective part design improvements covering material damage to defective part and consequential loss.

The above clauses are named in honour of organizations which elaborated these clauses: London Engineering Group (LEG) and Munich Re (MR).

Providing the coverage of defects on the basis of LEG 2 or LEG 3 for our clients we should carefully analyse a list of machinery to be assembled. Our analysis has to be based on the following principles:

- such machinery should consist of proven models (the problem of proven and non-proven models definition is described below):
- we should avoid insuring used equipment (if there are any doubts in newness of the equipment usually we implement into policy wording a special clause – Exclusion Concerning Used Machinery),
- it is obligatory (especially when we deal with LEG 3) to possess machinery value breakdown in order to have a proper information for calculating EML for scenario when the coverage of defects triggers off.

Underwriting of any engineering project shall consider a history of losses occurred during the similar projects realization. When the project imposes to assemble some equipment which has not been used earlier possible risks of such project are unpredictable. Certainly it is a problem for the insurers to assess these risk correctly and to provide such project with an appropriate coverage.

Therefore most of the underwriters are in a position to exclude prototype technologies from the coverage. Meanwhile sometimes market reality requires more flexible approach. Thus underwriters have to be ready for such market challenges providing coverage of prototype technologies with reasonably low limits of indemnity and with high deductibles.

Either practicing conservative approach (absolute exclusion of prototypes) or implementing limited coverage of not proven technologies requires exact and understandable definition of prototype.

Now it is a standard practice to classify a new model of machine as proven if machines of such model have run trouble-free for at least 8,000 operating hours. Trouble-free operation within the above period confirmed by the respective reference lists makes underwriters sure that there are no equipment design faults and allows to narrow probable loss scenarios at hot testing phase down to the errors of assembling team.

The most curious problem of prototype definition is an attitude to proven models modifications. From formal position every modification of proven equipment involves reclassification of such equipment back to prototype. In general it is a correct point of view but in order to be reasonable we should understand a degree of modification significance. Thus it is necessary to organize co-operation between risk-engineers of insurance companies and key equipment manufactures. Only such co-operation will allow to insurers to be aware of manufacturers' technologies and to understand whether one or another improvement of these technologies may influence a security of modified equipment within hot testing / initial operations phase.

The above-mentioned co-operation could be performed as manufacturer's plants survey with a purpose to assess processes of design elaboration and of equipment production.

It would also be useful to arrange conversations between insurers' risk-engineers and engineers of equipment manufacturers on regular basis – such conversations will allow engineers to exchange information of new unproven technologies and of proven technologies betterments.

In any case it is essential to define prototype equipment and specifics of such equipment coverage before insurance policy issuance. Otherwise we can hardly avoid arguments and conflicts if some insured (or not insured?) occurrence happens.

### **Location Considerations**

Specific risks (earth quake, corrosion)

The inherently strong steel construction of combined cycle plants make them impervious to severe wind damage. The HRSG stacks are designed to withstand a certain sustained rated wind speed, and that wind rating information can be determined from the stack's design specification data.

The area's most vulnerable to wind damage are wood or fiberglass frame evaporative cooling towers and from flying debris entering the switchyard and damaging cables and ceramic bushings. The loss of the cooling tower or switchyard can result in a significant property loss, but more importantly the restoration time can result in a serious business interruption loss.

Modern CCPPs constructed in known 100 year flood zone A or V (and their subsets AE, AO...VE V1...etc) should be inspected to ensure that critical controls, protective devices and major equipment elevations are for example at least 1 meter above the 100 yrs. base flood elevations (BFE).

If it's determined that there are items with flood exposure, then suitable active or passive fixed flood protection should be put in place, such as earthen flood berms, flood walls, flood doors and gates, emergency high capacity pumps, raising equipment controls and sealing below ground conduit and cable vaults with expanding foam sealant.

In addition to the natural catastrophe hazards, the location of a CCPP can have a significant effect on the risk quality. Combined cycle power plants located near the ocean, in the desert, close to an oil refinery, chemical plant or other industrial areas can subject the combustion turbines to contaminants which could cause fouling and corrosion of the compressor and hot gas path parts.

