Low Motion Floating Production Storage Offloading (LM-FPSO): Evolution of Offloading Production Systems

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1 Introduction

Oil & Gas industries have moved in ***deeper***, ***more remote*** and ***technically demanding regions*** in the last 30 years. With increasing technical complexity of the extraction facility, the fixed cost of the Oil & Gas upstream complex also increases, but in the persistent lower-for-longer price environment there is continuing pressure to develop these fields safely while reducing CAPEX and OPEX costs.

FPSO technology seems to be promising in offering a flexible solution to explore remote Oil fields while in maintaining competitive costs. Nonetheless, Semisubmersible units, SPAR platforms and tension-leg platforms (TLPs) are also common in deepwater regions. TLPs, in particular, find application in up to 1,500m-deep water wells, but FPSO has the advantage to offer the required onboard storage capacity and offloading capability without employing a separate storage vessel or infrastructure.

The ***high dynamic motion***, generated by the rough sea condition to which FPSO units are exposed when operating in remote sea areas, makes the ***Riser System*** design more challenging. In fact, it plays a fundamental rule in determining the feasibility of the extraction of hydrocarbons exploiting remote region resources. Thus, the development of a ***low-motion FPSO*** enables the utilization of conventional riser systems (such as *steel catenary risers* and *top-tensioned risers*). The use of conventional riser technologies, is also able to improve the life-cycle and reliability of a FPSO facility: the realization of a simple and effective installation (by the means of an additional facility structure) that is able to ***oppose*** to the high dynamic forces that rough sea environment exerts on the floating structure, is a technological step change, needed to open up less accessible or economically cost-prohibitive fields.

2 Low Motion – FPSO characteristics

2.1 Structure design[1]

INTECSEA has developed an innovative technology to deal with ***rough sea*** conditions, usually associated with ***deep-water FPSO applications***, that is based on a simple modification of the conventional FPSO design.
The innovation consists of the modification of the hull shape from a ship-based shape (that showed high dynamic motion) to a ***rectangular*** one and of the ***installation*** of a free-hanging *solid ballast tank* to the floater hull as represented in the Figure 1 below.

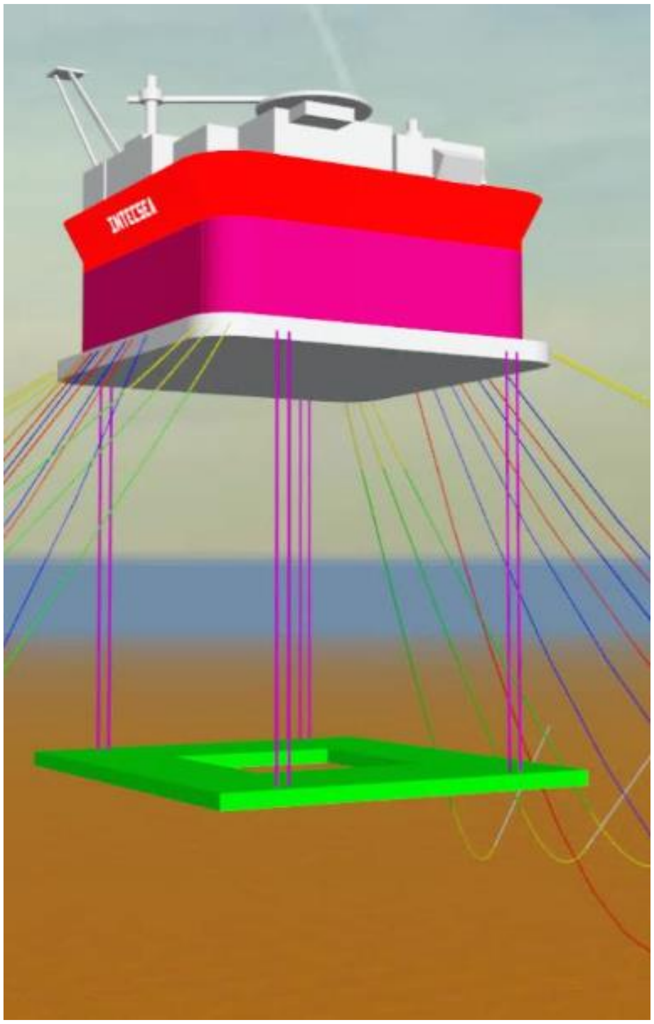

Figure 1: INTECSEA FPSO with low motion technology. The SBT is represented by the bottom green part.

