Enhancing PDH Plant Performance with Real-Time Dynamic Simulation Models

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inprocess 20 years

Agenda

- Inprocess in brief
- Motivation and Project Background
- Technical Solution of the Digital Twin
- Use Cases and Value to Operations
- Summary

Inprocess in Brief

Since 2006 helping the processing industries in solving design and operational issues by applying process simulation

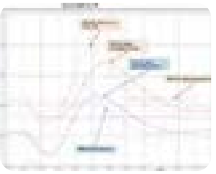
our **core business** is Process Simulation

enthusiastic about **sharing our knowledge** with our clients

all technologies (process simulator and control system)

2006 est. in Barcelona by domain experts	**65 countries** worldwide footprint	**160+ / 120+** employees / process simulation engineers
600+ executed projects	**110+** OTS / MPDS Projects	**400+** Training courses

Inprocess Solutions and Services



Engineering Studies

- Dynamic Simulation Studies (compressors, control,…)
- Flare Systems Analysis
- Flow Assurance Studies

Operators Training Simulators

- Multi-Purpose Dynamic Simulator / ICSS Emulators
- 3D Virtual Reality
- Foundation Training Courses

Process Digital Twins

- Real-Time Simulators
- What-if Analysis
- Anomaly Detection

Engineers Simulation Training

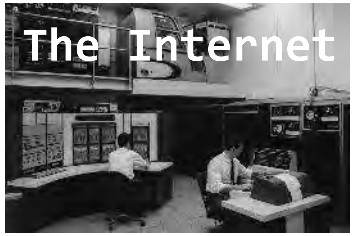
- Steady State, Dynamics
- Introductory, Intermediate, Advanced
- Upstream, Natural Gas, Refinery, …

Motivation and Project Background

The Blind Spots of Human Judgment

1876 Why talk remotely when you can send a telegram?

1977 *There is no reason for any individual to have a computer in their home.* – Ken Olsen, co-founder of DEC



1989 *The truth is no online database will replace your daily newspaper (…) and no computer network will change the way government works.* – Clifford Stoll (Newsweek, 1995)

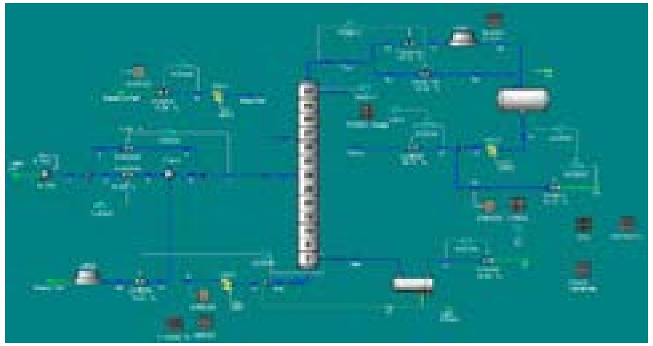
Are we underestimating Process Digital Twins today?

Inprocess’ Approach to Digital Twins

- Digital Twins (DTs) are virtual copies of physical assets and their operating behaviours
- This definition has several points of view:

Contextualized 3D models

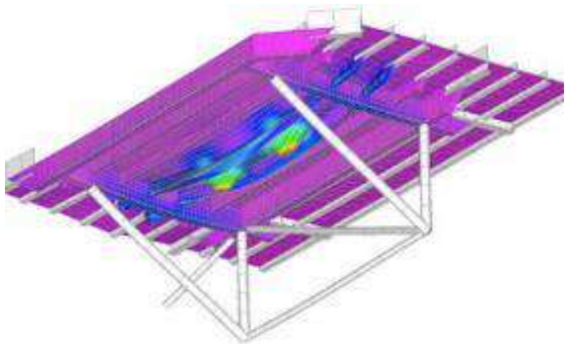
First-Principles Models



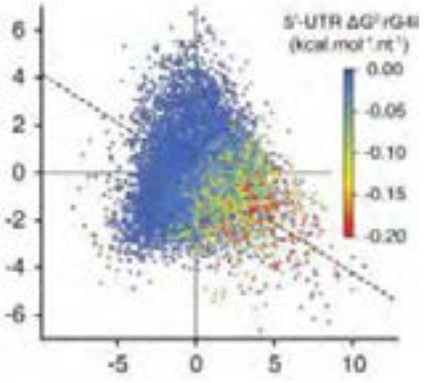
Centuries of Physics, Chemistry and thermodynamics knowledge are consolidated here!

Digital Twins

Mechanical and structure models



Empirical Models (data fitting)



Lifecycle Process Digital Twin

Plant lifecycle

Conceptual Design > Basic Design > Detailed Design > Set-up > Commissioning > Operation > Maintenance and Modernization

1 Design Simulation

2 Virtual commissioning and simulation-based engineering

3 Operators Training

4 Operation-associated decision support and optimization

Off-line

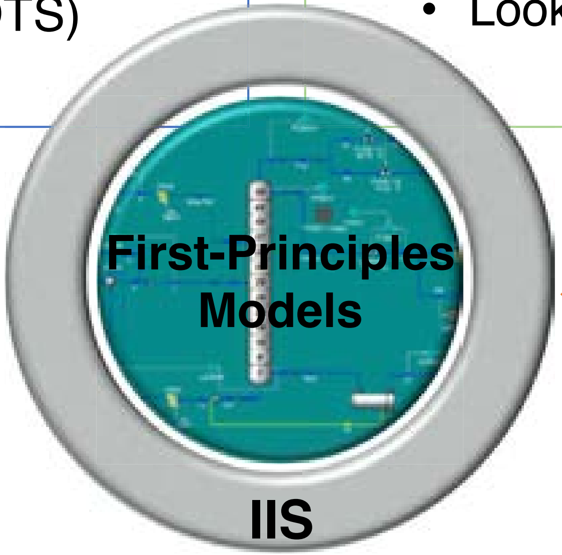
- Engineering Design validation
- Control Narrative & Procedures validation
- ICSS validation & tuning
- Operator Training Simulators (OTS)

Simulation Models can be re-used from previous studies or OTS.

On-Line

- Equipment Load & Efficiency Monitoring
- Inferentials
- Bad Actors Detection
- Look-ahead & What-if

Simulation Models can be saved and re-used for other purposes: off-line Engineering studies, etc.



