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TECHNICAL CONSIDERATIONS AND BENEFITS OF INSTALLING COMBINED CYCLE POWER PLANTS ON OFFSHORE OIL & GAS PRODUCTION FACILITIES

Travis Bowman, Siemens Energy
Peter Rop, Siemens Energy
Sebastiaan Rijgrok, Siemens Energy

Siemens Energy Inc
15375 Memorial Dr, Houston, TX 77079
travis.bowman@siemens-energy.com
(832) 679-8600

ABSTRACT

Open/simple gas turbines (GTs) have been the preferred means of power generation on offshore oil and gas production facilities over the past two decades. GT-based packages offer a number of advantages over other widely used power solutions, such as gas engines and diesel gensets – including high power density, increased availability, and reduced greenhouse gas (GHG) emissions. In recent years, however, with many offshore operators establishing targets for environmental footprint reductions, new pathways for decarbonization are being evaluated. Combined cycle is a concept that has been widely employed in onshore industrial applications and is now garnering more interest in the offshore segment. This paper will discuss the benefits combined cycle power plants can provide when compared to open cycle GTs and outlines installation and operability considerations for both greenfields and brownfields. In the case of the latter, special measures may need to be taken to ensure that the combined cycle package is within existing allowable tolerances for weight and footprint. Siemens Energy has developed a solution for this specific market need known as Ultra-light Combined Cycle (ULCC).

INTRODUCTION

Optimizing the lifecycle performance of floating, production, storage, and offloading (FPSO) vessels has become highly dependent on the use of rotating equipment packages that can deliver the necessary heat and power to meet production, processing, and compression requirements in deep waters and harsh operating environments. In recent years, decarbonization has also become a key priority.

Combustion associated with power generation typically represents the largest emissions source on an offshore production installation. With their high power density, GTs have served as the primary means of electricity generation. On many production facilities, additional turbines are also used as direct drives for required compression duties.

On all but a few production installations in operation today, GTs are used in open cycle configuration. Many facilities also employ some means of waste heat recovery, using hot-oil or water-glycol as a heat transfer medium. In such cases, thermal energy from the exhaust of the GT is used for providing heat, often for systems related to separation and/or processing. While this has proved to be an effective way to meet heat and power needs for production on FPSOs, it does not always result in the lowest emissions profile.

In the North Sea, approximately 80% of all emissions from oil and gas activities are generated from GTs (Norwegian Petroleum Directorate, 2014). In 1991, as an incentive to accelerate the development and adoption of emissions-reducing technologies, the Norwegian government introduced a carbon tax on combustibles from petroleum-related activities. This taxation is currently set at ~ \$52/ton of CO_2 released. These types of taxes, which are being evaluated in many other areas of the world, coupled with voluntary actions from global operators to meet established carbon neutrality targets, has led to a growing interest in novel/emerging technologies and solutions that can reduce emissions.

It has become clear that established//proven technologies will also have a role to play on the journey to carbon neutrality. According to McKinsey & Co., approximately 90% of known technological solutions for decarbonization are within the grasp of operators at a cost of no more than \$50 per tCO_2e — equivalent to an added cost of approximately \$0.50/barrel (assuming approximately an average production emissions of 10 kg CO_2e/boe). One of these technologies is combined cycle.

OPEN VS. COMBINED CYCLE

Topsides process heat requirements and integration complexity greatly impact the overall efficiency of an FPSO power plant. Generally speaking, however, the thermal efficiency of plants using modern open cycle GTs ranges from 35 – 45%. For combined cycle plants, efficiency can be as high as 50 - 65%.

In a combined cycle power plant, a Once-Through Steam Generator (OTSG) extracts thermal energy from the GT exhaust and uses it to convert water into superheated steam, which is then used to drive a steam turbine. The steam turbine produces additional power, along with the necessary heat load for oil/gas processing and separation. The system can be designed such that the production of steam for fulfilling process heating requirements is prioritized, even in the event of a steam turbine outage. In this way, the risk of interruption to oil and gas production is minimized.

