A FLEXIBLE SOLUTION FOR FLNG OFFLOADING

Marc Cahay
Department Manager, New Technology Offshore

Eric Luquiau
R&D Manager, New Technology Offshore

Cyril Morand
Offshore Unit, Substructure & System Manager

Technip
Paris, France

ABSTRACT

Floating Liquefied Natural Gas (FLNG) units under development for decades are now becoming reality. They combine design and installation of LNG units with traditional “FPSO”. It also requires a reliable system able to offload the LNG in the open sea and in harsh environments.

Several developments of projects are considering the tandem configuration where the LNG carrier is kept downstream the turret moored FLNG. This arrangement allows weathervaning and provides a safety distance between the two vessels. The nominal stern to bow distance is generally around 70 to 100m which provides an acceptable minimum safety distance considering the motions of the LNG carrier relative to the FLNG.

Several years ago, Technip initiated a program to develop an LNG offloading system. The program was initially for aerial stern-to-bow configurations based on specially develop Technip’s Mark 1 cryogenic flexible pipe. It is now focused on a floating system based on the cryogenic floating flexible pipe Mark 2 designed for stern-to-bow or midship manifold configurations. These systems are now part of the Technip portfolio. The aerial one is ready for implementation on new projects. The floating flexible offloading systems are still under development and are expected to be ready for offering in short term.

This paper focuses on systems proposed for both aerial and floating offloading configurations. It highlights the safety aspect and operational benefits of a robust, fully certified, continuous length of cryogenic flexible. The main drivers and capabilities of such systems including the operating procedure are outlined.

INTRODUCTION

The first commercial Liquefied Natural Gas (LNG) plant was started in Arzew in Algeria in 1964. It exported gas to Britain and then to France and the United States. Since then, the trade of liquefied natural gas has experienced uninterrupted growth, marked by the gradual diversification of suppliers, customers and technology. Like the offshore oil developments, technologies developments have created the conditions that makes possible today the commercial exploitation of offshore gas fields by floating liquefaction units also called FLNG.

The FLNG being directly located above the natural gas field (subsea development) and moored to sea bed, the gas is routed from the subsea field to the facility via several risers. The gas and condensates are separated. The separated gas is treated to remove undesirable components. The purified gas is then liquefied by cooling to -162°C and finally transferred into the storage containment systems within the hull.

On a regular basis, ocean-going LNG carriers (LNGC) will come close to the FLNG location to offload the different product for delivery to markets worldwide. There are two main families of solutions to achieve this operation:

- Tandem, when the LNG carrier is aligned with the FLNG with a safety distance around 90m.
- Side-by-side, when the LNG carrier is moored on the side of the FLNG.
The challenge of such operations in open seas resides in the fact that both units are floating and have their own response to wave excitation. The design of an offloading system is made even more complex due to:

- Large operational envelop
- The harsh environment conditions in open seas.
- The variation of draft during the operation that modify their response.
- The size difference between the FLNG and the LNG carrier.
- The different sizes of the LNG carrier (less than 100,000m³ or 260,000m³ for Q-Max).

In order to achieve these offloading operations with acceptable safety conditions and reasonable operational availability, Technip has been initiating a program of technological developments for at least a decade. The backbone of this ambitious program was centered on tandem configuration using flexible deployed in aerial catenary and now floating. Recently Technip developed at conceptual stage a new system for side-by-side configuration called FlexArm, combining rigid arm technology and cryogenic flexible. These different systems are described in this paper.

AMPLITUDE-LNG LOADING SYSTEM (ALLS)

The Amplitude-LNG Loading System (ALLS) developed in accordance with EN-1474 and Classification Society rules has obtained in 2008 a fitness for service certificate from DNV; for both tandem and side-by-side configurations. ALLS has been tested full scale in the GDF SUEZ LNG receiving terminal of Montoir-de-Bretagne in France. LNG flow was provided by a LNGC during its commercial unloading at one of the terminal jetty (Figure 1). These tests have allowed developing and certifying the set of operating procedures of the system as well as demonstrating a safe and reliable mechanical connection system under severe dynamic conditions. ALLS is designed to allow a large operating envelope and high availability in complex environmental conditions up to a sea-state of significant wave height (Hs) of 5.50 meters.