Communication

DATABASE

Sensors Data

ASSET

Two main approaches for implementation

GREENFIELDS

Dynamic process model

Engineering Studies

Early OTS

ICSS Checkout

DC OTS

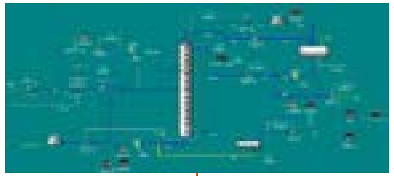
Model reuse

Dynamic process model

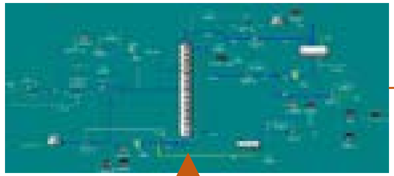
DIGITAL TWIN APPLICATION

BROWNFIELDS

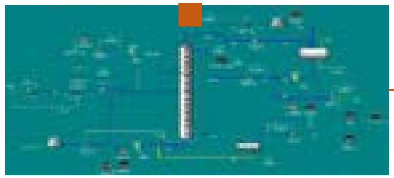
Dynamic process model



Engineering Studies



DIGITAL TWIN APPLICATION

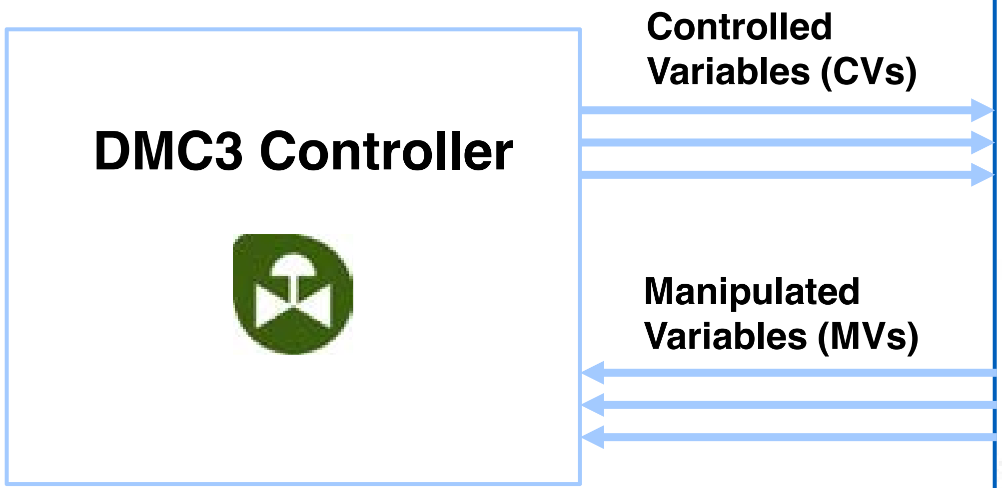


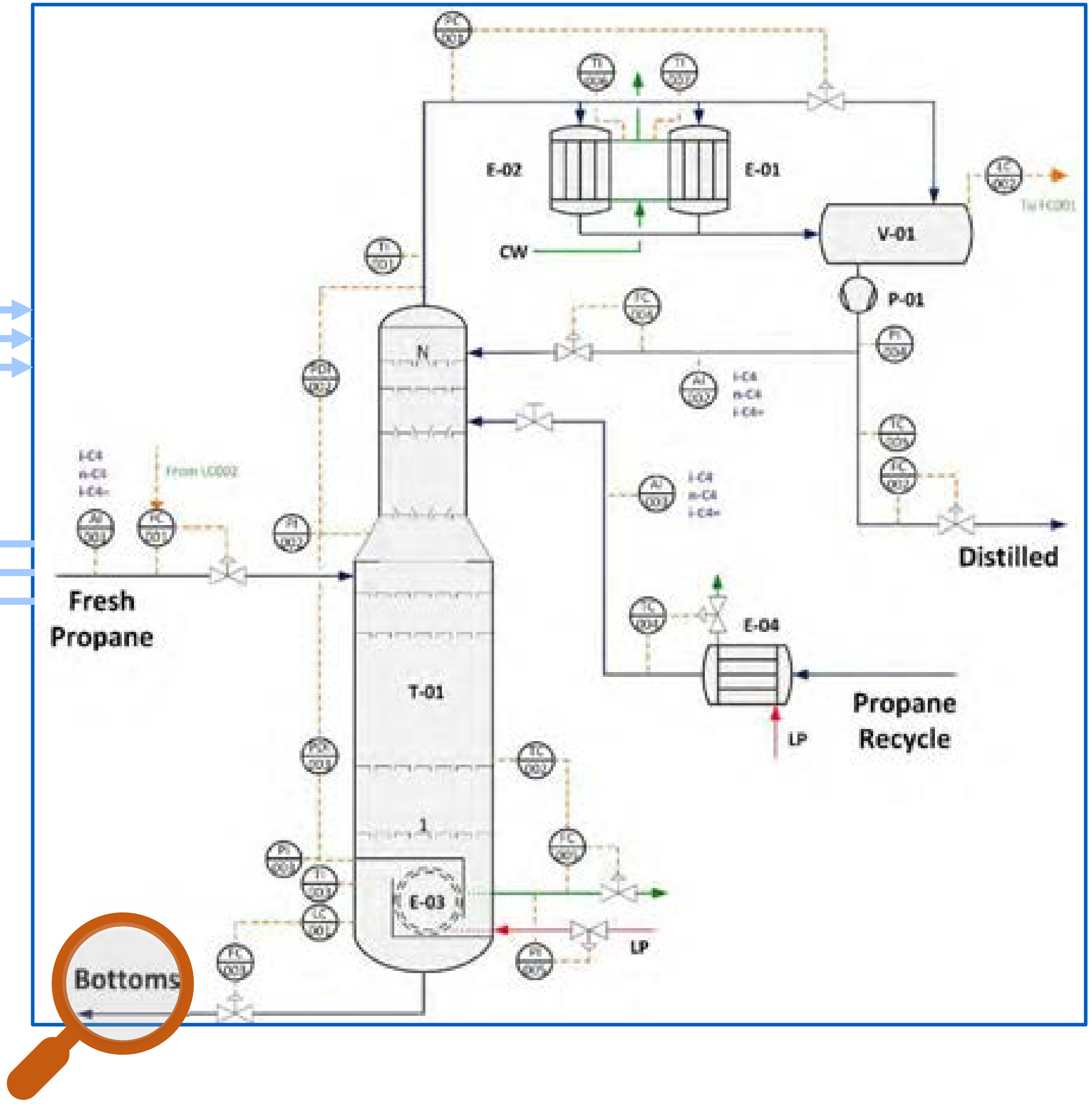
Direct-Connect OTS or Emulated OTS

Motivation and Project Background

Process Overview

In a Propane DeHydrogenation (PDH) plant, the front-end section consists of a Depropanizer that receives raw propane containing variable impurities.





Current Challenge

The APC engineer requested a **reliable** estimation of the impurity (C3) in the column bottoms.

Current Limitations:

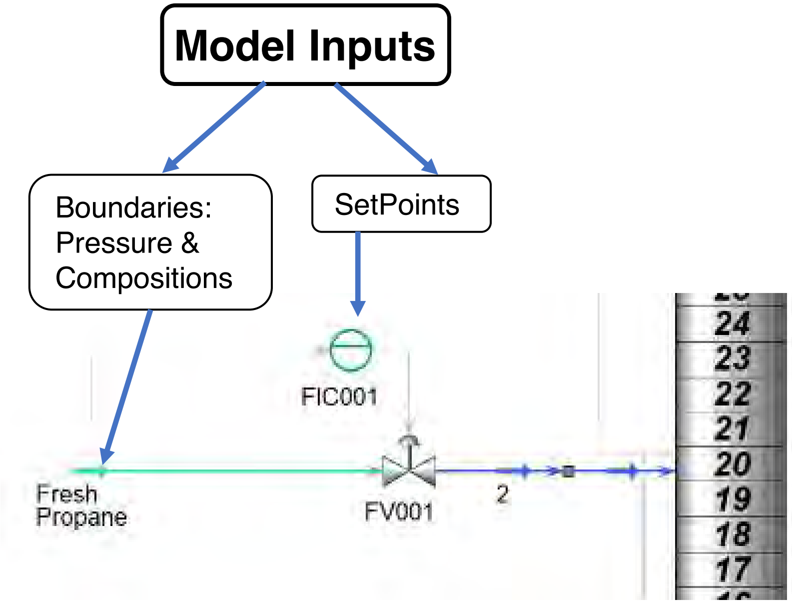
- ❌ No online analyser available
- ⌛ Delays in lab analysis
- Measurement inaccuracy due to sample vaporization

Dynamic Simulation Study: Depropanizer

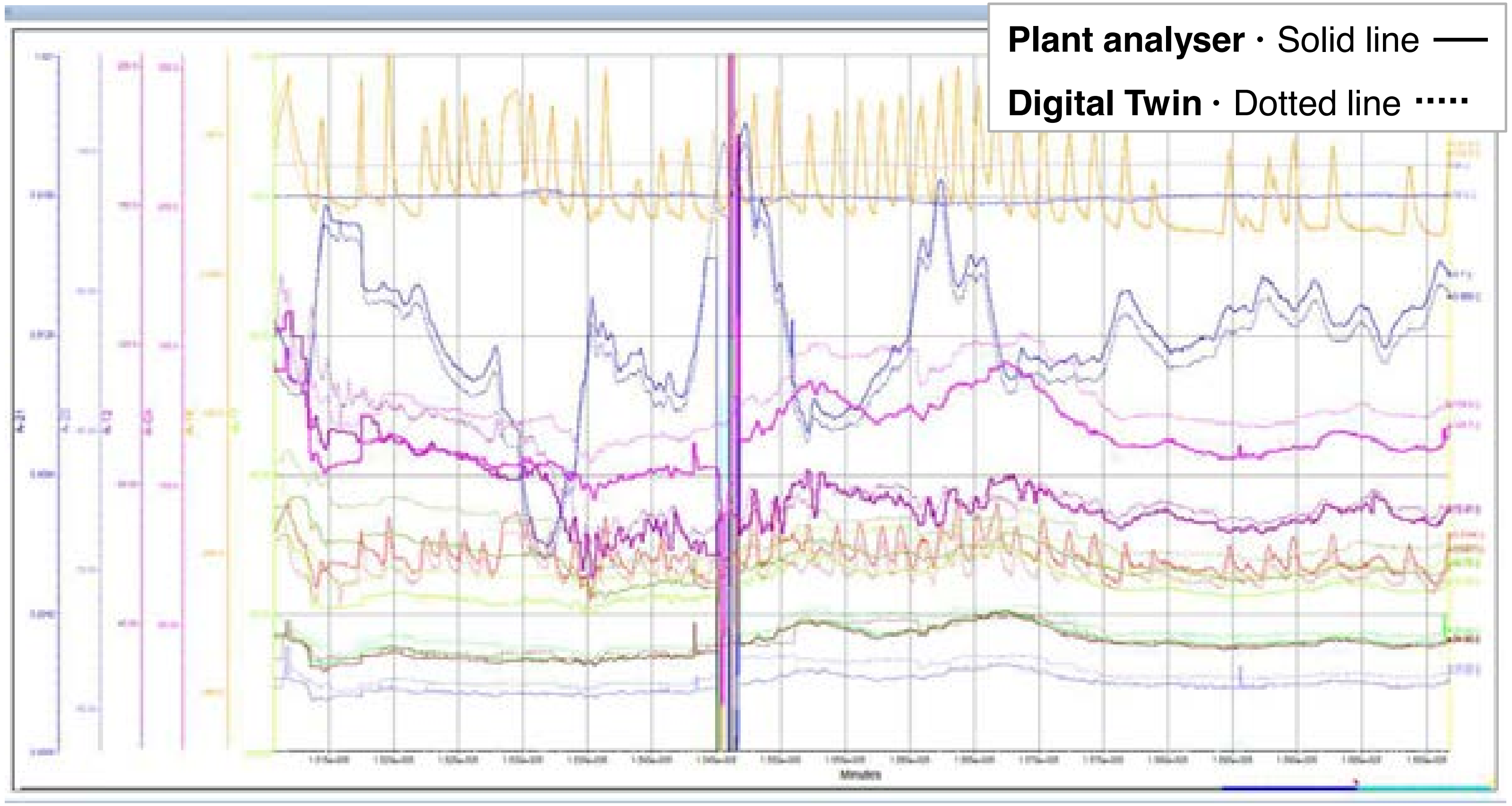
Model run against Historical Plant Data (Offline)

Any dynamic model can be **easily adapted** to run against historical plant data from a .csv file (i.e. 1 week 10 sec sampling).

A quick proof of concept demonstrating the potential of the Digital Twin **without the complexity** of hardware, software, or IT infrastructure.



The dynamic model **accurately** reproduced all sensor and analyser data for 1-week period.



Motivation and Project Background

Operators Training Simulator for 3 columns:
Depropanizer, Deethanizer & C3 Splitter

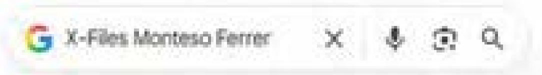
Plant Data
1 week 10 sec sampling
(.csv)

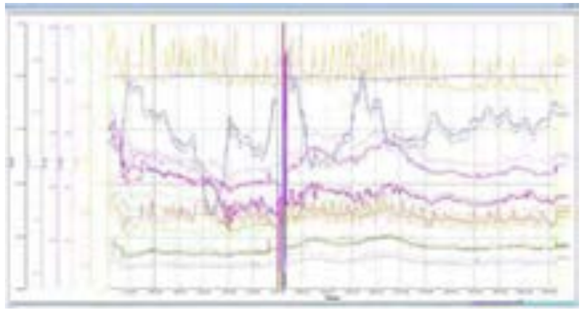
Dynamic Simulation Study: Depropanizer

Model run against Historical Plant Data (Offline)

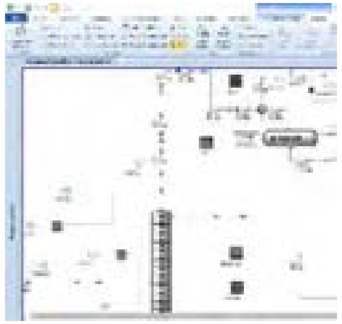
Digital Twin: Depropanizer

Digital Twin: Deethanizer & C3 Splitter

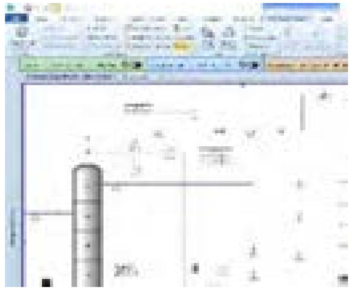




The dynamic model accurately reproduced all sensor and analyser data for that week.



Dynamic model running 24/7 on customer server, with an update frequency of 2 sec.