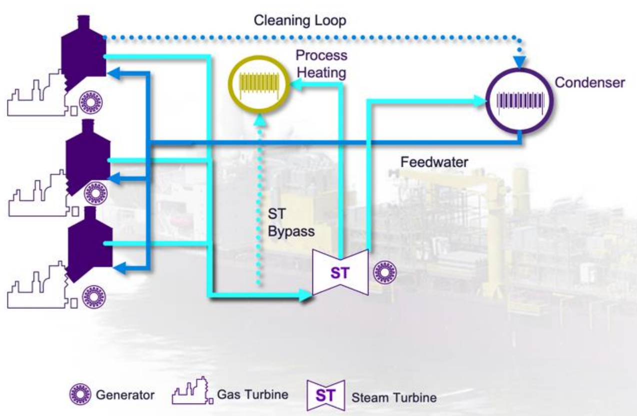

Figure 1. Simplified layout of offshore combined cycle power plant

Because there are often weight and footprint limitations, a vertical OTSG is preferred for offshore combined cycle plants. OTSGs contain once-through flow paths and do not require a steam drum or blowdown system, as is the case with other types of steam generators, such as boilers. This provides several benefits, such as reduced water inventory and elimination of circulation pumps. Installation is also much simpler, which is particularly valuable on brownfields.

Other advantages of OTSGs include a reduced piping run complexity, fewer casing penetrations, and lower thermal inertia. Rapid start-up and shutdown and "internal bypass" capability during upset conditions is also possible, which means that the bottoming cycle will not impact the availability of the GTs.

OPERABILITY CONSIDERATIONS

In an offshore combined cycle plant, production of heat for the process heating medium (HM) exchangers can be achieved in several ways. In this paper, we will focus on two approaches: 1) through steam production and 2) direct heating of HM bundles in the OTSG. Deciding which to employ will be dictated by control functions the operator finds preferable.

With Option 1, the HM heat is produced from steam production. In such cases, the role of the OTSG is entirely optimized for this duty and the required low-pressure steam is either extracted from the steam turbine mid-stage or is extracted at the high-pressure steam header and subsequently sent to the HM exchanger through a reducing station. This way, the steam turbine does not necessarily have to be in operation to provide process heat.

With Option 2, HM heating is achieved by using exhaust gas from the open cycle gas turbine and a secondary tube bundle within the OTSG. The bundle can be designed in a parallel or series arrangement. In all designs, it is preferable that the HM heat has priority.

Inherent to Option 2, variations in high-pressure steam demand or GT load will create a deviation in HM heating. This means that in the HM circuit, a dump cooler is needed to absorb the excess HM heat. Furthermore, there may be a shortage of HM heat when the GT is operating at part load. Increasing heat supply in this scenario could require running the GT at an unnecessary higher load or suppress steam production, both of which would impact cycle efficiency negatively. Moreover, the requirement of stable flow conditions for all streams under all operating conditions means that there is limited flexibility.

Producing only high-pressure steam in the OTSG and moving the production of HM heat to the steam turbine extraction (Option 1) allows for simplification within the OTSG and also allows the reduction in energy in HM steam to be utilized in power production through the steam turbine blade. This is optimal from a cycle dynamics perspective because the required amount of HM steam mass is not of such a substantial flow rate that it nullifies the existence of the remaining steam turbine blading beyond the extraction port. Depending on the duty of the both the steam turbine MWe and the required MWth, some combinations may not be able to support all available steam turbine casings and blade families. Steam turbine combined cycle designs of this nature employ a steam turbine bypass circuit to ensure HM heat production during any maintenance or upset of the steam turbine. Overall, this option is very flexible in operation and offers high availability.

In all designs, attemperator valves are employed to ensure downstream equipment is supplied with proper steam conditions. This would generally include attemperator at the OTSG high-pressure steam outlet and also at the HM heat exchanger steam side inlet.

In reference to the above, when adding the complexity of a combined cycle plant, alignment of scope is crucial. The traditional approach is often to overdesign, which results in engineering margin stacking, sub-optimal operation, and lower cycle efficiency.

When duties are defined for the project, they should be envisioned over the life of the project so as to identify operating scenarios throughout the entire lifecycle. Duties should also be defined with and without offloading MW. The duration of offloading is often short and therefore production of intermitted power for offloading can be examined as a use case instead of being aggregated within the required or guaranteed values for the project.