Fouling in the compressor can be caused by the ingestion of dust, dirt, sand, pollen, and insects for example. Corrosion can be caused by atmospheric contaminants or by the quality of the locally available liquid or gaseous fuel. Combustion turbine manufacturers publish fuel specifications which provide limits for these corrosive elements, and operation above these fuel quality specifications can void the initial OEM warranty.

Long term exposure to seawater humidity, sodium, potassium salts, sulfur, vanadium, and lead can cause corrosive pitting in the compressor and hot corrosion on the hot gas path components.

Combustion turbines are designed with inlet air filter systems to prevent fouling and to remove these contaminants. Most of the inlet air systems consist of a filter house fitted with replaceable box or can filters, and duct work that directs the filtered air into the combustion turbine compressor.

In locations affected by salt air and high humidity, built in filter coalescers or moisture separator vanes are used to separate the salt and water from the air entering the filters. In locations subjected to excessive dirt, dust or sand, self-cleaning pulse jet filters use compressed air to periodically blow the filters clean.

Properly selected combustion turbine inlet air filters will trap the majority of atmospheric contaminants. HEPA filters are gaining popularity due to their superior filtration and extended intervals before compressor airfoil fouling occurs and water washing is required. In addition, manufacturers apply corrosion resistant coatings to the combustion turbine components for hot corrosion protection.

Plant operators should periodically inspect the filter house and inlet air duct work for gaps, leaks and sources for unfiltered air to enter the combustion turbine. Plant operators should also monitor the differential pressure across the filters, and schedule filter replacements as outlined by the OEM. Failure to replace clogged inlet filters can result in a filter being ingested into the gas turbine compressor, resulting in foreign object damage.

In addition, salt pollution (from the sea) on external electrical switchgear insulation (maybe moving from 25mm/kV to alternatives such as 31 mm/kV, polymeric insulation and then indoor GIS). Sites with sea water intake systems can be vulnerable to increasing silt levels in the water (TDS) and fauna & flora issues

GTs working in locations with a high ambient temperature usually are fitted with additional air inlet cooling systems to preserve efficiencies. Such systems are more maintenance intensive, prone to breakdown.

In some of the more “security difficult” places in the world to operate obtaining the correct spares and technical expertise is a real problem. We have had many claims where BI elements are very large for no other reason than it’s very difficult to get spares onto site. It also has an impact on the training of local staff. I don’t think we should name regions but I’m sure most people will appreciate the issue.

## 4. Operational Considerations:

### Impact of Regulations, legislation and standards

Typically “good regulations” have a positive impact on the risk profile of a Combined Cycle Power plant, in that it is reduced as a result of the implementation of the these new regulations. Having said that, “good regulations” depend on the way these regulations are considered and applied. In other words, application of different regulations should consider how these regulations are intended rather than how they may have been written.

Impact of regulation is hereby considered on three main risk categories in a power plant: Safety, Environment and Commercial performance.

#### Environment

Environmental risks include emissions to air, water and land. Emissions to air rely on very well established regulations which have been implemented successfully over many years and have very low risk.

Emissions to water risk include foaming, which in low density would not be harmful, despite concerns over the way it looks to the untrained person. There are no specific ppm standards to apply and most of regulations rely on subjective criterions.

Emissions to land can include noise, impact of transportation and blow from ass fields. These emissions have low impact on insurers, as insurance for pollution risk is not common in the industry (at least in the UK). Typically, this limited risk is not transferred by operators.

### Health & safety

Risk on general safety of employees and operators is low and depends on process safety measures, plant integrity and proper implementation of general H&S standards.

Risks of most concern to operators are improper release of energy (electrocution risk) and improper release of fluids in the process. Risk assessment in the UK is driven by the 1999 Management to Work Regulations which drives the plant operation in terms of 1) plant condition, 2) plant operation, 3) plant maintenance and 4) plant emergency response.

Process safety as defined in the Baker report<sup>7</sup>, provides adequate management of safety risks on site of CAPP. Operators typically use their own in-house engineering departments or instruct third party OEM service providers to ensure the proper implementation of safety standards. The plant operations team would have to be in control of the process as they have the ultimate say in how the process is managed.

OEM involvement in design and implementation of process safety has a positive impact on the overall operation of the plant. However, as the plant starts to age and modifications are made repeatedly, the OEM involvement in process safety becomes increasingly irrelevant, especially in auxiliary plants. In these instances, it becomes more important for the operation team to be aware of the process and take on active role in process safety management.