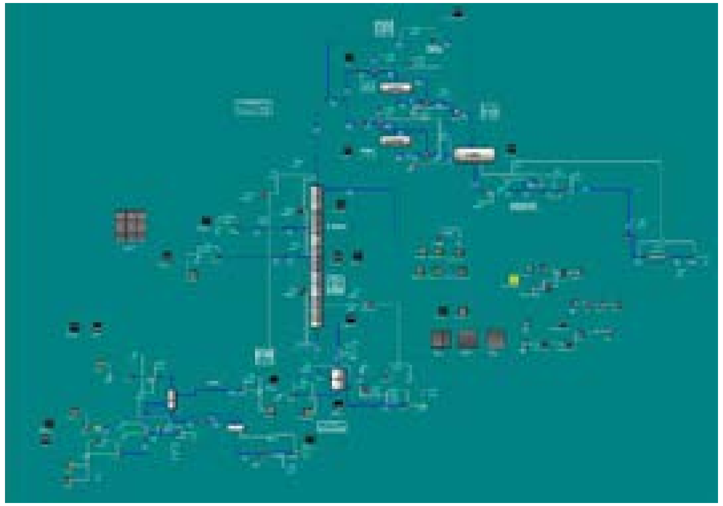
Technical Solution of the Digital Twin

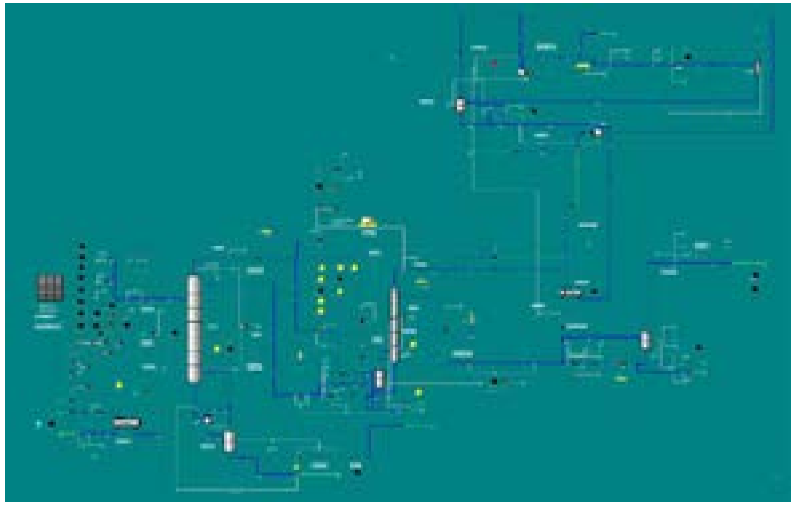
Steady State vs. Dynamic for Digital Twins

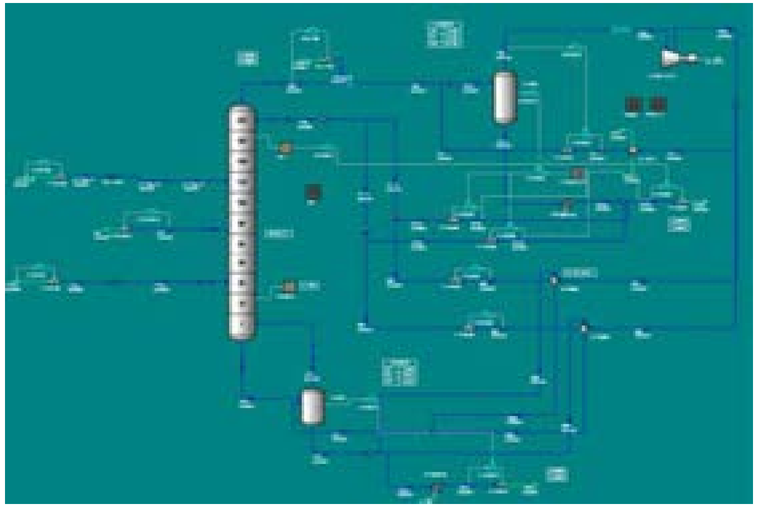
Item	HYSYS STEADY-STATE	HYSYS DYNAMIC	Dynamic advantage
Simulation equation solver	Time doesn't exist. Not Pressure driven. Solver iterate until converge.	Time is represented. Flows are driven by pressures. The model is always converged at every time step of the integrator.	Represent wider operating conditions (e.g. reverse flows). Higher robustness.
Represents Imbalances?	✗	✓	Transient states are represented.
Solving frequency	10 min to 1 hour (when steady conditions).	2 to 10 seconds (always).	More granularity. Better instrumentation fault checks.
Mass/Energy inventories for each phase	✗	✓	Better representation of the plant inertia, evolution of properties (qualities, Dew point, RVP).
Elevations/Static Head	✗	✓	Realistic pressure profiles and flows (Valves DP, Pumps NPSH...).
Control and Safety valves	Simplified.	Detailed (same degrees of freedom of the plant).	Easier to match plant data. Realistic dynamic representation related to control and safety events.
PID controllers	✗	✓, with same tuning parameters and algorithm type.	Possibility to study Process Control or Operating Procedures.
Non-equilibrium conditions	✗	✓ (Holdup flash efficiency calculation).	Better representation of Dynamic VLE phenomena.
Look-ahead/What-if capabilities	✓(Final state and quick results). Intermediate states (e.g. flaring episode) could be outside the operating window.	✓ (Time to obtain results depends on the model size / computer hardware).	Intermediate states are calculated.

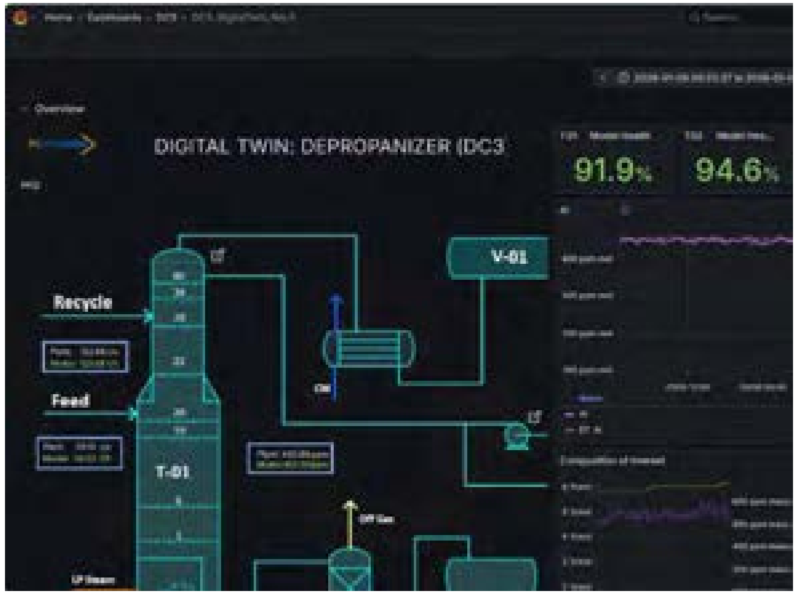
The Digital Twin application comprises 3 dynamic models

