Digital Twins in Industrial Automation

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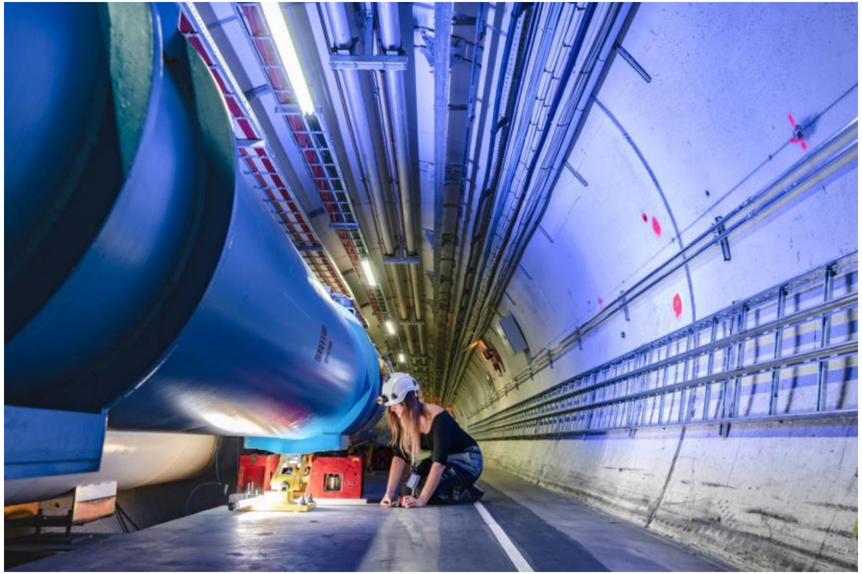
Contextually…

Use of digital twins in the industrial automation domain at CERN

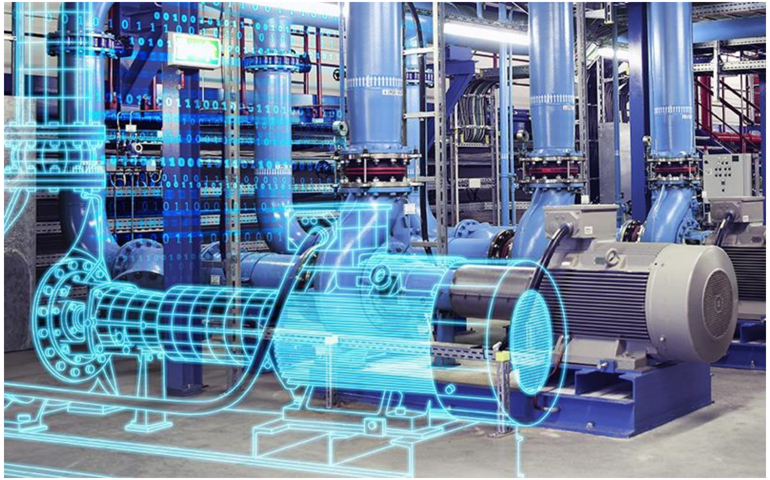


Definition

Maybe one of the **first use** of the digital twin phrase is seen in 2011/12 in NASA reports…
"A digital twin is an integrated multiphysics, multiscale simulation of a vehicle or system that uses the best available physical models, sensor updates, etc… to mirror the life of its corresponding flying twin"

*A digital twin is a **digital (virtual) representation** of a physical asset or system.

This digital representation includes a **dynamic model** based on the physics of your **machine or system** and behaves and responds to conditions exactly as it would be in a real operational scenario.

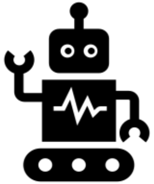


* One of the multiple definitions

Use cases (Industrial automation)

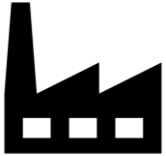
Process Knowledge

- Plant design and optimization
- Better understanding of the process to optimize operation



Advanced Control

- Offline tuning (PIDs)
- Control optimization (e.g. MBPC, reinforced learning in feedback control)



Virtual Commissioning

- Off-line commissioning leading to maximize availability

Training of operators

- Operator turnover
- Complex plants do not allow training online

Process knowledge

Process Knowledge

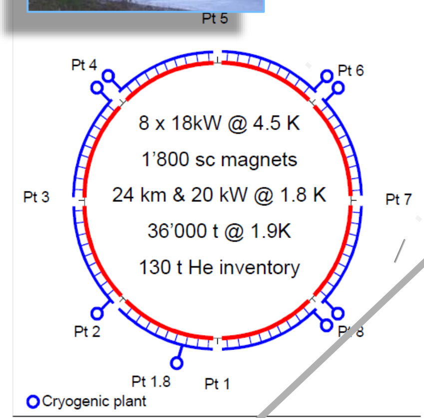
- CERN LHC cryogenic system
- Largest cryogenics plant in the world (-272^{O} C)