The ALLS is composed of two main components:

- A cryogenic flexible pipe (could be aerial or floating) linking the FLNG to the LNGC, able to transfer LNG and Boil Of Gas (BOG).
- A multifunction connecting system between the LNG carrier manifold and the flexible pipe end-fitting fully detailed in Ref. [4] and able to cope, while connecting, with large motions and accelerations relative to the LNGC.

In complement of ALLS, the overall offloading system is composed of:

- Storage and deployment system
- Tandem mooring system
- Emergency shutdown link
- Automation and control system
CRYOGENIC FLEXIBLE PIPE

Cryogenic flexible pipe is one of the key components of ALLS. The main drivers considered for the design of both aerial and floating flexible are:

- Allowable flow rate
- Manufacturing
- Reliability of the structure
- Burst pressure safety margin

Attention has been paid to the selection of each individual component of the flexible structure but also their compatibility and assembly within an industrial manufacturing process. The separation of functions in flexible pipe guarantees the predictable behavior of the line. Resulting from above aspects, the tested burst pressure is far beyond the expectations and leads to a large safety margin for accidental case during the offloading operation.

Figure 1 - Full scale test in 2007 in GDF-SUEZ LNG terminal in Montoir-de-Bretagne, France

Figure 2 – Mark 1&2 structures.

Aerial Mark 1

Floating Mark 2
Inner Layer (1)
The LNG containment and transfer functions are achieved by a corrugated steel hose made of bellows. Bellows can be single-plies for the Mark 1 and multi-plies for the Mark 2, in order to increase the fatigue life in sea. Due to the temperature constraints this inner layer is made of stainless steel. This ensures the leak-tightness of the structure, as well as sustaining the inner radial pressure.

Armors Layers (2)
Armors layers are in the cold area, just around the inner layer and before the thermal insulation layers and define the tensile capacity of flexible pipe. Doubly helically wound armors layers are made of polyester fibers covered with nylon braiding for the Mark 1 and stainless steel flat wire associated with anti-wear strips for the Mark 2.

Thermal Insulation Layers (3)
Made of polyethylene foam strip for Mark 1 and aerogel foam strip Mark 2, this layer ensures that the inner temperature is kept whilst preventing any build-up of ice on the exterior of the flexible.

Outer Sheaths (4)
Two layers for Mark 1 made of self-binding rubber mastic tape. Made of extruded thermoplastic for Mark 2, one sheath provides the water tightness and the other one the external protection.

The annulus allows the detection of any leak of LNG as soon as it may occur.

End Fitting
The end-fitting assembly is made of 316L stainless steel, and ensures two primary functions:

- The flexible termination incorporates the different layers of the flexible and ensures the integrity of each layer at its end. The construction is designed to allow the immediate detection of any LNG leak into the inner annulus
- The end connector, typically a standard industry ANSI flange, is connected to the associated piping at each end of the flexible line.

The main difference for the end-fitting of Mark 1 & 2 is the fixing of armors because of their nature. The polyester fibers of the Mark 1 are commonly clamped. The stainless steel flat wires of the Mark 2 are welded at their ends.

Leak & Temperature Monitoring
A leak & temperature monitoring is inserted in the structure of the flexible pipe allowing:

- To continuously control the temperature profile along the flexible pipe and follow the filling sequence.
- To instantaneously detect any LNG leakage along the flexible pipe.

It is composed of several optical fibers equipped with sensors wound following an helical path. Optical fiber connectors are provided in the end-fitting to ensure the connection to the interrogator unit as part of the offloading control system.

There is no intermediate connector on the optic fibers as for the fluid path. Hence, replacement any optic fiber is possible if required.
Predictability
The operating and fatigue behavior of both Mark 1 & 2 is fully predictable due to the use of corrugated steel bellows and well known materials with elastic behavior in the structure.

In addition, following the full scale test and operation held in Montoir de Bretagne, France, during 2007 & 2008, where 50m of flexible were tested in real offloading condition, several CFD studies were performed in order to characterize the LNG flow at different pressures and flow rates inside the flexible pipe. Those results, fully described in Ref. [8], have demonstrated the origin of the pressure drop level and validated the Montoir de Bretagne measurements. It has also confirmed the friction factor to be used when designing the flexible pipe.

FLEXIBLE TANDEM SYSTEM
Tandem offshore oil loading has become a standard practice in the industry in many locations including the harsh environment of the northern North Sea. Flexible LNG offloading in tandem configuration is designed to be similar to this “standard” oil offloading.