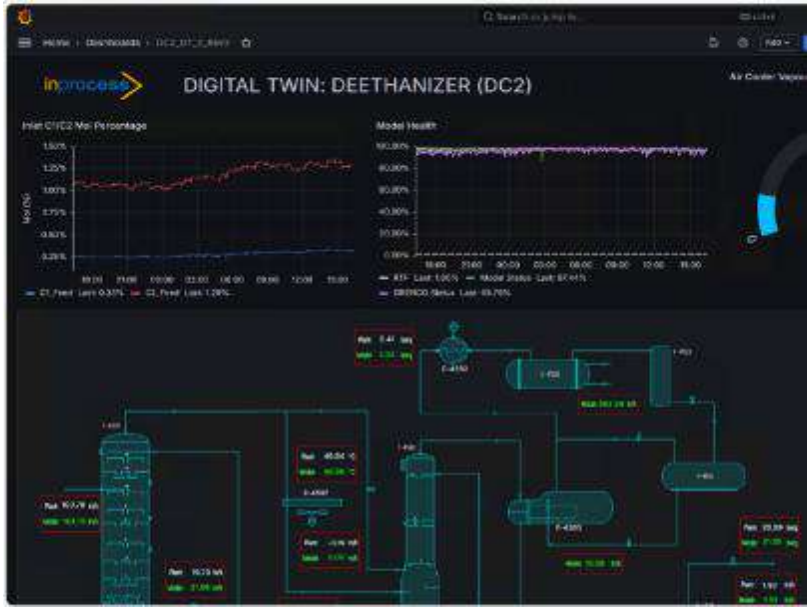
Depropanizer	Deethanizer	C3 Splitter

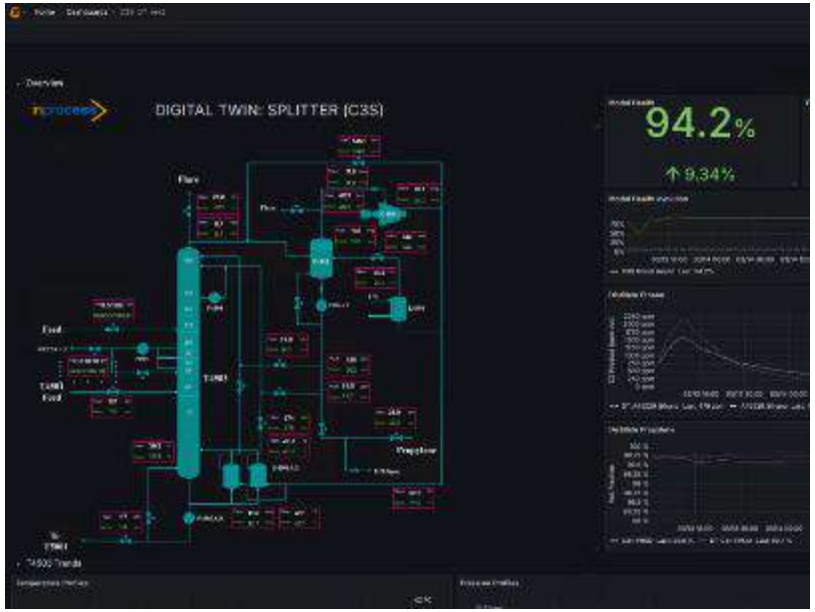












Architecture

Model Structure

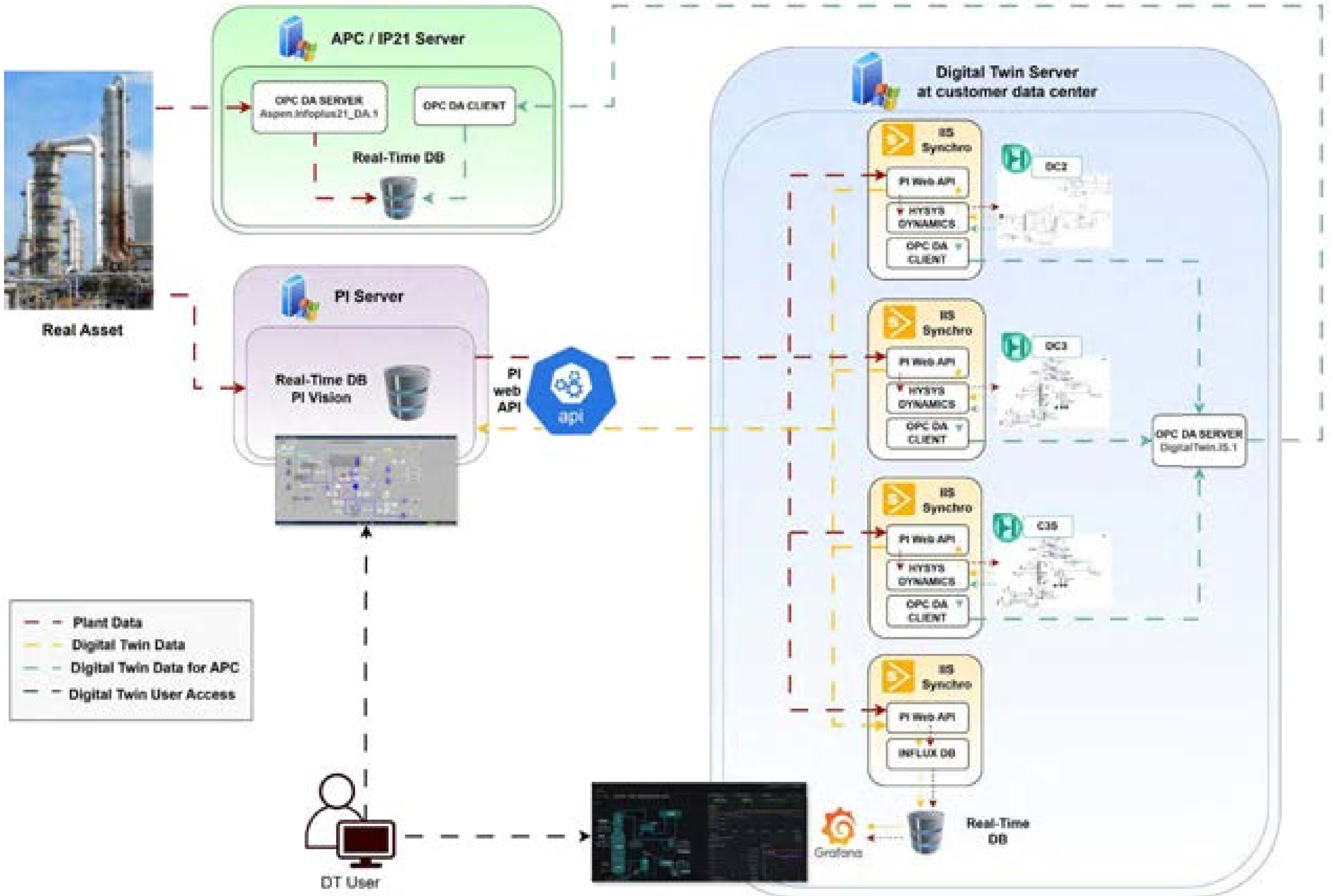
- **3 distillation column** flowsheets
- Model remain **visible** while DTs are running

Data Synchronization

- Data exchange through **OPC DA** and **PI Web API**
- Read/Write Interval: **2 sec**

User Dashboards

- Grafana
- PI Vision
- Web interface



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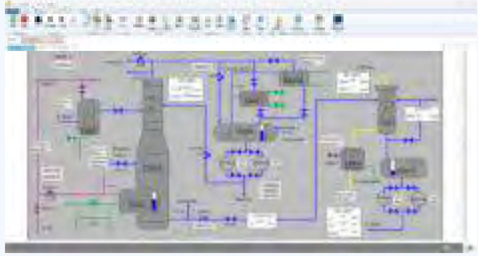
Digital Twin Interfaces

Inprocess allows user to configure the Digital Twin application with **three dashboarding** options

Custom App Dashboards

- Web interface
- Desktop client



Plant Historian Visualization

- Aspen Web 21 / PE
- PI Vision
- …

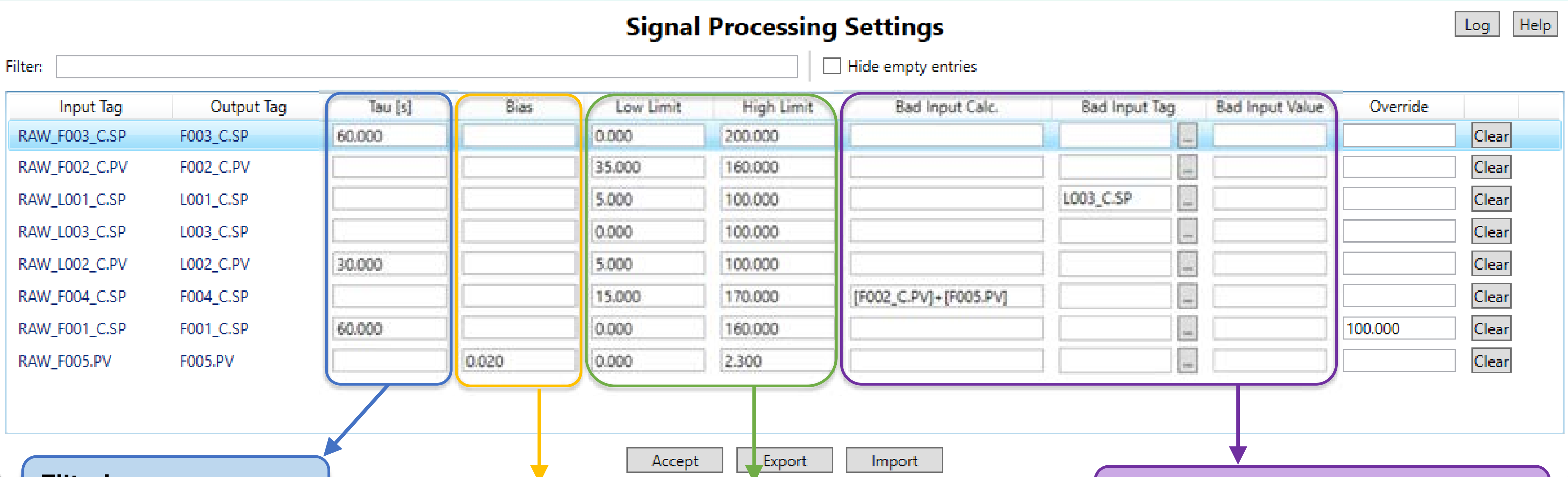
Third-Party Tools (via InfluxDB)

- InfluxDB Dashboards
- Grafana
- Seeq

Signal pre-processing and post-processing

The application provides **signal processing** capabilities for the Digital Twin signals

- ☑ Ensures stable and realistic inputs to the Digital Twin
- ☑ Prevent noise-driven oscillations
- ☑ Handles faulty or missing signals robustly
- ☑ Improves reliability of dynamic simulation



Input Tag	Output Tag	Tau [s]	Bias	Low Limit	High Limit	Bad Input Calc.	Bad Input Tag	Bad Input Value	Override	
RAW_F003_C.SP	F003_C.SP	60.000		0.000	200.000					Clear
RAW_F002_C.PV	F002_C.PV			35.000	160.000					Clear
RAW_L001_C.SP	L001_C.SP			5.000	100.000		L003_C.SP			Clear
RAW_L003_C.SP	L003_C.SP			0.000	100.000					Clear
RAW_L002_C.PV	L002_C.PV	30.000		5.000	100.000					Clear
RAW_F004_C.SP	F004_C.SP			15.000	170.000	[F002_C.PV]+[F005.PV]				Clear
RAW_F001_C.SP	F001_C.SP	60.000		0.000	160.000				100.000	Clear
RAW_F005.PV	F005.PV		0.020	0.000	2.300					Clear

Filtering
- Smooth noise using First Order Lag
- Tau (τ): Time constant

Bias
- Adds/ removes constant offset

Clamping
- Enforces upper and lower limits

Bad Signal Handling
- Defines fallback values, alternative tags, or calculations between tags for handling bad signals.

Model Health Indicator (MHI) for anomaly detection

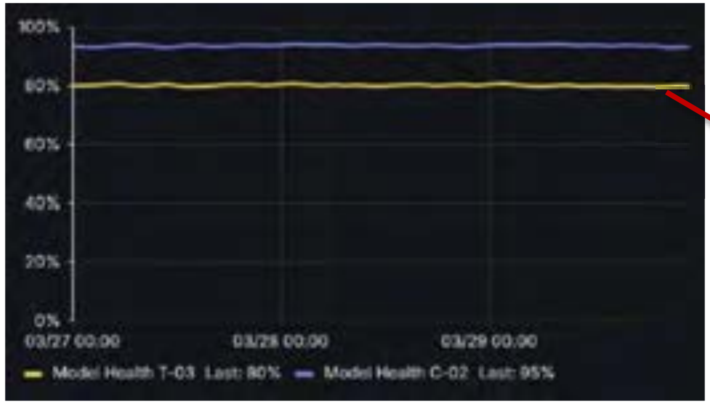
What is MHI?

The **Model Health Indicator (MHI)** indicates how closely the model matches the plant. It is derived from an equation that calculates the relative error between plant and model variables, such as temperatures, pressures, and compositions.

MHI Legend

MHI > 85% → Model aligned with plant
MHI < 85% → Potential anomaly or bad plant data

MHI in action



The MHI of T-03 area was lower than 85%

MHI value triggered an investigation. Feed Online Analyser had incorrect measurement (peaks) that lowered MHI:

MHI acts as an **early warning system** for **model mismatch** and **instrumentation issues**

Aspen HYSYS Modelling Details: PID Algorithm

Standard HYSYS PID Algorithm vs. **HYSYS PID Form C (I - On Error, PD – On PV)**

PV poor tracking

PV response closely aligned

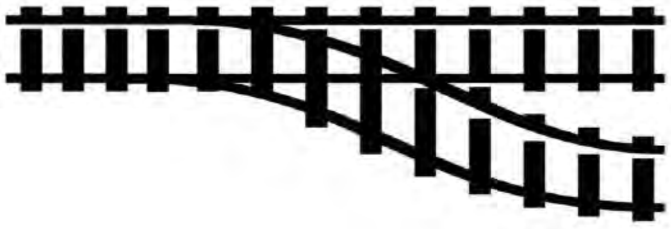
SP · Plant Transmitter & Digital Twin

PV · Plant Transmitter

PV · Digital Twin

Using the **same DCS PID Algorithm** led to **match plant dynamic response**.

What-If functionality



Base Digital Twin Model

What-If Digital Twin Model

The **What-If functionality** enables user to **evaluate** the **impact** of set point changes or other **process variable changes**, while the base Digital Twin continues running online in parallel with the plant.