[1] The Low Motion FPSO (LM-FPSO), The SCR and TTR Friendly Floater in Harsh Environment (INTECSEA report) source: http://7a55cadfc823f7512d24-d084a9f35e8709e3877657621c88363c.r68.cf3.rackcdn.com/The_Low_Motion_FPSO_(LM-FPSO).pdf

The mass of the solid blast tank (SBT), and ***additional masses added*** to it in order to increase the system performance, is chosen in order to fulfill different requirements:

- Maintain a ***positive tension*** in the tendons (further explained) in all the sea design conditions.
- Thanks to the positive tension, the ***hull-SBT displacement coupling*** is obtained for all the possible motions (i.e. heave, roll, pitch, surge, sway and yaw) as represented in the Figure 2.

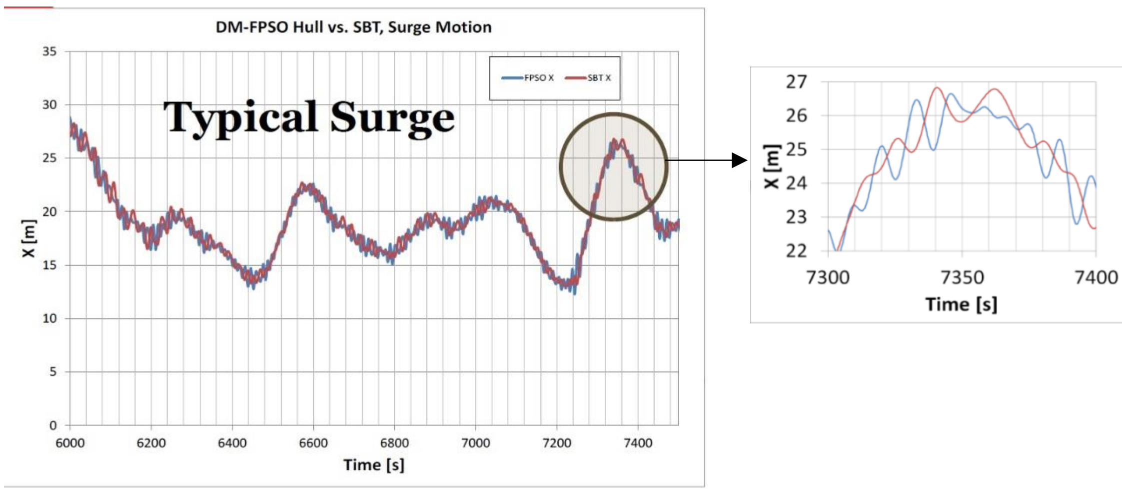

Figure 2: Surge X absolute displacement in time for FPSO hull strucutre (blue) and SBT (red)

- Obtain ***long*** movements ***natural periods.***
- ***Reduce*** the tendons ***displacement*** and the relative motion between hull and SBT. The following Figure 3 depicts the relative displacement reduction to which the LM-FPSO tendons are subjected to with respect to the tendons of a conventional TLP configuration.