BROWNFIELD APPLICATIONS

When it comes to converting from an existing open cycle GT-based power plant to combined cycle, several factors must be evaluated, including the existing points of load and structural rigidity. Typically, with most brownfields, these design areas will have been established decades prior and there is limited flexibility for expanding the power plant footprint or adding significant mass. This is especially the case for FPSOs and for many facilities operating in sour field developments. In such cases, there are often additional systems for production, processing, and storage, which may necessitate highly compact power modules.

In 2018, Siemens Energy began developing a combined cycle power solution to address this special market need. The solution, known as Ultra-light Combined Cycle (ULCC), has sought to solve typical offshore challenges, with a focus on constructability, maintainability, motions, footprint and weight. ULCC can be provided in various plant configurations with one, two, three or four GTs supplying exhaust heat to one steam turbine. The concept can be applied to any offshore installation, but is particularly well suited for brownfields as a “steam tail” or Ultra-Light Bottoming Cycle (ULBC) brownfields (Hossein, 2019).

ULCC concepts are designed for automated and flexible operation and serve to provide both the electrical auxiliary power and required heat load of an FPSO vessel, floating LNG facility or fixed platform, producing and processing oil or liquified natural gas. Depending on customer requirements, the entire ULCC module can be provided as a single-lift package for a reduction of offshore installation activities.

Key to ULCC is the newly developed and patented once-through cycle with focus on minimizing the equipment count (thus reducing weight and footprint, simplifying the system) and making the water-steam cycle practically hermitically closed. This greatly reduces water consumption and the risk of water contamination. All auxiliary equipment has been concentrated on the Balance of Plant module, which serves the water-steam cycle including the steam turbine and all OTSGs. The single pressure OTSGs are designed to allow a high number of starts and high GT load ramp rates. The OTSG has also been specially designed for maritime environment where the reduced weight helps to limit acceleration forces.

The Balance of Plant module is placed on top of the steam turbine module, which keeps connections with the turbine very short and compact. Each OTSG has its own steam bypass station connected to the condenser to enable independent start-up. The steam turbine has extraction ports to feed steam to a process heater. Condensate pumps are located close to the hotwell of the condenser. From the main steam line there is a reducing station with attemperator connected to the process heater, which bypasses the steam turbine. This way, in the event that the turbine is not in operation, or the steam turbine extraction doesn’t deliver enough steam, the heater can still be fed with steam.

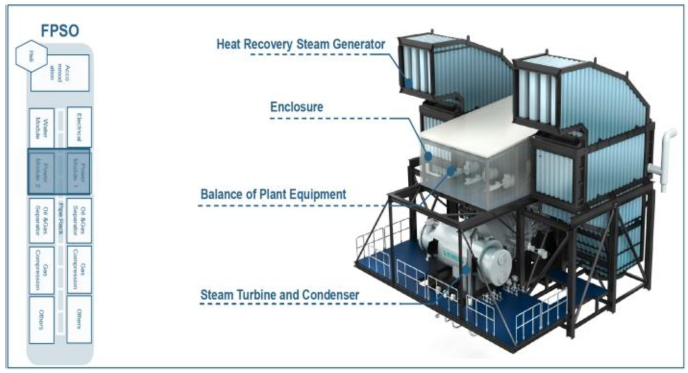

Figure 2. Illustration of ULCC power module

These modifications (among other measures) result in 50% less weight and footprint when compared to comparable, as-built steam bottoming cycles currently employed in the offshore environment.

Overall, power plant conversion projects often require an extra level of engineering finesse, along with the utilization of lightweight materials to meet the existing limitations of the vessel or platform. Nonetheless, they are possible. The return on investment (ROI) from such a decision will ultimately vary on a case-by-case basis and be dictated by the facility's requirements and the operator's objectives concerning cost, performance, and emissions

EMISSIONS SAVINGS AND BENEFITS

By increasing the efficiency of electricity production, the overall carbon footprint of the facility can be dramatically reduced. As an example, the conversion of two typical simple cycle GTs into a combined cycle plant can reduce facility emissions by up to 110,000 metric tons/year of CO_2 (~ 5,000 tons/year CO_2 savings per 1-MW generated from the steam turbine). For context, this is equivalent to the annual emissions of more than 23,000 combustion engine vehicles (U.S. EPA, 2019).