Burned of implementation of safety rules in a power plant varies in different countries. For example, in the USA and Germany, management of process safety is rules based. In other words, the rules must be applied regardless of their reasonableness or relevance to the specific plant. In contrast, in the UK, management of process safety is left to the operator to determine what is reasonable and relevant to their specific plant. This results in shift of responsibility for an accident, as the operator in rules based process safety can shift the responsibility to the rules as long as they were implemented accurately. In the UK, the operator is totally responsible for consequences as they were the party responsible for determining which safety rules to apply based on their own evaluation of reasonableness and relevance.

### Commercial Considerations

Accidents that cause damage to plant equipment are very costly and remove the plants ability to extract value from the plant. Each plant would have its own risk profile which varies from other plants based on the design and age of the plant. For example, the increased automation and self-diagnostics in a given plant improves the risk profile of a plant. This is, however, counterbalanced by the introduction of “Black Boxes” by OEM’s to protect proprietary technology. These “Black Boxes” can be a challenge to an operator and may increase the cost of recovery following a loss where damage to the equipment occurs.

Another commercial concern is the transparency or lack thereof from OEM’s with regard to failures around the world. OEM’s protectiveness of failure data erodes client’s ability to operate and manage losses. It may also impede their ability to implement a good and reasonable process safety within the plant.

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<sup>7</sup> A panel, led by former US Secretary James Baker III, was appointed by BP Group Chief Executive John Browne in October 2005. The panel published its report on 16 January 2007. It identified material deficiencies in process safety performance at BP’s US refineries. A summary of recommendations can be found at: <http://www.hse.gov.uk/leadership/bakerreport.pdf>



## Operational Concerns of CCPP

- New design of CCPP's are pushing GT boundaries to new limits at all times.
- Design of free standing LSB (Last Stage Blades) in steam turbines are also being pushed to new limits.
- Ability to decipher and integrate the DCS (Digital Control System) in a CCPP is a complex and relatively difficult process.
  - Integration of plant event to allow assessment of minor events so that major events can be avoided is difficult.
- Risk surveyors look less at emergency response systems than operators are actually concerned about.
  - Most surveys focus on fire risk (which is fairly light) when compared to risk of failure as a result of a blade failure in a GT or steam turbine.
- Plant testing is very critical and should be evaluated constantly.
- Depletion of corporate and industry memory about past events as a result of workforce evolution contributes to lack of understanding of what can go wrong, instead of what meets "written standards".

## 5. Claims Examples

Year	Cover	Gross Loss Estimated	Scenario	Lessons Learned
2014	EAR	Circa USD 125 million (close to EML)	<p>This failure occurred at a CCHP 2:2:1 site designed with two 137MW rated gas turbines connected to two independent HRSG. The output from the HRSG's was supplied to a single 190MW steam turbine located in a separate building.</p> <p>In this failure, an electrical fault opened the HV generator circuit breaker when the unit was near full load output. However, as a result of this trip the main steam inlet valves to the steam turbine did not "slam shut" As a result the steam turbine rotor accelerated and broke out of the casing causing major damage to the turbine, the ancillary systems and the turbine building.</p>	<p>Of note in this claim was the omission of an exhaust stack directly after the gas turbines in the design. Such a stack would have allowed the GTs to operate in simple cycle if required.</p> <p>As a result of the failure of the steam turbine it was also not possible to operate the GTs as there was no exhaust path. Thus in addition to the property damage loss to the steam turbine assets the site has had to design, have fabricated and install two additional exhaust stacks in the transition section between the GT and the HRSGs' to allow the GTs to operate and so lessen the business interruption cost.</p> <p>The RCA has yet to be finalized but the omission of a simple cycle exhaust stack after the GTs has led to a significantly high business Interruption cost as well as additional mitigating costs.</p> <p>Insurers should note that this original design feature also has the inherent characteristic that any stoppage on the steam turbine, for any reason, would have the consequence of shutting down the entire output of the station.</p>

