Digital Twin of Upstream Oil & Gas Production Facilities

The design and operation of upstream oil & gas production facilities, in particular Floating Production Storage and Offloading facilities (FPSO) and deep offshore projects, face technical challenges that require numerous detailed process, control, safety and flow assurance simulations to secure investments and maximize production. Such calculations rely on a holistic understanding of production processes that an integrated digital model from well-bore to topside facilities can supply.[i]

First principles Digital Twin

Digital twin refers to a digital replica of physical assets. High-fidelity dynamic simulators are offline digital twins that provide a digital representation of physical processes and their dynamics. They are based on physicochemical knowledge models and the first principles of chemical engineering, i.e. conservation of mass, momentum and energy.

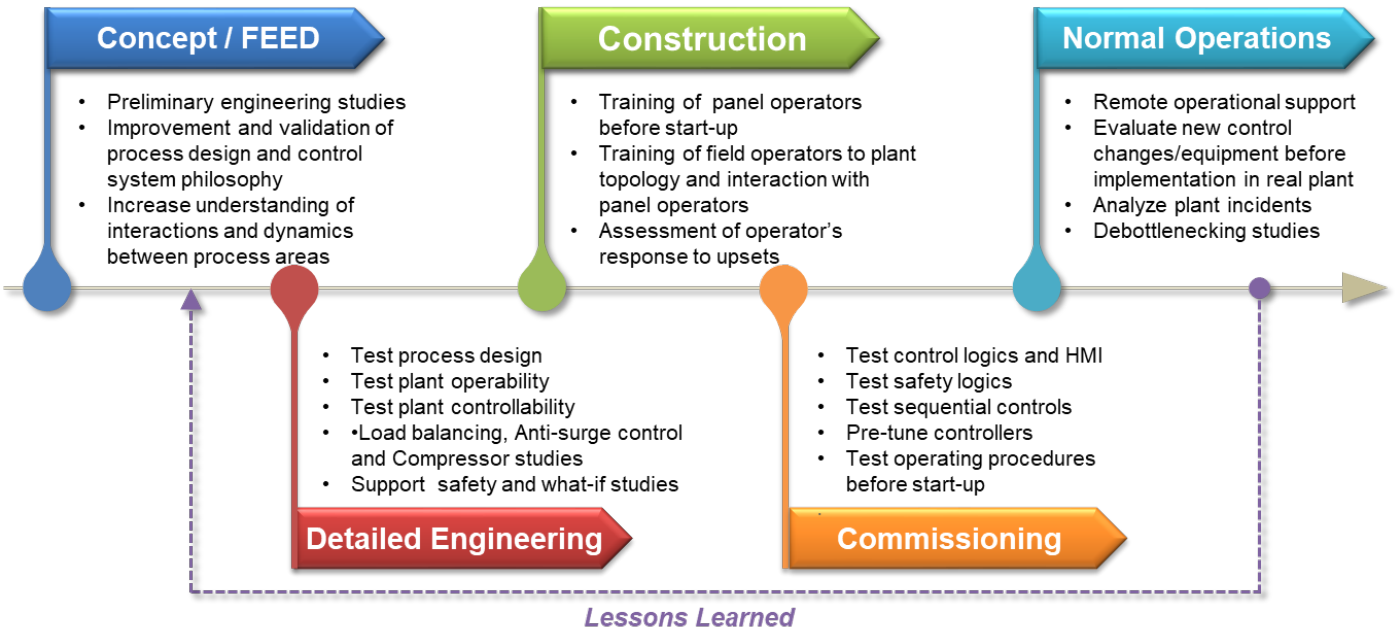
Dynamic process models are built with a high-fidelity simulation platform providing simulation solutions based on physically-based fluid dynamics, rigorous thermodynamics and equipment models. They integrate the process model as well as the associated control and security logics. They use a global resolution of the hydraulic network to provide a fully consistent state of the process at every time step.

Modern computing tools make it possible to develop dynamic simulators that represent a complete industrial process unit and its behaviour over time.