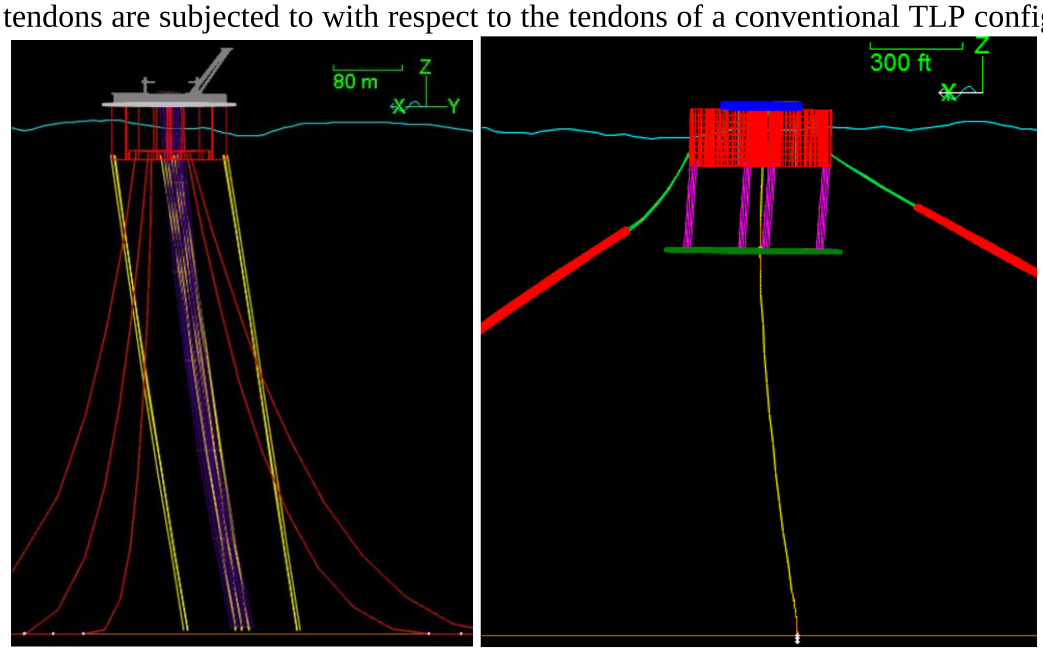

Figure 3: Simulation of tendons displacement for conventional TLP and LM-FPSO

Solid ballast tank (SBT) represents the key innovation of the technology and it is attached to the floater hull through groups of short tendons (violet lines in Figure 1).
This offers increased stability and allows a better motion response of the platform motion in wave surge, sway and yaw.
The performance of a LM-FPSO in terms of motion response is ***less than a third*** of a SPAR platform and ***similar*** to the tension-leg platform performance.
The tendons are of the ***same type*** as used in the TLPs (tension-leg platforms) applications. In the TLPs case, the buoyancy of the facility's hull compensates the weight of the platform and a cluster of tight tendons, or tension legs, is required, to secure the structure to the foundation on the seabed. The foundation is then kept stationary by piles driven into the seabed.
The tension leg mooring system allows for the hull horizontal movement upon wave disturbances, but does not permit vertical, or bobbing, movements.