Year	Cover	Gross Loss Estimated	Scenario	Lessons Learned
2010	EAR	US \$235m 17 months restoration	USA, Construction explosion at a 600 MW combined cycle plant during “natural gas blow” pipe cleaning. The site erupted in fire while workers were using pressurized natural gas to blow debris out of pipes, in preparation for making the nearly completed plant operational. The highly flammable gas ignited, creating a catastrophic explosion that could be felt 40 miles away. Six workers were killed and approximately 50 were injured.	For natural gas pipe cleaning, it is recommended to use inherently safer alternatives such as air blows and pigging with air in lieu of flammable gas blows. If flammable gas blows are performed, a comprehensive site wide safety plan and training is required to eliminate sources of combustion and to communicate the hazards. Combustible gas detectors should be used to monitor the atmosphere for dangerous levels of natural gas, and piping should be purged to a safe location outdoors. <a href="http://www.csb.gov/kleen-energy-natural-gas-explosion/">http://www.csb.gov/kleen-energy-natural-gas-explosion/</a>
2012	OPS	US \$41m 14.5 months restoration	USA, flooding of a 950 MW operating combined cycle power plant. Superstorm Sandy came ashore with winds gusting up to 78 miles per hour. A significant storm surge resulted in flood waters reaching 3ft on site. Extensive damage occurred in the control room building’s uninterruptable power system, switchgear, and emergency batteries, resulting in loss of emergency lube oil damage to turbine generator bearings.	Low cost flood countermeasures can prevent excessive storm surge flooding. Storm hardening projects include: storm preparedness plans, storm preparation training, staging of flood pumps and supplies, the addition of surge walls, concrete moats, water tight doors, sealing low conduit & cable trenches, and raising critical electrical equipment above flood levels. <a href="http://www.districtenergy.org/assets/pdfs/2014Campus.../2Rommel.pdf">www.districtenergy.org/assets/pdfs/2014Campus.../2Rommel.pdf</a>
2012	OPS	US \$21m 37 days restoration	USA, Machinery breakdown at a 1,000 MW operating combined cycle power plant. Accumulation of combustion turbine operating hours lead to compressor stator airfoil lock up in the casing, tip rubbing, high cycle fatigue cracking, and blade tip liberation resulting in severe FOD (foreign object damage), and downstream damage throughout the turbine. Repairs were completed with a major overhaul using a completely rebuilt bladed rotor, compressor discharge casing, upgraded compressor components, and new combustion and turbine hot gas path parts.	To reduce combustion turbine compressor losses, clients should comply with the manufacturer’s maintenance intervals, perform bi-annual high resolution video borescope inspections, Implement OEM reliability upgrades, and comply with manufacturer’s TILs (technical information Letters), TA’s (technical advisories), and SB’s (service bulletins). Obsolete OEM replace in kind compressor components are no longer available from manufacturers. Repairs require new design / upgraded components, which can significantly escalate the cost of repair. <a href="http://www.ccj-online.com/best-practices-lessons-learned-from-compressor-session-paid-expenses-several-times-over/">www.ccj-online.com/best-practices-lessons-learned-from-compressor-session-paid-expenses-several-times-over/</a>

## 6. Summary & Conclusions

1. CCGT's are the most efficient method of adding electrical capacity to areas with an abundance of natural gas, due to:
  - a. Low capital cost
  - b. Shorter construction time
  - c. Low fuel cost
  - d. Lower emissions
  - e. High efficiency and high power density
2. The main pieces of capital equipment, that in the event of a loss can exceed the policy deductible, are
  - a. Combustion turbine,
  - b. Steam turbine,
  - c. Generator,
  - d. HRSG,
  - e. Generator Step Up (GSU) transformer
3. Today's advanced combined cycle plants operate alongside increasing levels of wind turbine and solar energy power plants, and are subjected to daily start up peaking operation and load following to smooth out fluctuations in renewable solar and wind generation.
4. An emerging issue for combined cycle power plants is ageing equipment.
5. Frequent causes of loss for combustion turbines, include:
  - a. Compressor high cycle fatigue air foil cracking
  - b. Loss of lube oil supply during operation,
  - c. Oxidation and low cycle thermal fatigue cracking
  - d. Rotor overspeed damage
6. The HRSG is basically a series of heat exchangers that create steam for the steam turbine by passing the hot exhaust gas flow from a gas turbine or combustion engine through banks of heat exchanger tubes.
7. Combined cycle power plants (CCGT) are categorized as a highly engineered risk where it's important for underwriters to gain some transparency into the account risk quality.
8. A survey should be requested whenever there is prototypical equipment, high Nat Cat exposure, changes in values, unfamiliar processes or occupancies, or abnormal loss history frequency or severity.
9. There are three types of surveys:
  - a. Property survey
  - b. Machinery breakdown survey
  - c. All-risk survey
10. Basic principles of CAR / EAR coverage for CCGT power plants depend on the following phases of project:
  - a. **Early Works Phase:** simple coverage is required. Usually the coverage of works within this period is based on Munich Re Construction All Risks (MRe CAR) wording with minimal number of extensions.
  - b. **Construction phase:** Coverage of this phase shall include specific clauses regulating fire safety requirements and measures which have to be provided by the designers in