Operational envelope limits the LNGC position relatively to the FLNG and is defined by the following parameters:

- The stern-to-bow distance:
  The appropriate range of nominal distance ("target radius" in Figure 3) between FLNG and LNGC for offloading operation with ALLS is in the range of 70m to 90m. Around this nominal value the distance between FLNG and LNGC could vary in a range of ±10m for normal loading operation,
- The angle of the stern to bow line relative to the FLNG longitudinal axis:
  With ALLS the angular sector could vary in a range of ±40° for normal loading operation,
- The heading offset of the LNGC relative to the stern to bow line:
  With ALLS the LNGC heading could vary in a range of ±40° for normal loading operation.

These values could be changed on case by case according to project specificities (complex environment, station keeping system performance etc.). In case of complex environmental conditions, a Dynamic Positioning (DP) system could be specified for LNGC to reach the minimum required offloading operational availability. Outside of the normal operating envelope, an Emergency Shut Down (ESD) procedure is defined in order to protect the transfer system and the ship’s manifold, hence both floating units. In case of drift of the LNGC outside of the predetermined operating envelope, this procedure is launched.
Green zone: normal offloading operation.
Yellow zone: stop the cargo transfer process in a controlled manner (ESD-1).
Red zone: activates the Emergency Release System (ERS) installed on transfer system (ESD-2).

Three basic architectures are possible in tandem configuration. All of them consider the offloading system located on the stern of the FLNG and connected to the bow or midship of the LNGC with the flexible. Floating flexible can be used for both arrangements while the aerial one is restricted to a stern-to-bow connection.

In order to reach a total flow rate of 10,000 m$^3$/h, three flexible pipes are used for liquid with an additional one used for vapor return. This multi-lines configuration is the best compromise regarding flexible pipe behavior and process arrangement. It has also interest in terms of operational aspects and redundancy considering that each line can carry liquids or gas.

**Aerial stern-to-bow configuration**

The aerial configuration (Figure 4) is composed of two dual reels. Each reel supports two cryogenic flexible pipes (described earlier in this paper) and one conventional umbilical to achieve the transfer of hydraulic power and signals (e.g. electrical information) to the ERS. At LNGC side each pair of lines and the umbilical are connected to the connection head through a “twin connection system” described later.
The reels are controlled during operation through the ALLS Control & Safety System (ALCSS) and locked in a fix position function of the mean relative position of the LNGC. The flexible pipe length deployed between the two vessels shapes a catenary which allows withstanding at least the wave frequency relative motions between the FLNG and the LNGC. For significant modification of the LNGC position, in case of environmental condition changes, the reels are unlocked, adjusted and locked in a new position.

The reels are able to:

- Rotate around their horizontal axis (reel) to pay in (or pay out) the flexible pipes for their storage and control of the length of the catenaries.
- Rotate around a vertical axis (pedestal), to be aligned with the plane containing the catenaries and to be turned inboard during stand-by for easy access to the connection systems and for maintenance.

These rotations are ensured by mechanisms very similar to those of an offshore crane.
Twin Connection System

The Twin Connection System is based on the Connectis™ that has been developed jointly by Technip and KSB and obtained a type approval certificate from Bureau Veritas in 2003.

A Twin Connection System is associated to each pair of flexible pipes. Its design ensures a complete, automatic and safe dynamic connection of a pair of the flexible pipes to the connection heads of the LNGC, and the Emergency Release System (ERS) units included ensure safety during transfer.

As for the Connectis™ it includes different subsystems:

- Handling and guiding devices,
- Quick Connect/Disconnect Coupler (QC/DC),
- Two ERS each composed of Double Butterfly Valves (DBV) and an Emergency Release Coupler (ERC).
- A braking system to control emergency release.

Each flexible pipe has its own independent ERS (including ERC and DBV) and QC/DC.
Service connection/disconnection function is realized through the handling and guiding device in a first step, and by the QC/DC in a second step. The twin connection system is fitted with two independent QC/DC installed on each connection head. Each QC/DC ensures separately a sealed connection for each pipe. The QC/DC is composed of several clamps operated by hydraulic jacks; it achieves the final approach and the clamping on the connecting flange.

In case of emergency disconnection, the ERS allows quick release of the line (within 8 seconds) with minimum spillage (less than 2 liters for 16” valves). Additionally, the DBV ensure, for service disconnection operations, a safe confining (lock chamber principle) of the internal atmosphere of the flexible pipe which contains remaining LNG.