Operations

- Set-Points of controllers
- Plant Utilities conditions (Cooling Water Temp, Steam Pressure, Air Temp)
- Raw materials compositions (Crudes types, impurities, chemicals injections)
- Start-Stop equipment (Pumps, Compressors, Air coolers, Heaters)
- Field valves position

Process Control

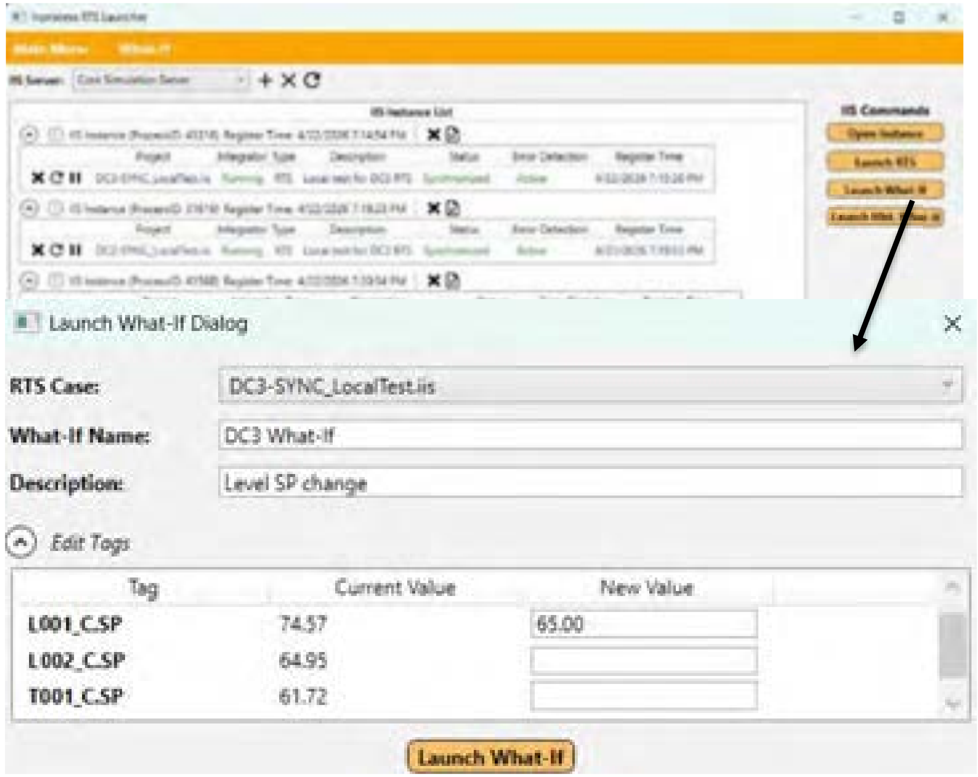
- Tunning of controllers (Gains, ramps, limits)
- Mode of controllers (Cascade, Auto, Manual, Selectors)

Safety

- Failure of any instrument or equipment
- Changes in the Cause & Effect Matrix definition
- HAZOP Revalidation and Process Safety Time

Equipment Failure / Change

- Size or capacity of equipment (Valve size, vessel size, HX UA, Pump/Compressor capacity, PSV setting, etc)

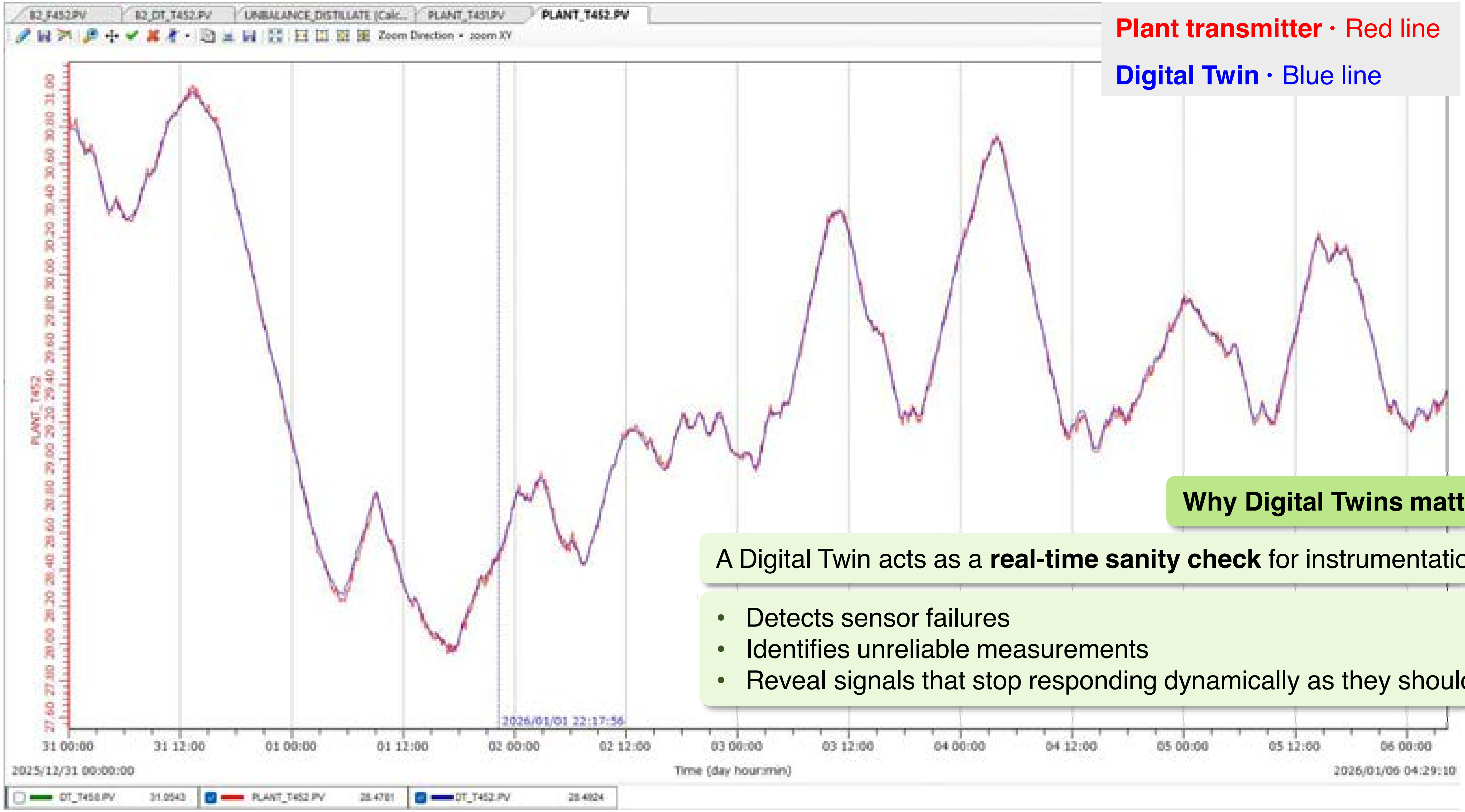


Use Cases and Value to Operations

Instrumentation checker

Temperature Transmitter – C3 Splitter Top

Temperature Scale Span: 4°C



Plant transmitter · Red line

Digital Twin · Blue line

Why Digital Twins matter

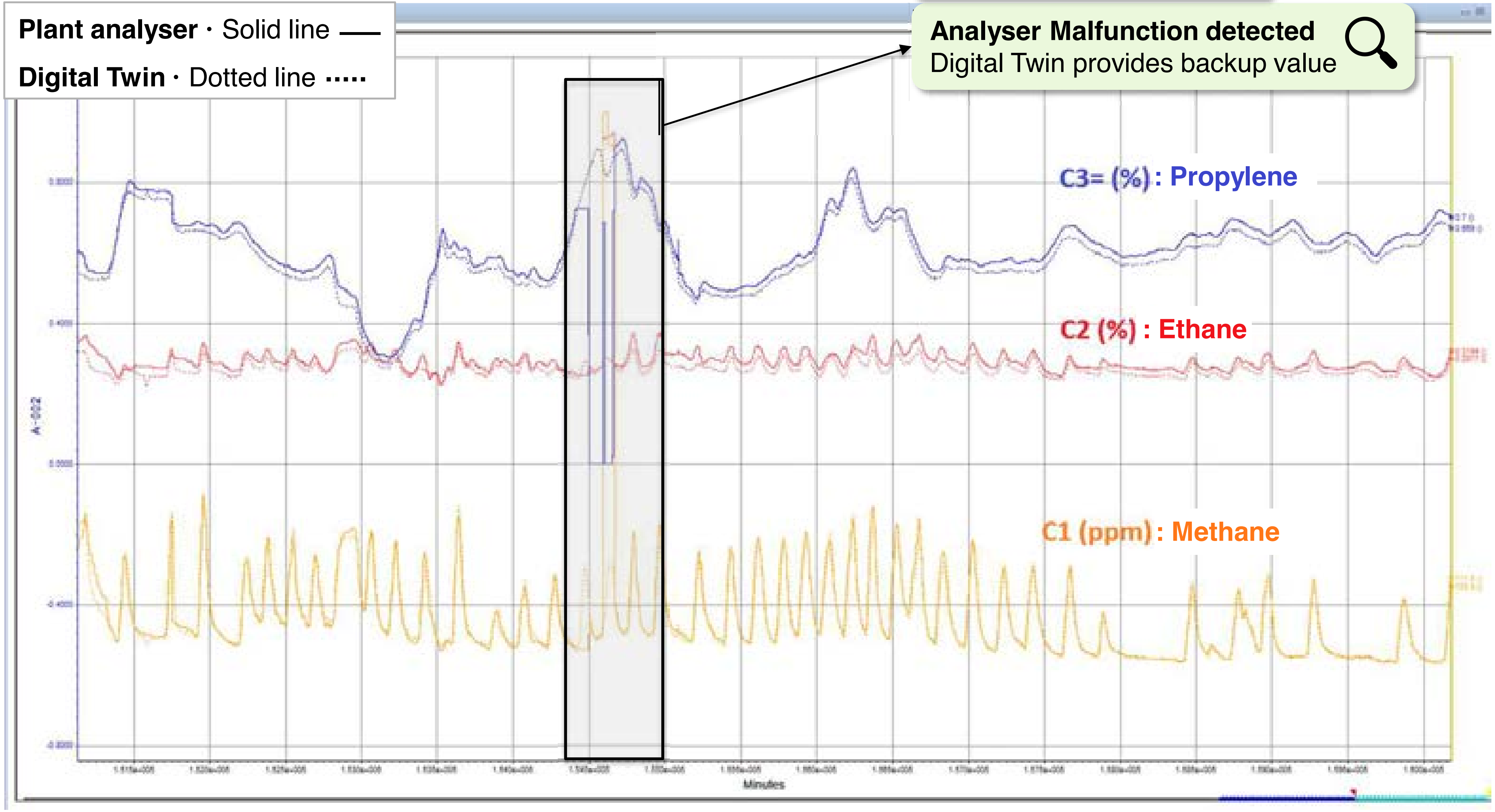
A Digital Twin acts as a **real-time sanity check** for instrumentation.

