For decades the challenge of floating LNG production was constrained by the feasibility, safety and availability of offloading operations in complex offshore environments. Experts from technology companies developed, assessed and tested extremely diverse solutions for offshore LNG offloading, until the first few FLNG projects materialized and started operations. With the first three offshore FLNG projects now operating or in start-up phase, all using side-by-side offloading configuration with proven articulated offshore arms, the industry can now rely on a unique source of lessons learned that will provide valuable input for the selection of transfer solutions for future FLNGs.

The proposed paper will discuss and answer questions on:

- The criticality of offshore FLNG offloading, the main differences between nearshore FSRU and offshore FLNG offloading, and how the availability level of the transfer function impacts the whole FLNG performance,
- The methodology for integrating the transfer system and FLNG design, the associated savings and other advantages,
- The lessons learned from the world first FLNG offloading operations,
- The comparison between the different offshore FLNG offloading technologies.

Being the only company able to propose both articulated or flexible LNG offloading technologies, TechnipFMC offers unique advisory capabilities for the selection of the most efficient solution, with a totally unbiased approach.
FLNG concepts have been studied since the 70’s and faced several showstoppers identified; the offloading system was one of them. A wide range of offloading concepts were developed by the industry covering both side-by-side and tandem vessel to vessel configurations but the viability of FLNG projects was severely challenged by the number of novelties; Stake holders were not ready to endorse the risks, considering that any significant downtime of the offloading system would completely stop LNG production.

In the early 2000’s, TechnipFMC Loading Systems developed the Targeting System which is an additional device fully integrated to the loading arms to allow the connection and disconnection of the loading arms under dynamic offshore conditions. The first loading arms equipped with the targeting system were installed on the GBS (Gravity Based Structure) of Adriatic LNG, Italy, in operation since 2009. This operating reference enable all following FLNG in side by side configurations where risks related to this novelty were drastically reduced.

In 2011, Shell signed the FID for Prelude FLNG, paving the way to a new era of LNG production. A side-by-side offloading configuration was preferred to tandem, primarily to enable the LNG transfer to standard LNG & LPG carriers. Despite the learning from loading arms design and operation in Adriatic LNG, several challenges were identified for the loading arms installed onboard Prelude FLNG:

- The loading arms are installed for the first time on a floating base, which added design criteria for operation, parked and towing phases
- Severe dynamic conditions, up to 2.5m significant wave height (Hs), with 2 bodies moving (LNGC and FLNG) required new stress analysis methods; while quasi-static analysis are relevant and acceptable for conventional onshore loading arms, nonlinear dynamic stress analysis are mandatory to capture both inertial and frequential loads applied to the loading arms and to the LNGC manifold
- The difference of elevation between the FLNG and the LNGC/LPGC, particularly valid for mega-FLNG such as Prelude FLNG, required to develop a new loading arms kinematic, the OLAF (Offshore Loading Arm Footless), to reduce the weight of articulated assembly of the loading arms and consequently the dynamic loads transferred to the LNGC/LPGC manifolds
- The integration of offshore standards, impacting the safety margin, calculation methods and welding specifications
- The safety and integrity level expectations raised from SIL2 normally considered to SIL3 impacting significantly the control systems architecture and Emergency Shut Down (ESD) philosophy
- Given the limited access offshore, the maintenance philosophy was reviewed and adapted, taking into account that the loading arms needed to be available in average every 4 days for offloading.

Comprehensive engineering studies associated with an extensive qualification plan were required to comply with the high expectations related to offshore conditions and to the full operability of the offloading system; an instrumented ¼ scale model was built to validate the theoretical studies and the operating sequences.
Two other FLNG projects have been completed by Petronas (Satu) and Golar/Perenco (Hilli Episeyo) for which similar requirements were considered, except the loading arm kinematic was similar to conventional onshore arms rather than OLAF type.

Looking at the installation phase for projects so far, each loading arm has been shipped in 5 main parts to take advantage of conventional transportation and is reassembled on a dedicated area on the dock of partnered shipyards, then lifted and installed one after the other onboard the FLNG’s. Auxiliaries, such as Hydraulic Power Units or Local Control Panels are installed onboard the FLNG’s in parallel; electric and hydraulic routing is performed to interconnect each package. Finally, the loading arms startup and pre-commissioning activities are carried out onboard the FLNG, which require to deal with a high coactivity and therefore a reduced efficiency.

Consequently, the duration of the installation and pre-commissioning phases is one of the main improvements identified from the learnings of the 3 first FLNG projects; like any other topsides modules installed onboard the FLNG, TechnipFMC has now developed a new execution plan to assemble and pre-commission the set of loading arms in a skidded submodule so the complete package is delivered to the shipyard and installed through a single lift operation onboard the FLNG.
Each loading arm and auxiliaries can be installed in the submodule, interconnected, the hydraulic lines flushed and pressure tested, the electric continuity and loop tests carried out and the loading arms tested and pre-commissioned prior to installation on the deck.

In a conventional installation process, the control system equipment is tested first during an electric & hydraulic Factory Acceptance Tests (FAT), then is followed by a loading arm FAT, with one loading arm erected and fully tested. The validation of the control systems operating with the 4 operating loading arms can be validated only during pre-commissioning at the yard, which could be a risk if not properly managed.