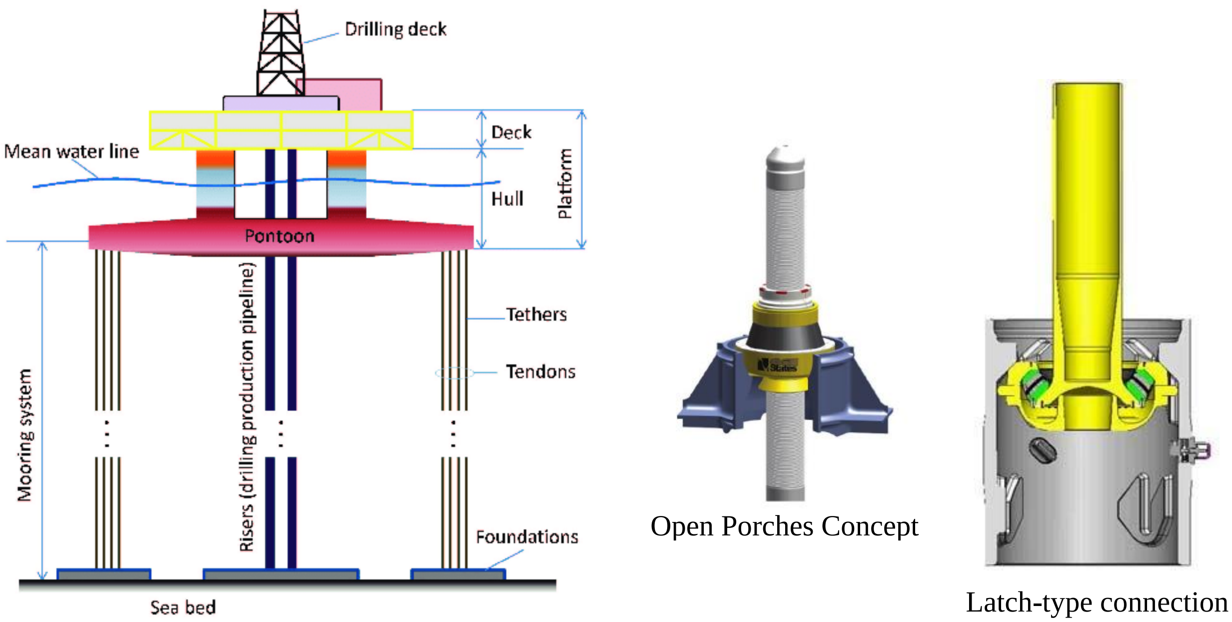

Figure 4: Tension-leg platform (TLP) scheme[2], Tendons top connection[3] to the hull (open porches) detail and tendons bottom connection[4] (latches) detail

In

Figure ***4*** a simplified sketch of a TLP tendons configuration is reported. Tendons are connected to the hull structure via ***open*** or ***closed porches*** and to the seabed (bottom connection) via latch type connection that allows them to rotate.
In the translation of TLPs tendons configuration to SBT tendons for LM-FPSO application, the same ***porches/latches*** connection scheme is reproduced, but the seabed is substituted by the SBT.

[2] Reza, Arash & Sedighi, Hamid M. (2014). Nonlinear Vertical Vibration of Tension Leg Platforms with Homotopy Analysis Method. Advances in Applied Mathematics and Mechanics. 7. 10.4208/aamm.2013.m314.
[3] Integrity Management Process of Tension Leg Platforms, BSEE Project Number: E17PC00018, September 2018
[4] D'Angelo, Luis & Viteri, Martha & Bradberry, Ross & Grimont, Raphael. (2015). Technology Qualification of Tendon Connectors for Deep and Ultra Deep Water Application. 10.4043/26146-MS.

2.2 Riser configurations

A ***production riser system*** consists of conductor pipes connected to floaters on the surface and the wellheads at the seabed. Also, it is the primary device of the floating production system to convey fluids to and from the vessel. It is one of the most complex aspects of a deepwater production system.

There are 4 types of production rise systems:

- *Steel Catenary* riser (SCR): The achievement of a low motion behavior for FPSOs makes feasible to utilize ***Steel Catenary Risers*** and ***Top Tension Risers*** (TTRs) as riser typologies.
  Steel Catenary Risers were developed starting from the '90s; they consist of a long steel pipe that connects the well head with the off-shore facility. Whenever a very long steel structure, as a steel catenary riser is, lies in a fluid environment, as in the sea, its shape follows the mathematical representation of a ***catenary*** curve, no matter what and how strong the material's stiffness is[5].
  Such a type of risers is particularly suitable for wet-tree application; it is considered the most robust riser solution thanks to its simplicity, long history and low failure occurrence. SCRs are preferred because they represent the minimal CAPEX plus OPEX cost commercial solution and on top of this economic advantage, they show high robustness and long life-cycle compared to other flexible but lees robust risers.