- Detects sensor failures
- Identifies unreliable measurements
- Reveal signals that stop responding dynamically as they should

Composition Online Analyser – Depropanizer Top

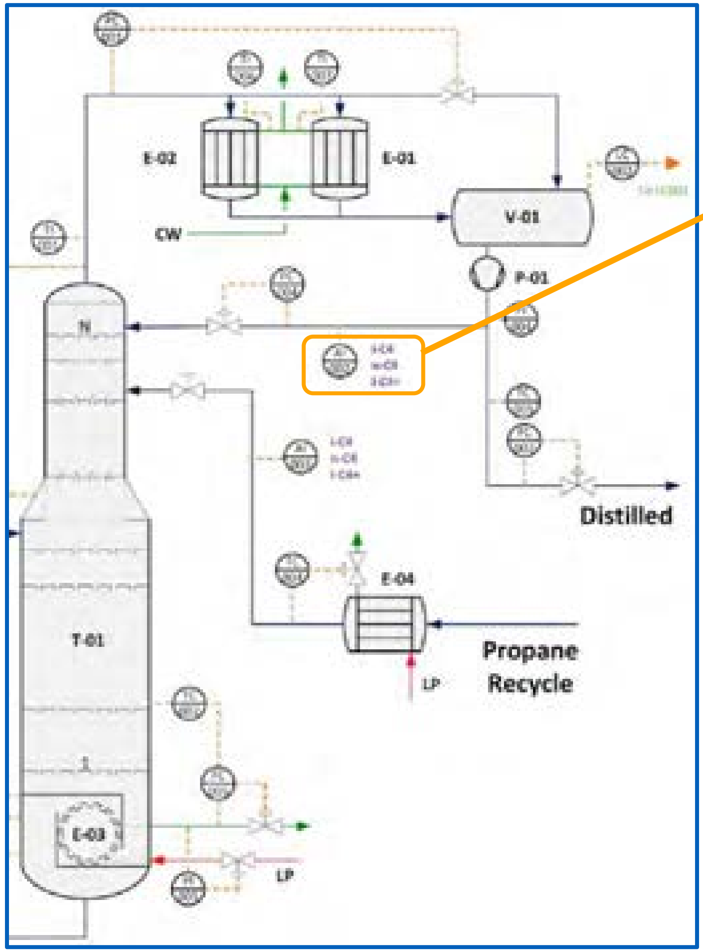
Why Digital Twins matter

Analyser Malfunction detected
Digital Twin provides backup value



Digital Twin values are not affected by analyser delay

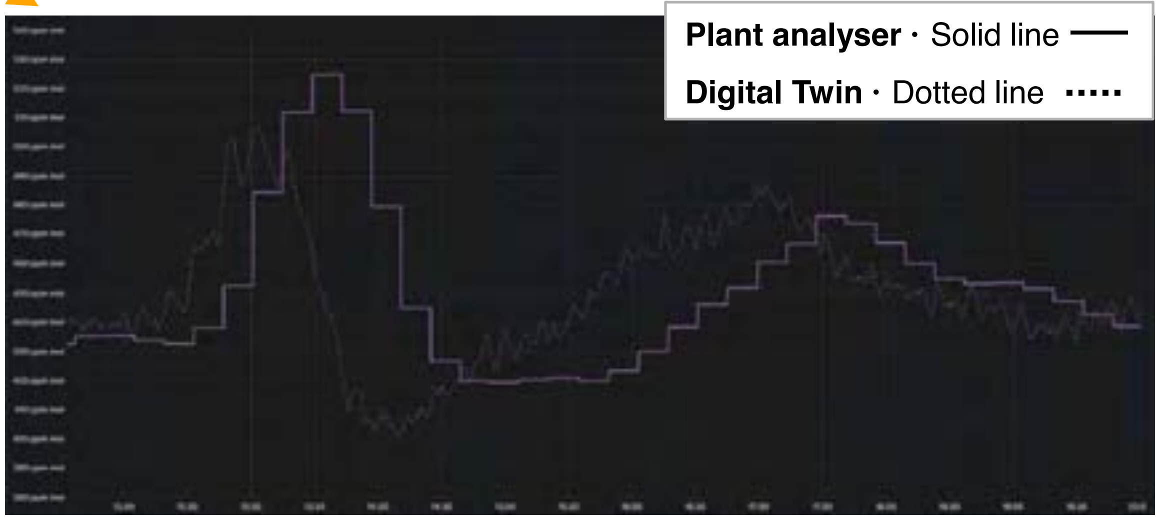
Composition Online Analyser – Depropanizer Top



Why Digital Twins matter

Digital Twin for the Sum of C4s is giving the value **30 min ahead of time** of the online analyser.

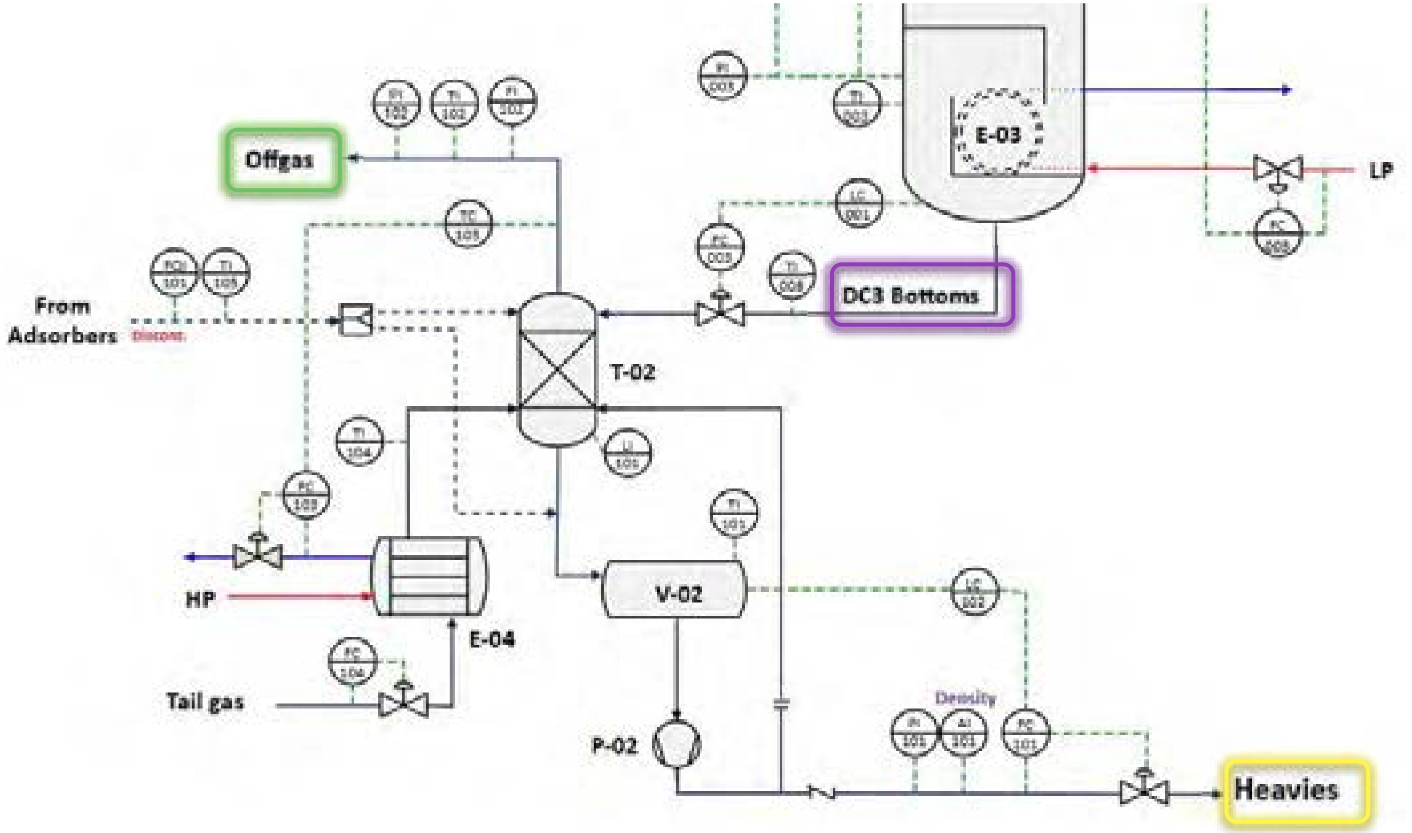
APC Controller performance can be improved by using this prediction.

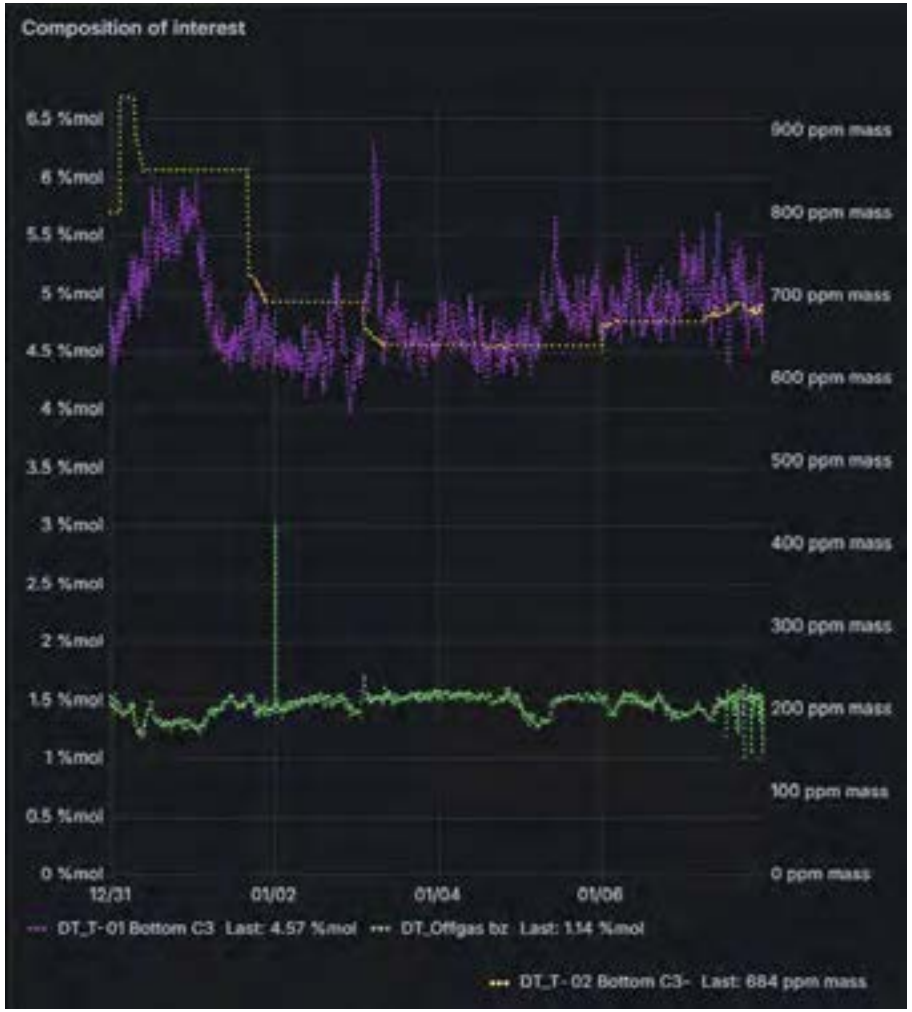


Soft Sensors: Composition of key streams

Why Digital Twins matter

Digital Twin provides real-time composition estimates where no online analyser exist.