order to avoid destructive consequences of inundation, ground subsidence and earthquake.

- c. **Erection phase:** This phase shall be covered by using Erection All Risks (EAR) Wording which provides specific terms and conditions of such works coverage.
  - d. **Hot testing:** It is a phase of the very high risk exposure
  - e. **Trial run:** is a final stage of hot testing when machinery goes through the peak load. .
  - f. **Initial operations:** This phase starts when trial run is finished and when it is necessary to get all necessary approvals of the technical authorities and to sign commissioning documents between principal, contractor and the above mentioned authorities.
11. Typically “good regulations” have a positive impact on the risk profile of a Combined Cycle Power plant, in that it is reduced as a result of the implementation of the these new regulations.

12. Operational Concerns of CCPP

- New design of CCPP’s are pushing GT and design of free standing LSB boundaries
- Integration of the DCS (Digital Control System) in a CCPP is a complex
- Risk surveyors look less at emergency response systems than operators are actually concerned about.
- Plant testing is very critical and should be evaluated constantly.
- Depletion of corporate and industry memory about past events

## Appendix 1 – Set of Abbreviations

ACC - Air Cooled Condenser

ASME - American Society of Mechanical Engineers

BMS - Burner Management System

BOP - Balance-of-Plant

CCCW - Closed Circuit Cooling Water

CCR - Central Control Room

CCTV - Closed Circuit Television

CD ROM - Compact Disc Read Only Memory

CEMS - Continuous Emissions Monitoring System

CHP - Combined Heat & Power

DCS - Distributed Control System

DVR -Digital Video Recorder

EDI Electro De-Ionisation

ESD Emergency Shut-down (system)

ETP Effluent Treatment Plant

EWS Engineer's Workstation

FMEA Failure Mode and Effect Analysis

FO Fibre Optic

GTG Gas Turbine Generator

GSU Generator Step-Up (Transformer)

HART Highway Addressable Remote Transducer

HAZOP Hazard and Operability Study

HMI Human-Machine Interface (Operator Station)

HRSG Heat Recovery Steam Generator (Waste Heat Boiler)

HVAC Heating, Ventilation and Air Conditioning

I&C Instrumentation and Control

IEC International Electrotechnical Commission Intimate Term indicating the ability to operate individual plant items (motors, valves etc) directly through a DCS

HMI irrespective of control loops and sequences. Analogous with "Computer Manual" control

i/o Input and/or output

IP Internet Protocol

LAN Local Area Network

LSZH Low Smoke Zero Halogen (also called LSOH or LSOH)

LVDT Linear Variable Differential Transformer

MCC Motor Control Centre

MKV Speedtronic

Mark V governor made by GE

NFPA National Fire Prevention Association

OLE Object Linking & Embedding (enables one computer to extract data from another) One Button (start) The ability to start the complete plant by a single operation at an HMI

OPC OLE for Process Control PA Public Address

PLC Programmable Logic Controller (Note: Nowadays these include analogue functions)

PPA Power Purchase Agreement QA Quality Assurance

RMS Root Mean Square

RO Reverse Osmosis

RTD Resistance Thermometry Device (generally Platinum Resistance Thermometers)

RTU Remote Terminal Unit

ST Steam Turbine

STG Steam Turbine Generator Supervisory: Term indicating the ability to operate the plant within a plant area at a high level only. Typically, to start a sequence, raise/lower load, etc. Operation of individual plant items (motors, valves etc) is excluded. (Compare with intimate control)

SWA Steel Wire Armoured

TCP Transmission Control Protocol

UPS Uninterruptible Power Supply

WT Water Treatment

WWTP Waste Water (sanitary water) Treatment Plant

2oo3 A voting system based on having triplicated measurements, and/or processors and/or actuators, whereby any one differing from the other two is ignored.