Multi-Purpose Dynamic Simulator (MPDS) Concept

A MPDS is used throughout the different engineering and operational phases. It is developed and leveraged through the entire project cycle from conceptual, Front End Engineering and Design (FEED), through commissioning phases all the way to operations and long-term operations support.

The amount of technical information available and the complexity of the model increases continuously from the conceptual phase to commissioning, and the simulator evolve in parallel incorporating updated technical information into the model.



The dynamic simulator is built at the early design stage, starting from critical equipment such as centrifugal compressors and separators, and expanded throughout the design and construction cycle, providing a consistent set of information dedicated to each critical choice to be made during the design phase. The modular design of the simulation platforms allows a "build as you go" approach, adding and updating equipment and control systems as new information becomes available.

Based on the chosen design, the virtual plant is used to develop and validate reliable, safe and optimal operating procedures before the actual plant comes on line. To aid in safe and effective commissioning, the virtual plant is employed to verify control & safety logic, pre-tune instrumentation, and train operations personnel.

Once the plant comes on line and normal operations begin, the digital twin plant is then used in a variety of ways to improve day-to-day performance. This is accomplished by testing, validating and instructing the operators in operating practices and optimization theories, for anticipating upcoming production changes, and testing various operating strategies.

The next sections describe different uses of a digital twin of a FPSO.

High Pressure (HP) and Low Pressure (LP) Flare Studies

This simulator developed for these studies includes flare lines from HP and LP flare drums to SDVs. Main objective is to assess opening time of fast opening BDV's downstream HP and LP flare drums during flaring events. Scenarios include 1st stage separator blocked outlet case, both HP compression train trip case, gas blow-by from the 1st stage separator to 2nd stage separator and 2nd stage separator blocked outlet.

High Integrity Pressure Protection System (HIPPS) Studies

The simulator includes production wells & manifolds, separators, export lines, ESD valves and HIPPS. It is used to investigate various overpressure scenarios and evaluate robustness of the protection system employed in case of overpressure coming from the production risers and to define the response time of the HIPPS system needed for 1st stage separator and HP flare protection.

Topside Studies

The holistic model includes flowlines and production manifold, oil production & stabilization, LP/HP compression and gas dehydration, gas lift and gas export, fuel gas system, produced water system, wash tanks, HC blanket gas recovery system and HP and LP flare System.

It is used to check the design and system response in case of emergency, flow or pressure disturbances and manual operation. Scenarios include HP and LP compressor suction SDV closure, trip of HP or LP compressor(s).

Operator Training Simulator (OTS)

The OTS model is based on the holistic engineering model. It includes subsea loops, topsides crude oil treatment, produced oil storage, gas treatment and export and produced water treatment. The integrated subsea-topside model also includes emulation of the control and safety logics, complex sequential controls such as Overall Control of Wells and Risers (OCWR) and Overall Control of Cargo Tanks (OCCT) and associated Human Machine Interface (HMI). The primary objective is the training of operators prior to and after start-up activities of the subsea and topside systems.