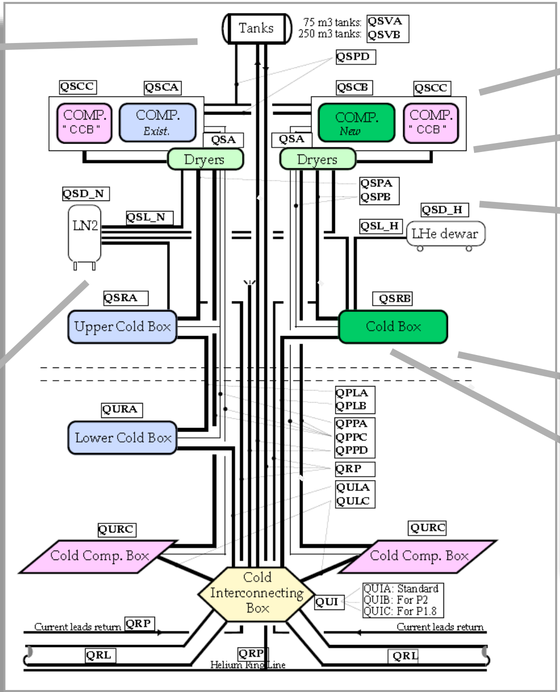
LHC Cryogenics

compressor stations

helium storage

liquid helium storage





3.3 km

3.3 km

cold boxes

liquid nitrogen storage

helium transfer

Process knowledge

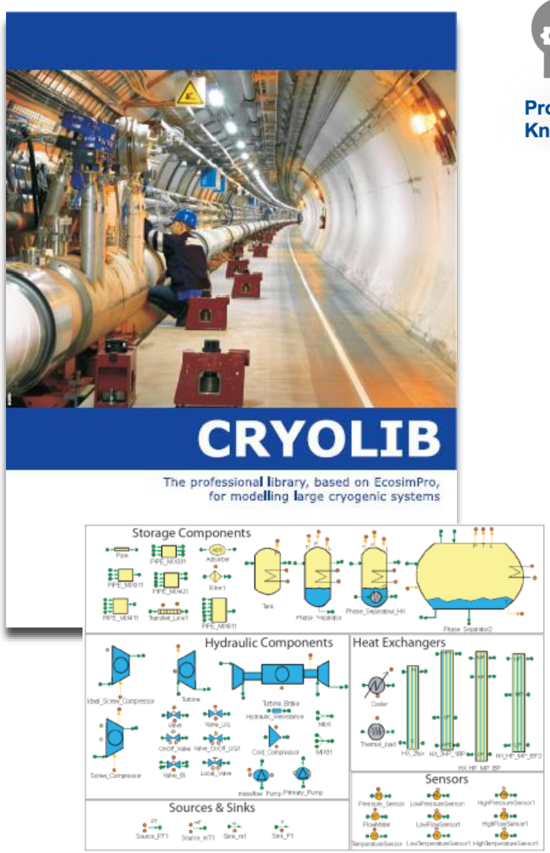
Process Knowledge

CERN developed a **cryogenic library** with the commercial simulation software **EcosimPro*** (*Empresarios Agrupados*)

EcosimPro is a powerful modelling and simulation tool with a simple interface that makes the design of multi- disciplinary dynamic systems easy and intuitive using graphic diagrams.

It is capable of processing complex systems represented by **DAE**, **ODE** and discrete events.

Under a special Spanish programme of industry support to Science the library was the object of a **technology transfer** to EA International (2011)