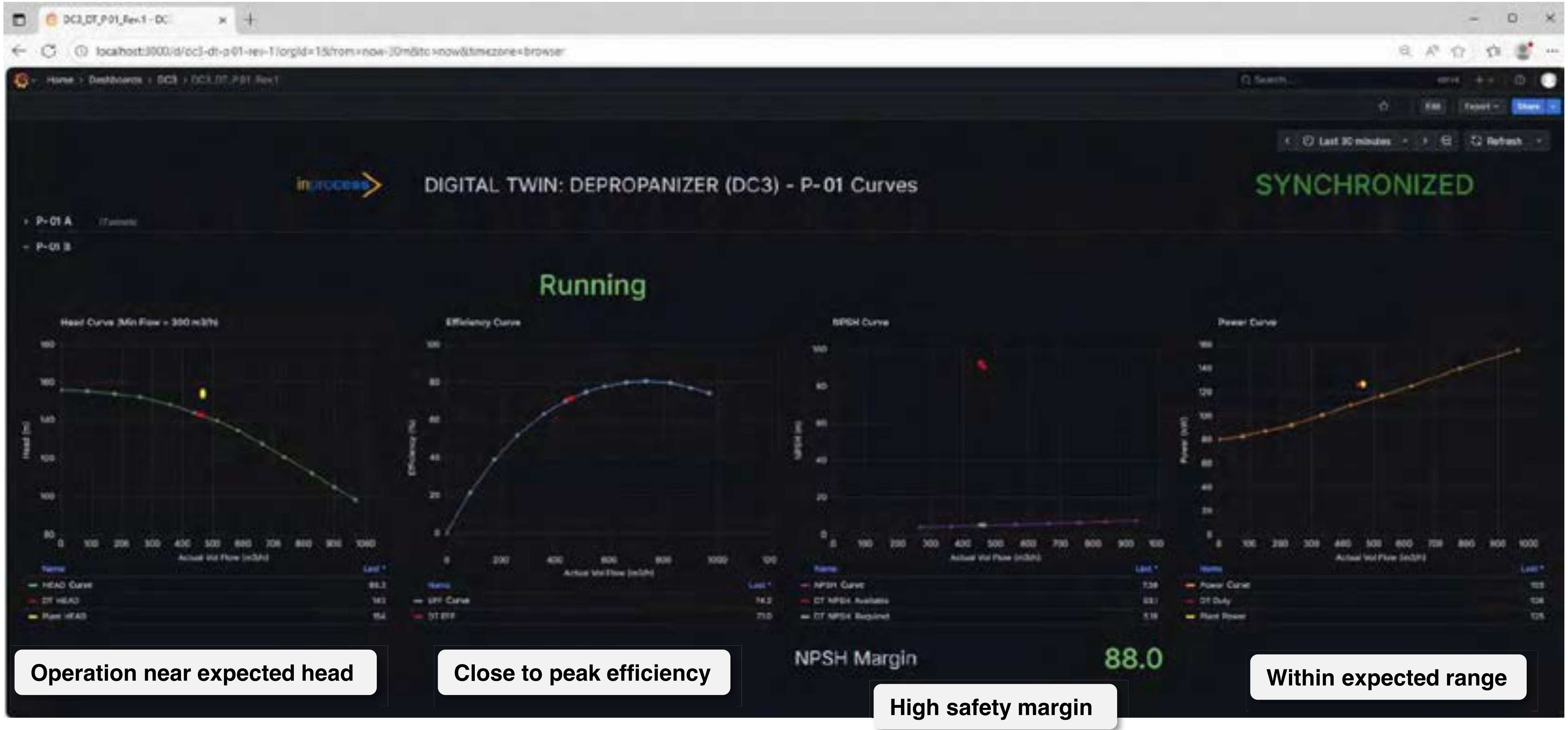


Pumps Monitoring

- **Digital Twin** Operating Point
  Theoretical performance – based on Vendor's curve
- **Plant** Operating Point
  Actual performance – based of plant transmitters

Why Digital Twins matter

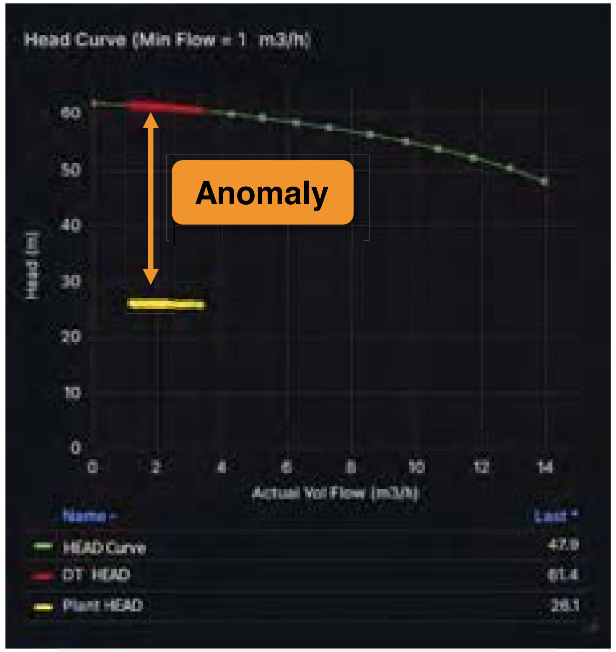
Digital Twin and Plant Operation are aligned, indicating a stable pump performance.



Real Case: Anomaly detection in Pumps

Anomaly detected

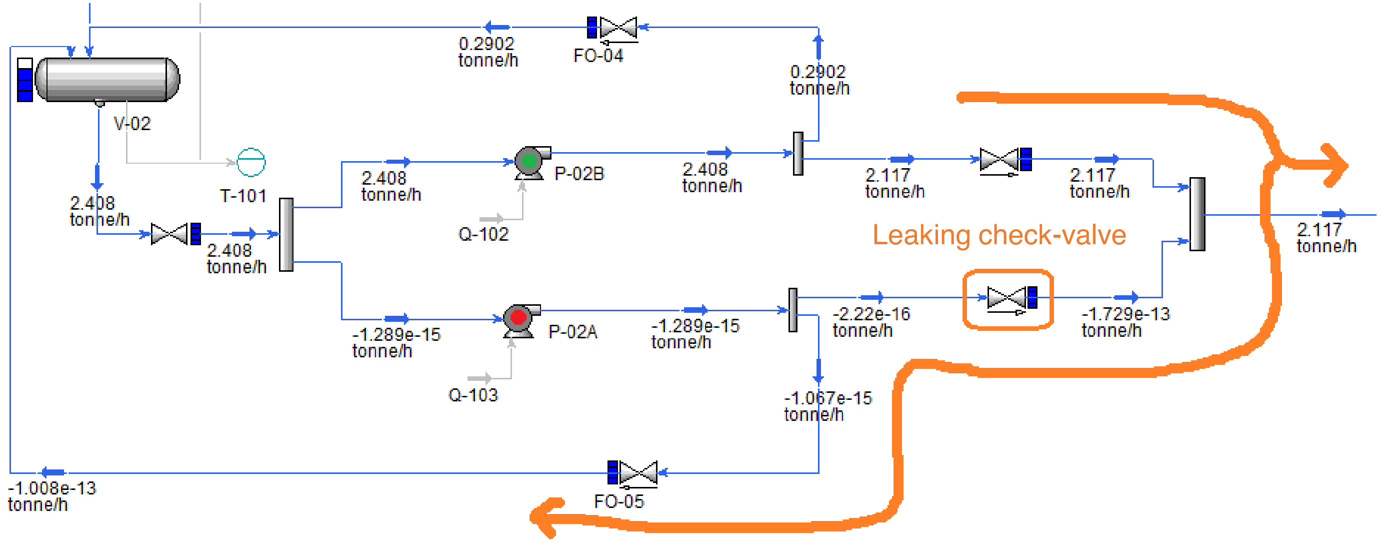
Theoretically, according to the DT, the pump head was expected to be ~ 60 m (red dot), whereas the actual pump delivered only ~ 25 m (yellow dot).



- **Digital Twin** Operating Point
- **Plant** Operating Point

Root Cause Identified

Severe leakage in the check valve of Pump A caused flow recirculation, reducing pump head.



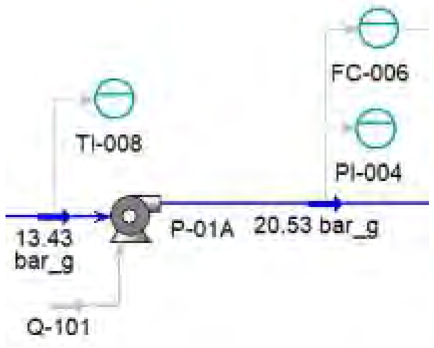
Why Digital Twins matter

Digital Twin detected a performance deviation and enabled rapid root cause identification.

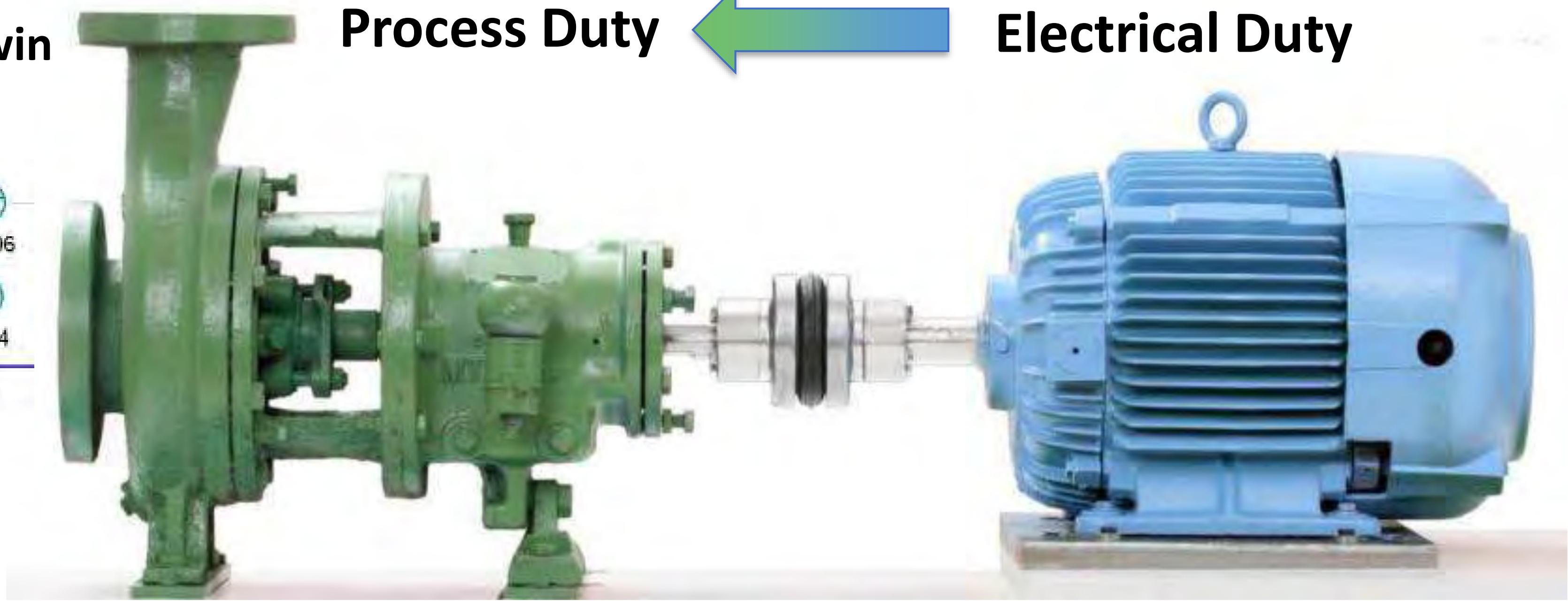
Pumps Power Monitoring: Connecting two worlds