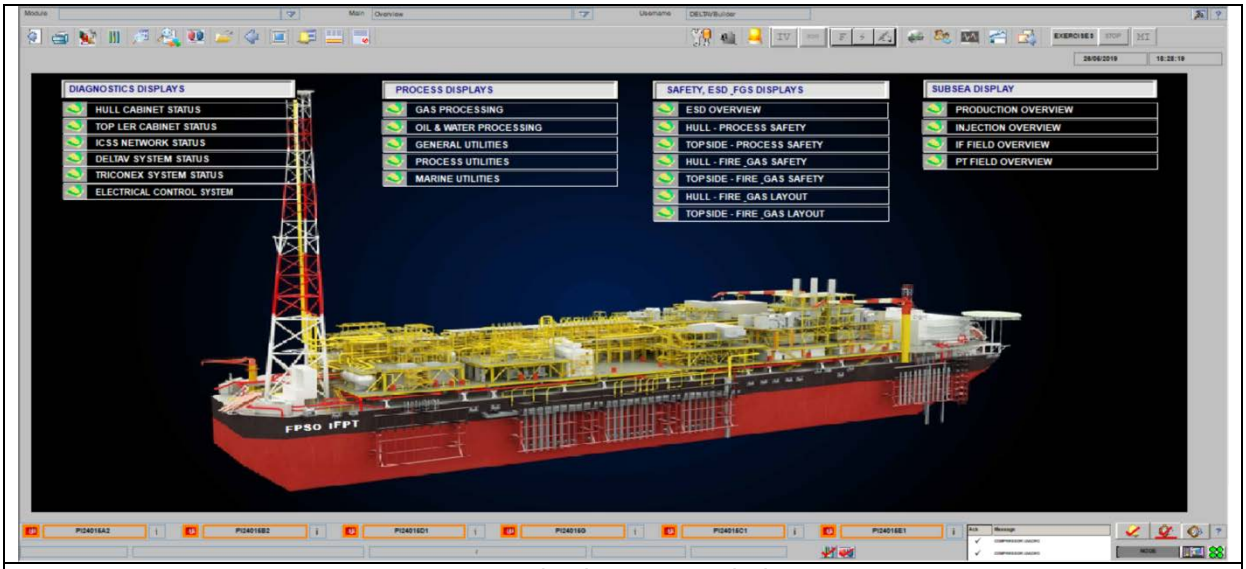
With the OTS, the operational staff can practice without any risks for the plant and as often as necessary the actions that ensure safe plant operations under rare or exceptional circumstances, and consequently become confident in his ability to operate the plant efficiently and safely under upset conditions.

Panel operator certification program using OTS

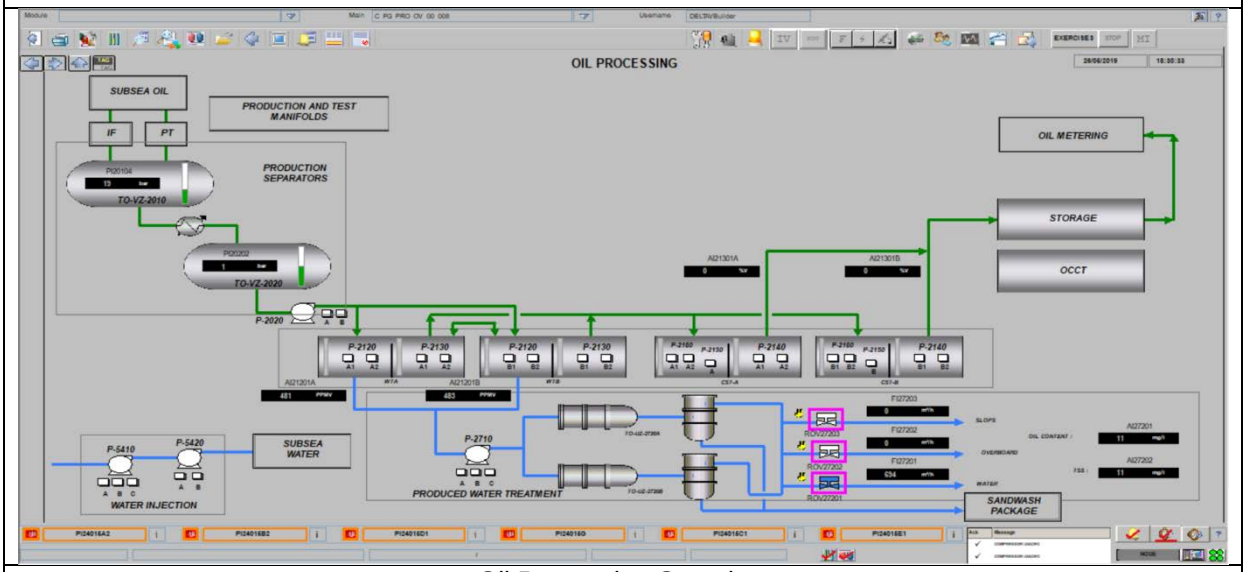
IFP Training developed with the integrated subsea-topside OTS a 35-day panel operator certification program[ii]. The program is based on extensive hands-on practice on dynamic simulators more than 50% of the time and with multiple case studies based on real events.