Tandem Mooring System
The tandem mooring system is very similar to that of oil tandem offloading system. The shuttle carrier is physically moored to the FLNG unit by a hawser.

Emergency Shut Down (ESD) link
The purpose of this interface is to transfer ESD signals to secure the offloading operation between the FLNG and the LNGC.

Automation and control system
The ALLS Control & Safety System (ALCSS) is part of the overall offloading system. It provides control of reels and ensures all safety functions during the operation.

The Integrated Control & Safety System (ICSS) that covers the entire FLNG unit contributes to ensure the safety of the offloading operations of the FLNG unit.

Floating stern-to-bow configuration
The general arrangement of the floating stern-to-bow configuration is similar to the aerial one. The main difference is that this solution is fully passive. The storage and deployment reels are not controlled according to the position of the LNGC relative to FLNG. The variations of heading and distance between both units during operation are compensate by the full length of the floating Mark 2 flexible pipe. It is continuous over its entire length, i.e. no intermediate flange that could result in leak source in water. Its efficient thermal insulation ensures that outer sheath is at ambient temperature which prevents from ice built up on its circumference.
The storage and deployment reels have a smaller diameter than the aerial solution. They are similar to typical oil ones (Figure 7). Each transfer line has its own storage and deployment reels on which a spooling device can be installed to control the correct spooling of the flexible pipe.

![Figure 7 - Floating stern-to-bow configuration](image)

Floating stern-to-midship configuration
As for standard oil offloading where the tanker manifold is connected to the production unit by a floating flexible, the floating stern to midship configuration allows the LNG offloading operation with a passive system and “standard” LNGC without adjacency of bow loading system and minimizing the adaptations.

The handling operation of the flexible pipes from the FLNG to the LNGC is performed with the assistance of a workboat. The operational conditions of the system are mainly driven by the safety of such operation.
According to the tandem mooring system which guarantees an acceptable stern-to-bow distance, possible reinforcement of the bow and stern mooring points of the LNGC may be required in order to accept the FLNG tandem mooring line and tug back pull line loads.

In order to achieve the separation distance between the two floating units, there is about 300m length of floating flexible pipe (Figure ). One line is required for vapor return whilst two or three are used for LNG transfer. The number of fluid lines is a result of an optimization study of the governing parameters, such as:

- Required flow rate
- Offloading pumps
- Line diameter

![Figure 9 - Schematic view of stern to midship configuration during operation](image)

The storage and deployment reels, similar to typical oil ones (Figure ), are located at the stern of the FLNG. Each reel is designed for handling and storage of up to 300m of flexible pipe in one layer. The reels are hydraulically driven, spooling device is installed to control the correct spooling of the flexible pipe. An inert gas purging system is included in order to warm up and purge the flexible pipes when stored on the reels.

For the operation, a spool piece has to be added on the LNGC in order to keep the loads, coming from the offloading lines, in the allowable envelope of the manifold as defined in Ref. [2]. In addition, it allows an outboard connection avoiding any clash using the winch, the pulling cable and the guiding system of the ALLS. The spool piece must be retrieved or parked during normal operation of the LNGC such as shipping or transfer with loading arms in LNG terminals.

During LNGC dry docking, for planned maintenance, a simplified spool piece has been installed and the flexible connection procedure were tested successfully (Figure 6).
Operation and control
The system is designed to be remotely controlled and does not require personnel presence in the stern of FLNG or at the midship of the LNGC during fluid transfers. In normal operations the loading operation will be monitored from the central control room on the FLNG and the bridge of the LNGC.

It is locally controlled from the maneuver console on the FLNG hull deck aft. During offloading, the shuttle carrier stays moored on taut hawser to the FLNG, with the flexible pipe hanging from the storage reel down into the water. The main part of the flexible pipe is floating between the two units and connected to the spool piece on the shuttle’s manifold.

FLEXIBLE SIDE-BY-SIDE SYSTEM

The FlexArm is combining the rigid arm technology and cryogenic flexible pipes for the liquid export and vapor return between FLNG and LNGC in side-by-side configuration. In term of FLNG layout, the FlexArm configuration is comparable to other side-by-side offloading (i.e. rigid arms) systems currently under development for offshore LNG offloading. The flexible is hung by a wire to the main support including a swinging arm. The vertical displacement of the LNGC relative to the FLNG is compensated by the oscillation of the swing arm. The relative horizontal motions of floating units are compensated by the pendulum displacement of the flexible pipes.