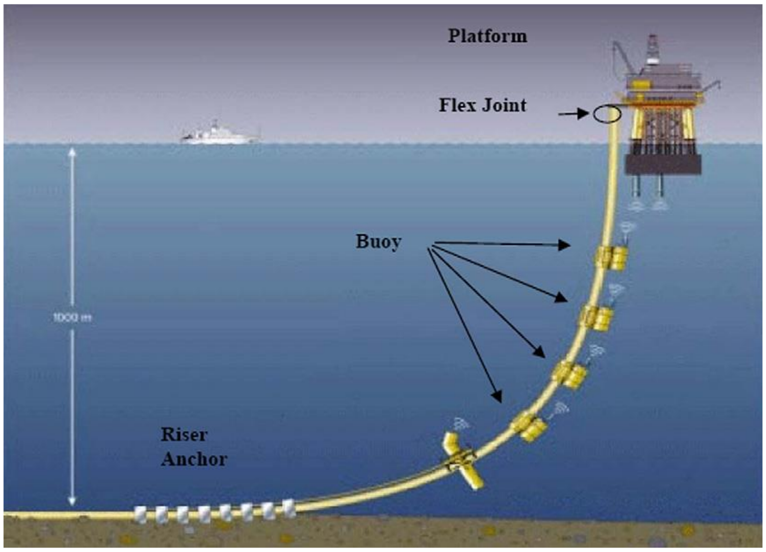

Figure 5: Steel Catenary Riser configuration

[5] https://petrowiki.org/Production_risers and https://www.offshore-mag.com/rigs-vessels/article/16763270/field-platform-specifics-for-the-design-of-steel-catenary-risers

- *Top Tensioned* riser (TTR): They are constituted by long cylinders used to link the seabed to a floating platform. Their distinct characteristic is the presence of ***tensiometers*** in the platform; they are used to remove the excess of their apparent weight in order to improve the stability and to keep the riser in the desired position[6]. The tension requirements for production risers are generally lower than those for drilling risers. The risers often appear in a group arranged in a rectangular or circular array. Figure 6 shows the TTRs configuration.