The training scenarios have been jointly developed by Total, IFP Training and CORYS\RSI and include:

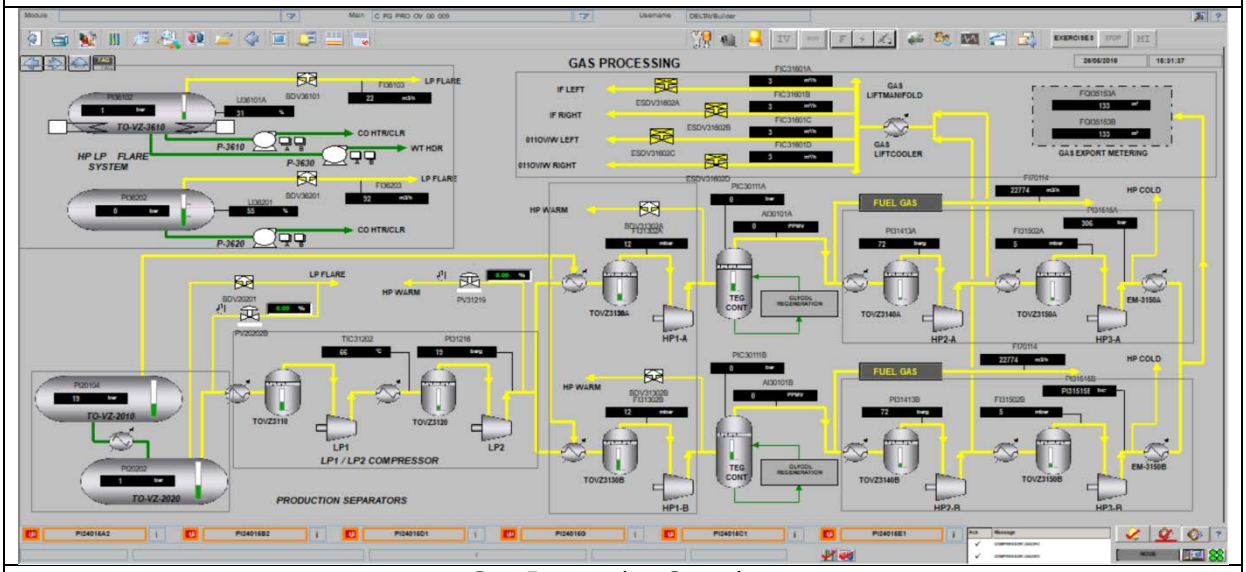
- Managing process control loops and automats, such as running/standby pump switch
- Managing compressor start-up and shutdown with automatic sequences
- Complete plant start-up and shutdown without flaring
- Monitoring a pressure build-up to understand the structure and function of safety systems
- Troubleshooting and investigation to find out the root cause of upsets by using trends and all the available DCS HMI tools
- Consequences of operating parameter modification on centrifugal compressors and pumps
- Well operation in manual or automatic control system including start-up/shutdown/preservation
- Managing emergency shutdown situation with or without depressurization