In regions of the world where carbon taxation frameworks exist, this can result in significant OpEx savings. Again, in Norway, the cost of emissions permits/certificates for an FPSO or fixed platform in certain countries equates to approximately \$52/ton of CO_2. On these projects, the resultant monetary permit/certificate savings from the emissions reduction in this case is over \$5.5 million. Further savings are realized by reducing fuel consumption by ~25 Mio Sm3/year. Overall, with a combined cycle power plant, up to 70% efficiency can be achieved for power and heat provision. This is roughly double the efficiency of an open cycle GT.

High-efficiency power also provides the gateway for electric motor-driven (EMD) compression. Aside from operational advantages, such as increased availability and efficiency, and better turndown capabilities, this provides the added benefit of centralizing and optimizing emissions on the facility. It also enables more effective emissions monitoring and control by eliminating the need for mechanical drive GTs.

REAL-WORLD APPLICATION OF COMBINED CYCLE FOR OFFSHORE

In recent years, an increasing number of offshore operators have considered combined cycle power plants for their production assets. While very few have actually been installed, there are several FPSO projects currently under development which have specified combined cycle.

One of the world's first offshore projects to feature a combined cycle power plant was a production platform in the Gulf of Mexico.

Siemens Energy delivered the entire power generation package for the facility 2016. The power plant features four 27MW aeroderivative gas turbine-driven generator sets and a 40MW steam turbine generator (total output ~150MW).

Each gas turbine has an OTSG designed as a single pressure unit that recovers waste heat from the exhaust stream. They are equipped with supplementary firing, which allows for additional power production by using hot exhaust gas from the turbine as an oxygen source. In a typical setup, the burner is placed in the exhaust gas stream and is fired directly into the high-pressure superheater, leading to increased heat flow. In some instances, the turbine exhaust gas temperature can be raised by as much as 400–600°F. This ultimately results in more steam production that enables more power production.

Implementing the combined cycle power plant was a notable success. Since starting up, it has operated well below regulations for NO_x emissions. Reduced fuel consumption and associated carbon emissions have also been key benefits.

EMBRACING DIGITALIZATION

In the context of offshore power plants, equipment design and selection will have the largest impact on overall facility performance and emissions. However, incremental carbon savings are also possible through digitalization, and more specifically through the application of advanced software tools that aim to ensure that GTs are running at optimal setpoints.

Such tools can take into account variables, such as current power demand and outside ambient conditions, and adjust GT operation so that all units in the power plant are collectively operating in a manner that minimizes fuel consumption. While this may not seem significant in terms of its impact on emissions, on an FPSO with four 30MW aeroderivative gas turbines (80MW total power demand), just a 1% increase in power plant efficiency could produce approximately 6,500 metric tons of CO_2 savings annually (Talakar, 2021).

Similar digital tools can also be applied to improve the availability of GTs. This is sometimes known as "dynamic lifing" and aims to create a more accurate picture of the turbine's as-is condition and performance, allowing operators to be more flexible in scheduling maintenance activities.

Today, many operators use standard operating hours (SOH) as the primary metric for scheduling their turbines' service and/or overhaul activities. This typically assumes that the units are being operated at 100% of their rated load in an environment with constant temperature, humidity, etc., which is never the case.

By using Equivalent operating hours (EOH), it becomes possible for operators to transition away from schedule-based (i.e., fixed interval) maintenance. In some cases, it may potentially allow for certain tasks (which would normally require a shutdown) to be delayed so that production is not impacted.

EOH can also be employed as a strategy to use intermittent peaking of the GT sets to achieve high short-term power requirements. Depending on the frequency and duration of the peaking, it could result in a decision to reduce the total number of GTs in the power plant, thus reducing space and weight, and conserving CAPEX.

CONCLUSION: PROJECT EXECUTION CONSIDERATIONS

As is the case when implementing any new concept or, in the case of combined cycle, a novel application of established technology, there is a perception of increased risk. This is particularly true in oil and gas and even more so in the offshore environment, where production downtime costs are magnified. In the case of combined cycle power plants, sole-source provisioning of equipment (e.g., gas turbine, steam turbine, OTSG, the balance of plant systems, etc.) can be an effective method of mitigating risks, particularly when it comes to system integration and off-design operational flexibility. Operational risks are also reduced by simplifying the optimization of the water-steam cycle. The equipment utilized in a combined cycle power plants are long-lived in the onshore space, and thus the evolution to offshore, although uncommon, is not unprecedented.

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