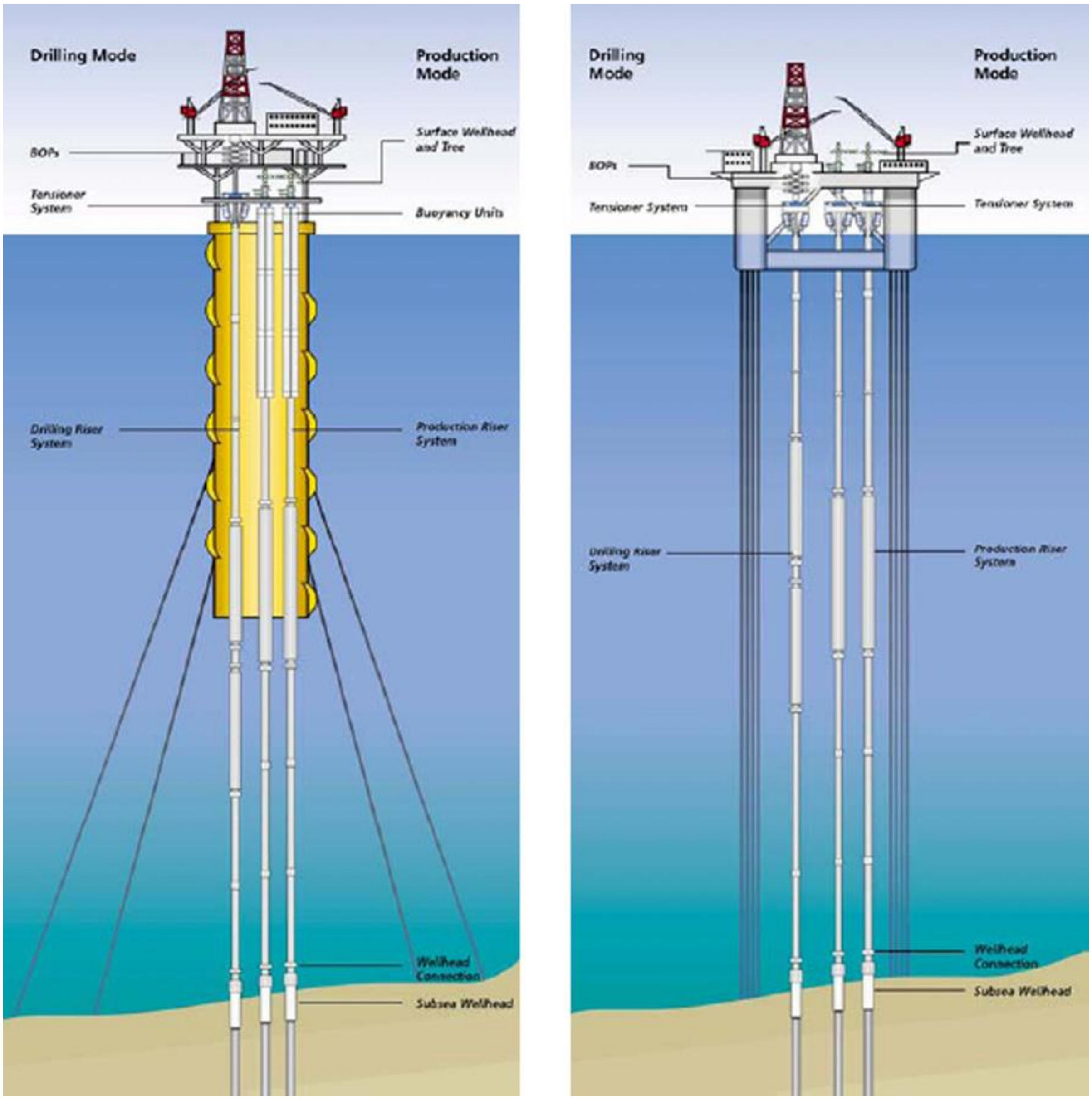

Figure 6: Top Tensioned Risers Used on Spar and TLP7

[6] http://www.oilfieldwiki.com/wiki/Top_Tensioned_Riser_Systems
[7] World Oil, Composite Catalog of Oilfield Equipment & Services, Fourty Fifth ed.,2002, March.

- *Flexible* riser: They are one of the common types of production risers. Their configuration varies, depending on the water depth and environment. Flexible pipes have traditionally been limited by diameter and water depth; however, many deepwater[8] projects in the Gulf of Mexico and Brazil are now employing SCRs for both export and import risers. The choice between a flexible riser and an SCR ***is not clear cut***; in terms of flexible risers CAPEX cost, compared to SCR of the same diameter, they are more expensive in the purchasing phase, but less expensive in installation and more resistant to dynamic action.

- *Hybrid system* riser: They accommodate the necessity to deal with the high relative motion between the floating structure and a rigid metal riser, by connecting them with flexible jumpers. The buoyancy of a hybrid system is provided by the addition of synthetic foam inside the central tubular section of the risers.

3 Conclusion

Through the development of a LM-FPSO all the advantages of a conventional floating system (i.e. less subsea structure, lightweight installation, operation flexibility, storage and offloading capabilities) are maintained while offering superior motions and improved dynamic stability.

LM-FPSO offers easiness in constructability thanks to the simple rectangular box-shape hull and also facilitates the topside layout. The presence of the free-hanging solid ballast tank (SBT) is an enabling factor for large diameter SCRs on FPSO in deep-water and harsh environment, instead of expensive and sophisticated riser systems[9].

The challenge for the industry is whether it can reconcile the seemingly incongruent requirements to develop fields in increasingly greater depths and hostile conditions while at a significantly reduced cost. INTECSEA modeling estimates that overall field development capex savings of up to 19% is achieved when comparing a conventional FPSO unit with the wet-tree LM-FPSO with SCRs and a dry-tree LM-FPSO with TTRs.

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[8] Water depth more than 500m

[9] Mansour, Alaa M., Zuccolo, Ricardo, Peng, Cheng, Wu, Chunfa, Greiner, Bill, Kumar, Dhiraj, and Azevedo, Jefferson. "An Innovative FPSO Design Hosting SCRs in the North Sea Harsh Environment." *Proceedings of the ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering. Volume 1: Offshore Technology; Offshore Geotechnics*. Busan, South Korea. June 19–24, 2016. V001T01A051. ASME.