In addition, the validation of all operating sequences, and the targeting system in particular, imposes the loading arms to be connected to a dummy manifold placed inside the defined operating envelope, which, considering there is no LNGC aside of the FLNG, is somewhere in the air.

Hence a temporary testing platform becomes mandatory to carry out the final setting and tests campaign of the control systems, and optionally to carry out a cryogenic ESD testing.

For future projects a skid-based submodule will allow installation, startup and pre-commissioning phases to be performed at the quayside in a temporary area, limiting the activities onboard the FLNG to pure commissioning; the time spent onboard the FLNG and consequently the overall cost of the installation will therefore be drastically reduced.

The world first LNG ship-to-ship transfer happened in March 2017 from Petronas FLNG Satu, followed by Golar Hilli Episeyo in May 2018.
onboard Golar Hilli Episeyo FLNG

These first offshore operations highlighted the importance of the preparation of the equipment first, through a solid commissioning program, but also of the people, through a comprehensive training program to ramp up competencies onboard the FLNG, with the support of TechnipFMC site engineers.

Regarding the dynamics of the vessel during LNG transfer, comprehensive stress analysis is performed at design stage to screen and assess millions of sea state configurations, responses of the 2 vessels and their impact on the dynamics of the loading arms. The loading arms positions and accelerations are constantly monitored during LNG transfer, thanks to the Constant Position Monitoring System (CPMS), which calculates the loads seen by the LNGC manifold and the loading arms.

Positions records of the first offloading have been downloaded from the CPMS, converted in time traces and ran in FEA to assess real resulting loads comparatively to theoretical analysis. The correlation between position / accelerations and loads seen by the loading arms and LNGC manifold established during the engineering phase has been successfully reproduced with the site measurements, which confirms the consistency and the reliability of the stress analysis campaign.

Respectively for their second FLNG (Rotan) and for the South Coral Field in Mozambique currently under construction, both Petronas and ENI maintained their trust in TechnipFMC Loading Systems for the supply of the offloading solution, allowing TechnipFMC to pursue its offshore success story with 100% market share on offshore side-by-side loading systems.

It is anticipated that offshore gas field operators will continue to consider FLNG as a prime option for LNG export, extending to areas with more severe sea states where side-by-side offloading configuration will not provide acceptable operability.

To address the needs imposed by harsh environments, TechnipFMC’s expanded portfolio now includes ATOL (Articulated Tandem Offshore Loader) technology. ATOL, developed for tandem LNG loading applications, allows a stern-to-bow separation distance up to 115 meters for severe sea states that preclude side-by-side mooring.

ATOL, designed for LNGCs equipped with the Bow Loading Skid, is an integrated solution with an articulated piping assembly. The solution is supported by proven technology, tests, components qualifications, and conceptual certification.
Use of an articulated architecture well proven in traditional provides unique motion capability with long life expectancy and no fatigue on the cryogenic fluid conduit. The aerial configuration of the system avoids any seawater ingress into the critical cryogenic components, preventing the risk of ice formation that could affect sealing performance, operation, and reduce the life-expectancy of the cryogenic safety systems.

The ATOL system permits simultaneous connection and disconnection of all product lines, enabling setup of fluid paths in a few minutes through a set of cables and winches. The transfer is typically performed using two lines for the LNG transfer at a nominal flow rate of 16,000 m³/h – faster than in conventional onshore terminals, thereby maximizing use of LNGCs and minimizing the time required to complete this critical offshore operation. The vapor is returned using the third line, and the extremely low overall system pressure loss does not generate any restriction in the flow rate or in the management of the boil-off gas.

Once the offloading is completed, the ATOL articulated members are simply drained through a port, eliminating the need to wait several hours for the LNG to evaporate.

ATOL was designed with fully field-proven components and configured to safely meet the functional requirements for offloading in up to 5.5 m Hs. No pioneering scientific development was required – just sound engineering targeting simple and reliable solutions. Similarly, it required no revolutionary fabrication method, and the execution plan of ATOL has been fully developed in cooperation with renowned fabrication yards. The TechnipFMC network now enables an even larger range of optimized options for ATOL fabrication.

The flexible pipe based solution ALLS (Amplitude LNG Loading System) has been developed, tested and fully qualified in the 2000’s and provides a complementary tandem offloading solution, which offers an alternative solution for instance when the separation distance between the FLNG and the LNGC must be increased.

**ALLS (Amplitude LNG Loading System)**

Offloading configurations and requirements being specific to each single project, TechnipFMC can provide an unbiased comparative analysis between several different offloading solutions.

Finally, while the ATOL and ALLS systems were developed for tandem offloading of LNG onto a dedicated LNGC with a bow-loading skid, the option to use it within the HiLoad LNG Parallel Loading System (PLS) configuration is also a significant opportunity. This would allow unmodified LNGCs to receive LNG at maximum rates of typically 14,000 m³/h and a minimal pressure drop of 2 bars. This arrangement is a very powerful combination of technologies for the fast and safe transfer of LNG from the FLNGs of the future, enabling higher production rates from a given hull size, and operation in harsh seas.
HiLoad LNG parallel loading system with TechnipFMC ATOL

TechnipFMC has demonstrated its capacity to design and prove loading systems to make possible safe and reliable transfer of LNG offshore in side-by-side configuration while opening the door to operations in harsher environments with PLS and ATOL.