## Appendix 2: CCGP Risk Assessment Questions for Operating Power Accounts

1. Is the overall condition of the plant clean and organized in appearance?  
\_\_\_\_\_  
\_\_\_\_\_
2. Is there a formalized training program for the plant staff?  
\_\_\_\_\_  
\_\_\_\_\_
3. Are there written procedures for the start-up, shutdown, and daily operations and maintenance tasks?  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
4. Does the plant maintain a stock of critical long lead time spare parts, such as combustion turbine hardware, transformer bushings, and critical instrumentation?  
\_\_\_\_\_  
\_\_\_\_\_
5. Are there any outstanding TIL's, Service Bulletins, Technical Advisories or other form of OEM communication that are not completed for the major pieces of equipment (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?  
\_\_\_\_\_  
\_\_\_\_\_
6. Provide a brief history of the major pieces of equipment, particularly any repairs resulting from failures (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?
  - a. Combustion Turbine:  
\_\_\_\_\_  
\_\_\_\_\_
  - b. Steam Turbine:  
\_\_\_\_\_  
\_\_\_\_\_
  - c. HRSG's:  
\_\_\_\_\_  
\_\_\_\_\_
  - d. Generators:  
\_\_\_\_\_  
\_\_\_\_\_
  - e. Transformers:  
\_\_\_\_\_  
\_\_\_\_\_
  - f. Gearboxes:  
\_\_\_\_\_  
\_\_\_\_\_

g. Pumps:

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7. Are long term service agreements in place for the major equipment OEM or a third party (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?

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8. Are the OEM maintenance intervals being adhered to for the major pieces of equipment, particularly any repairs resulting from failures (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?

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9. Are copies of the maintenance reports available for review for the major pieces of equipment, particularly any repairs resulting from failures (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?

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10. What level of critical spare parts are available for the major pieces of equipment (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?

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11. Please provide the operational history for the gas and steam turbines: equivalent operating hours, starts, trips, etc. (secure DCS and TCS logs, if possible)

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12. How often are the turbines and generators borescope inspected? (secure most recent inspection report with any recommendations)

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13. What is the make, model, and serial numbers for the major pieces of equipment (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?

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14. Does the plant rely on, own or operate a natural gas compressor?

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15. Is there adequate freeze protection for cold climate plants?

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16. Has the plant experienced any HRSG tube failures? What location of the HRSG and what material were the tubes? (secure inspection photographs and reports from repair time)

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17. What level of critical instrumentation redundancy is present?

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18. Does the switchyard incorporate a ring bus design that allows for part of the plant to generate electricity if either one gas or steam turbine is out of service?

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19. Does the HRSG have automated vents and drains, feed water heaters, and are they sufficient to prevent water ingestion into the steam turbine?

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20. Are the combustion turbines equipped with stack bypass doors?

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21. Is the plant designed to operate in full steam turbine by-pass mode?

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22. Does the plant utilize an air-cooled condenser or a cooling tower for steam condensation?

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23. Is there a predictive maintenance / periodic oil analysis program in place for the major pieces of equipment (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?

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24. Is the plant located in a corrosive environment such as near the ocean, chemical plant, or a refinery?

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25. Are the major pieces of equipment connected via an integrated control system (turbines, HRSG's, generators, transformers, gearboxes, and pumps)?

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26. Is there a pipe hangar periodic maintenance plan to address stresses on piping and equipment?

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27. Is the plant equipped with OEM online monitoring and technical support?

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28. Is the plant control system equipped with a data historian to capture a snapshot of any operational upsets?

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29. Are the combustion turbines equipped with dual fuel capability and what type of fuels?

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30. Are the combustion turbines equipped with a dry low NOx (DLN) combustion system?

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31. What is the owner's fleet size for major equipment, and are they actively engaged in industry owner's groups for the turbines, HRSG's, generators, transformers, gearboxes, and pumps?

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32. Describe the owner's operation and maintenance (O&M) training and certification program? Are personnel required to be licensed by any agency to operate the equipment?

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33. Is a reliability centred maintenance (RCM) program in place? Are vibration, oil, thermography, and ultrasonic analysis performed?

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34. Are the combustion turbines equipped with evaporative cooling, wet compression, inlet chillers or fogging?