Calculated by HYSYS Digital Twin

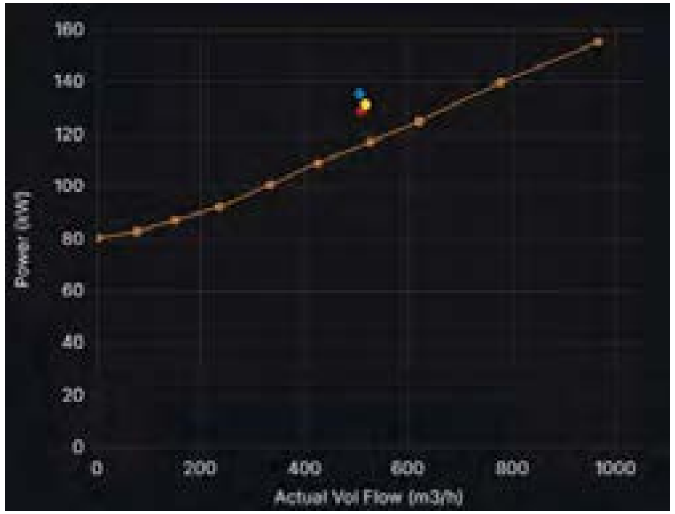
Measured MCC Room



Process Duty ← **Electrical Duty**



- **Power Curve from Pump vendor**
  Based on measured Power to Shaft during performance FAT of pump (API 610), valid for a given fluid density.
- **Plant Motor Power** Operating Point
  Actual Electrical Duty – based on measured Active Power and Efficiency´s curves of motor



- **Digital Twin** Operating Point
  Theoretical Process Duty – based on Head and Efficiency of pump Vendor's curves
- **Plant Process** Operating Point
  Actual Process Duty – based on plant instrumentation Suction and Discharge Pressures and Flow

Column Flooding

Flooding problem

- Excess liquid accumulation in column
- Leads to performance degradation

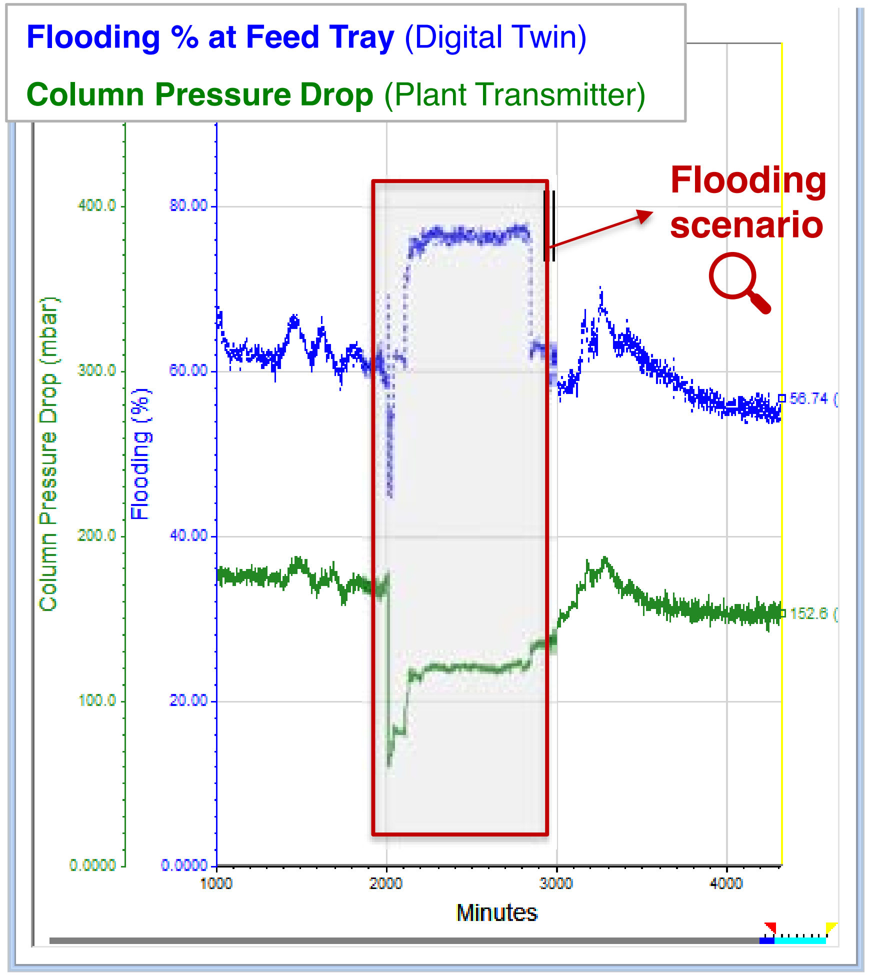
Source: LinkedIn Post - Ahmed Yehia

Flooding Calculation

- DT provides tray-by-tray flooding using **Kister & Haas correlation**
- Identifies critical trays approaching flooding

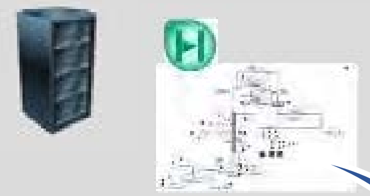
Why Digital Twins matter

- DT identified flooding conditions not visible in plant instrumentation
- Flooding exceeded design limits, while the pressure drop transmitter did not show the expected increase



Straightforward Dynamic Engineering Study

DT Server

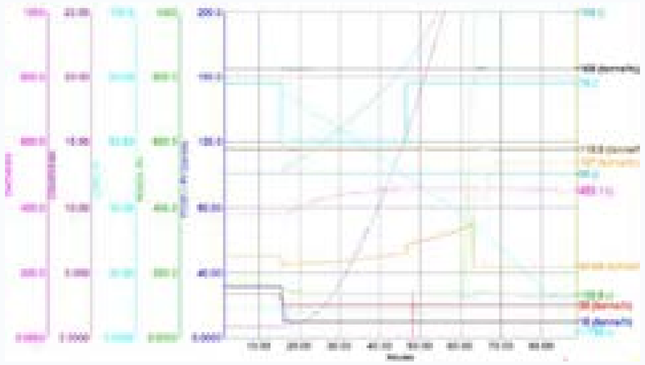


Pick an always updated HYSYS Dynamic Model

Dynamic Engineering Studies performed offline using the DT Model

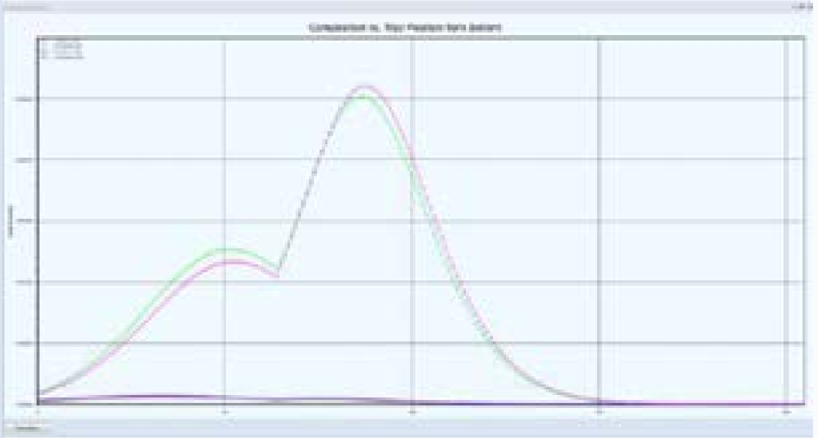
Steam Cut Optimization

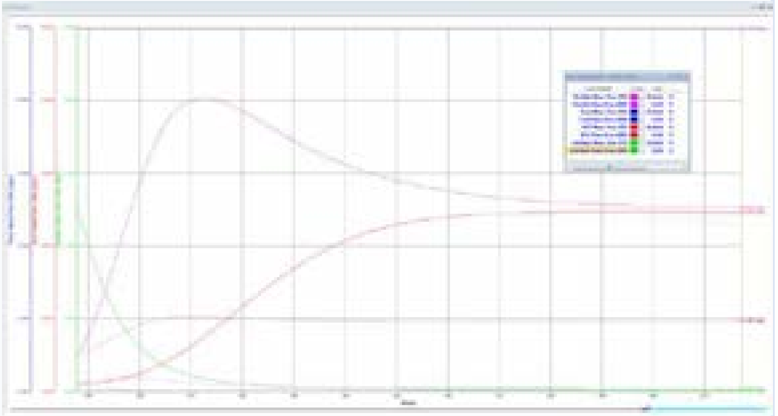
- Determine the minimum feed/reflux rate to reduce steam consumption.
- Ensure columns stability beyond specifications limits.



M-Acetylene and Propadiene (MAPD) presence in the feed

- Impact of increasing the MAPD content from 0 to 120 ppm in the feed tray.
- Analyse the resulting MAPD balance and accumulation in the column.





Why Digital Twins matter

Engineers can quickly perform advanced Dynamic Studies directly on a validated plant model retrieved from the DT server.

Summary

Summary: Digital Twins Key Aspects

Digital Twins are virtual copies of physical assets and their operational behaviour.

HYSYS consolidates centuries of knowledge in Physics, Chemistry and Thermodynamics into a single modelling environment

Existing **Engineering or OTS dynamic models** can be reused for Digital Twin.

Digital Twins models can be **validated offline**, avoiding the complexity of hardware, software and IT infrastructure.

Digital Twins do not need to cover the entire plant initially – they can be **implemented progressively** based on specific use cases.

Inprocess solutions can adapt to existing client environments and IT infrastructure.

Summary: Digital Twins Use Cases

SCOPE

- Three distillation columns: Depropanizer, Deethanizer, C3 Splitter
- Future expansion: Cold box & Effluent Compressor

DIGITAL TWIN CONTRIBUTIONS

- ☑ **Reduction** of **propane losses** at the Depropanizer column bottom **by 10%.**
- ☑ **Reduction** of **benzene** in the **wastewater**, lowering environmental impact

KEY USE CASES

Instrumentation checker	Instrumentation validation (e.g. orifice plate correction factor)
Anomaly detector	Model Health Indicators
Analyser reliability	Bias detection, backup and APC Inferentials
Soft sensors	Composition & Properties (RVP, Heating Value, Dew Point…) for unknown streams
Equipment monitoring	Columns (internal flow, flooding, weeping), Pumps, Compressors, Heat Exchangers
Dynamic eng. studies	Straightforward and reliable scenario analysis
What-if simulations	Operational and optimization insights

Additional Use Cases by Inprocess

Separators Carryover using specialized software (MySep)

Hydrate Formation & Mitigation Dosing

Erosional Velocity Ratios & CO_2 Corrosion Rate for pipes

Rigorous GHG Emissions calculation and KPIs

Chemical Injection Monitoring

Control Valve Monitoring & Anomaly detection

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inprocess
20 years