It is designed to operate with any LNG carrier without any prior modification.

The main advantages of the FlexArm are:

- The architecture allows for large operating envelope, not only dynamic but also “static” which corresponds to the positioning envelope of the LNGC manifold relative to the FLNG. In particular, when a large FLNG have to offload on a “small” LNGC, requiring to reach a very low manifold from the FLNG deck.
- There is no swivel. This minimizes the potential leakage by avoiding mechanical pieces on the fluid path.
The main support (made of carbon steel) consists of:

- A swinging arm supports a counter weight and the gooseneck by the mean of wire cable & pulleys.
- A rigid arm supported by a pedestal and allowing two positions: operating and storage. The angular position of the rigid arm is operated by the rigid arm rotating mechanism. Two main equipment are fixed on the rigid arm:
  - The FlexArm winch, where the gooseneck cable is fixed.
  - The swinging arm damping device.
- A pedestal fixed on the main deck level of the FLNG. At its top a transition piece supports the rigid arm rotating mechanism.

The number of parallel units can be optimized after process study. The main fluid transfer lines consist in a LNG flexible pipe. For this FlexArm application, the flexible pipe is based on Mark 2 where the protection sheaths, dedicated to sea water tightness for floating applications, are replaced by a light & flexible sheath to protect from offshore environment. The fluid line is made in two parts of flexible with an intermediate gooseneck to avoid very low radius at the cable connection. Geometric parameters can be adapted in order to fit to the required operating envelope.

**Connection system**

A connection system is associated to each FlexArm and fixed to the flexible end-fitting. Its design ensures a complete, automatic and safe dynamic connection of the flexible pipe to the connection head, and the Emergency Release Systems unit included ensures safety during transfer.
The connection system of the FlexArm is based on the Connectis™ that has been developed jointly by Technip and KSB and obtained a type approval certificate from Bureau Veritas in 2003. It includes all safety devices required for LNG transfer operation.

The selected arrangement of the connection system is similar to the system tested in Montoir-de-Bretagne, France, in 2008. It includes QC/DC, ERS with ERC and guiding device. The connection system is hydraulically driven. The Hydraulic Power Unit (HPU) is located and managed from FLNG.

**Targeting system**

The targeting system allows approaching the connection system to the elbow flange fixed on LNGC manifold. This elbow flange, including guiding pines, has to be installed on LNGC during its approach and mooring to FLNG.

**CONCLUSION**

Technip has acquired real know-how in LNG offloading systems through onshore LNG projects and more than a decade of R&D programs. These programs have included full scale tests on LNG flexible pipe and offloading systems, not only in house but also through Joint Industry Projects (JIP) with the major LNG operating companies.

Building on our experience as a leading provider of flexible pipe systems for oil and gas field developments, with manufacturing units located in France, Brazil and Malaysia, the cryogenic flexible Mark 1 & 2 were designed from the conceptual phase by integrating all the constraints related to their future manufacturing in our factories and offshore operation in open sea.

All these developments strengthen Technip’s expertise in the design and realization of floating gas liquefaction units.

Although FLNG EPC projects under implementation have selected side-by-side configuration with rigid arms, the technology breakthrough of tandem offloading is expected for the next generation of FLNG projects. This makes possible the oil “look alike” LNG offloading operation.

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**JIP Flexible hose**

Participants and sponsors: BHP, BP, Chevron, GdFSuez and Shell.
Contractor: Technip.
Certification authority: BV

**JIP Amplitude-LNG**

Participants and sponsors: BP, Chevron, Eni Agip division, GdFSuez, Höegh LNG, and Total.
Contractors: Technip, Eurodim, KSB.
Certification authority: DNV
JIP ALLS OPU “Amplitude-LNG Loading System Operational Pilot Unit”
Participants and sponsors: BP, Chevron, Total, GdFSuez, Petrobras, Conoco and Höegh LNG.
Contractor: Technip, GdFSuez, KSB, Eurodim.
Certification authority: DNV

JIP Floating Flexible Phase II
Participants and sponsors: BP, Chevron, ExxonMobil, GdFSuez, Höegh LNG, Shell, Statoil, Total, Petrobras, BG Group and NYK.
Contractor: Technip.
Certification authority: BV

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