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35. Is the plant operated in a base load, intermediate or peaking duty?

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36. Is the plant a full merchant facility, or does it have a fully allocated power purchase agreement?

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37. Is the plant equipped with shell and tube gas fuel pre-heaters? Is the source of the heating medium from the HRSG feedwater?

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## Appendix 3: Typical Scope of Work for Conversion of Simple Cycle Gas turbine to CCGP

### **Scope of Work**

Scope of work for this project includes design, engineering, procurement, supply and transportation of material and equipment, installation, erection and construction, testing and commissioning, on-load testing, startup and putting into service Heat Recovery Steam Generators (HRSGs), Steam Turbine Generators (STGs) and associated plant.

The main supply will include but not limited to the following:

#### **Mechanical:**

- Forty (40) nos. Vertical/Horizontal Single/Dual Pressure Heat Recovery Steam Generating (HRSG) units with natural circulation
- Ten (10) nos. Steam Turbine & Generator
- Ten (10) Air Cooled Condenser
- Boiler feed pump system and its associated auxiliaries
- Continuous Emissions Monitoring System (CEMS) to monitor stacks emissions
- Closed Circuit Cooling Water System
- Raw Water Supply Pipeline & Pumping Station
- Raw Water System
- Water Treatment Plant ( Two Pass R.O. and resin based mixed bed Demin Plant)
- Waste Water Treatment & Disposal System
- Bulk Chemical Storage System
- Fire Protection & Detection System
- Compressed Air System
- HVAC System
- Hydrogen Generation Plant
- Bulk Lubrication Oil Storage System for Steam Turbines

#### **Electrical:**

- Steam Turbine Generating Units
- Generator Step-Up Transformers
- Isolated phase bus bars to interconnect the generator and generator step-up transformer
- Extension of existing MV switchgear (13.8 kV and 4.16 kV) required for CCGT project
- New MV cubicles (13.8 kV, 4.16 kV)
- Control and monitoring of MV, LV and UPS system with DCS.
- LV station auxiliary transformers (13.8-4.16-0.48 kV)
- 480 V LV switchgear (PCC, MCC, PMCC, etc)
- DC Switchgear
- Fault recording and diagnosis system
- Protective relay equipment
- Interfacing and totalizing of tariff metering system
- Motors and variable speed drives
- New lighting & earthing system
- Independent grounding system for each steam turbine
- Separate earthing system for DCS and PLC
- Interfacing with 380 kV Substation
- MV/LV cabling, cable tray, cable trenches, cable ducts, etc.
- Supply of EHV 380 kV XLPE cable between GSU & 380 kV Substation

#### **Instrumentation & Control:**

- Complete control, protection and monitoring systems for HRSGs, STGs, Air Cooled Condensers, Water Systems, Electrical Systems, Fire Detection System and other common services and auxiliary systems.
- Supply of new dual redundant DCS

- Automatic start of the GT, ST, and HRSG from main control room and local technical room
- All necessary modifications to the existing Electrical, Fuel and Fire Protection operator workstations and large screen displays.
- Emergency shutdown systems
- Interfaces with existing DCS and Central Control Room.
- Plant performance monitoring equipment
- Condition monitoring equipment
- New PLC systems for BOP/package/auxiliary plants with communication interface with DCS controllers
- Air and Water emissions monitoring equipment
- Extension of the existing SCGT Communication systems to cover the CCGT
- Extension to the existing DCS historical data storage retrieval, logging, reporting, trends, graphics and alarms.

**Civil:**

- Site preparation (excavation, filling, grading)
- Site access roads and pavements
- Utilities pipe work
- Pipe and cable racks
- Storm, foul, oily and plant drainage systems
- Utilities and underground services
- Fencing and gates
- Site services
- Steam Turbine Generator Hall
- ST electrical/station and unit auxiliary switchgear buildings including control rooms
- Hydrogen Generation System Building
- Chemical Building and Laboratory
- Hypochlorite Dosing System Building
- Instrument and Service Air Compressor Building
- Water Pump Shelter
- Chemical Store Building
- Foundations for STGs, HRSGs, Transformer compound, Air Cooled Condenser (ACC), Raw Water System and Pump house, Water Storage Tanks, Compressed Air Equipment, Service ways, ducts and trenches, pipe racks and bridges.