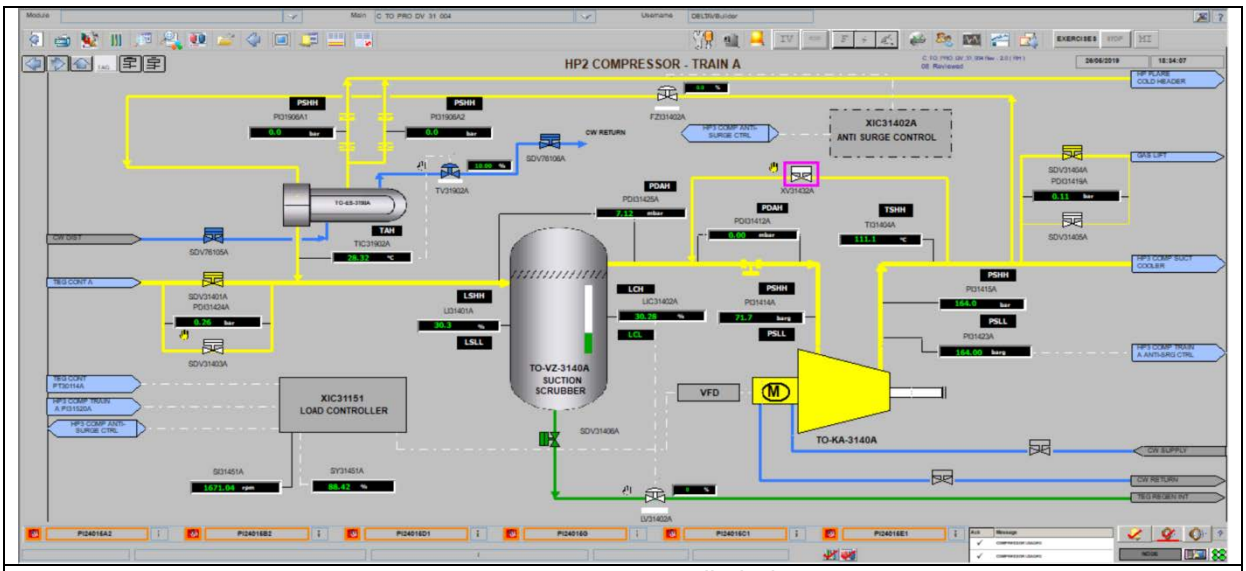
FPSO Simulator General View



Oil Processing Overview



Gas Processing Overview



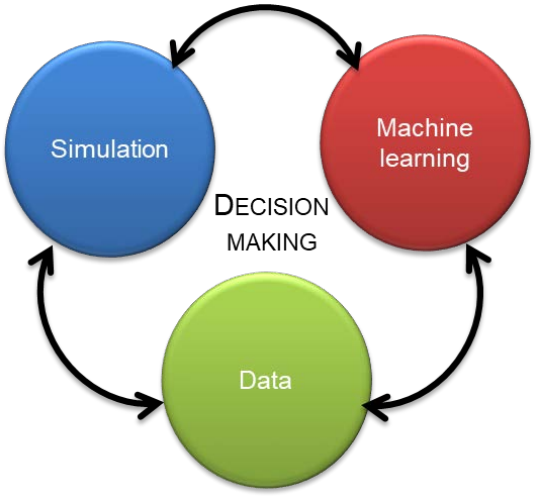
HP2 Compressor Detailed View

The extensive practice on simulators allows participants to adopt the fundamental methodology and philosophy to operate production facilities from the control room.[iii] Upon completion of the course, trainees are convinced of the absolute necessity of a proactive behaviour and are able to analyse and react methodically to anomalies, incidents and emergency situations in a safe manner mastering emergency procedures.

The integrated and sub-system simulators are also used for production supervisor and production superintendent certification programs.

Hybrid Digital Twins – New uses and benefits

Hybrid approach combining first principle physics-based and data-driven approach could potentially leverage the strengths of both approaches and provide superior insights.



Knowledge-based models bring constraints based on nonlinear physical laws to statistical models.

First-principles dynamic process model could be tuned with advanced numerical technics and artificial intelligence to match real plant data.

Combining machine learning on historical data and high fidelity dynamic simulation might provide better solutions for a larger range of operations with a self-calibrating “first-principles” model allowing:

- Real-time monitoring and predictive maintenance: When a divergence will be noticed between online dynamic model and real plant data trend, this could highlight a potential instrument or equipment failure or a manual action in the field not recorded by plant historian.
- Look-ahead and what-if study: The self-calibrating online model can be used to initialize the offline model which can run faster than real-time providing look-ahead predictions of critical variables, allowing what-if scenario
- Virtual Sensors: Dynamic online models could provide virtual sensors for temperature, pressure, flow rate and compositions, Composition virtual sensor could be used as backups of online analysers which require costly maintenance.
  Virtual sensors will generate additional simulated data that can be added to real plant data for machine learning

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[i] Benefits of Life Cycle Dynamic Simulation for FPSO Projects & Offshore Developments, Philippe Thiabaud, Copyright 2011, Society of Petroleum Engineers

[ii] Panel Operator Certification, PROP/PANELOPGB, https://www.ifptraining.com/course/panel-operator-certification.html

[iii] Develop best practices of control room operation using a complete dynamic simulator of O&G production facilities, Patrick Steiblé, presentation at SIMTECH Conference 2017,