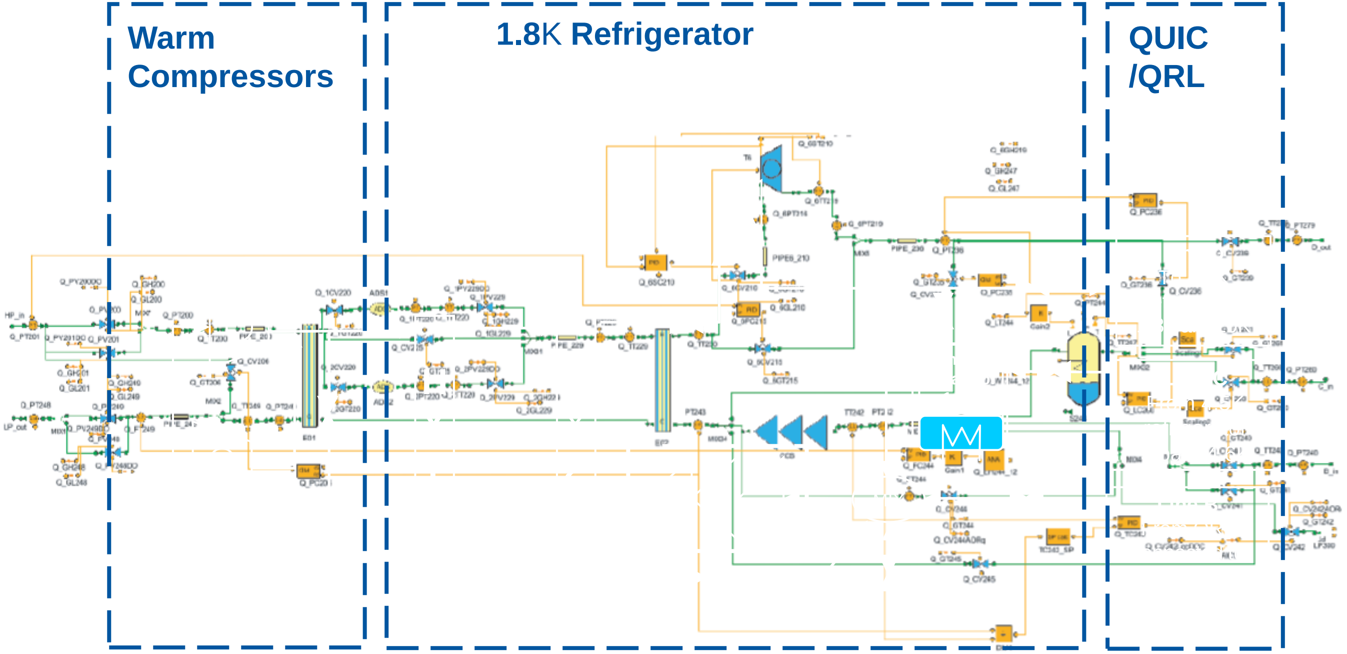


* https://www.ecosimpro.com/products/cryolib/

Process knowledge

Process Knowledge

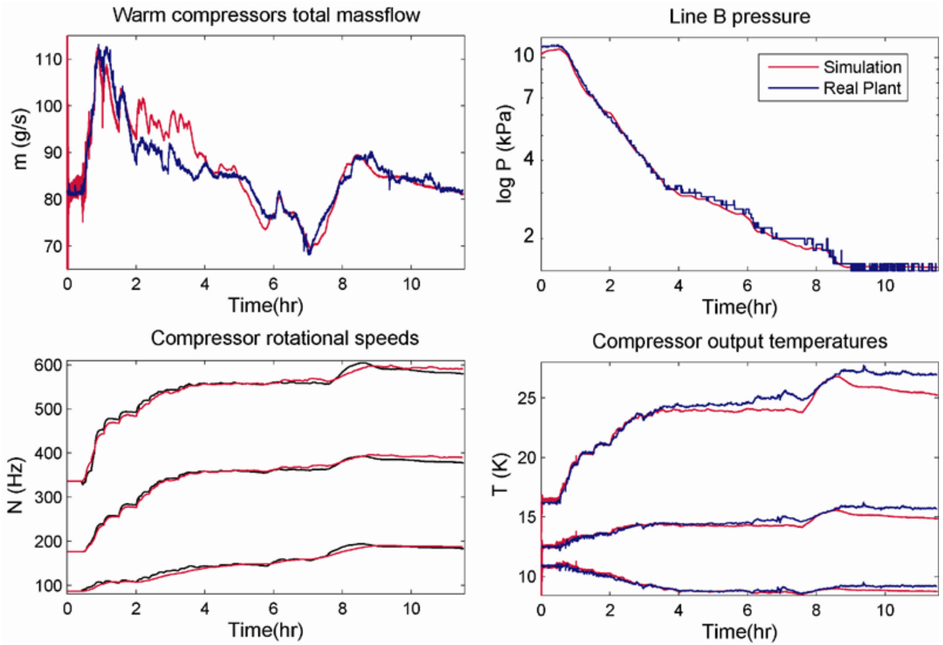
1.8 K refrigeration unit: Schema



Courtesy of Benjamin Bradu

Process knowledge

- 1.8 K refrigeration unit: Simulation results (Pumping between 100 and16 mbar)



Courtesy of Benjamin Bradu

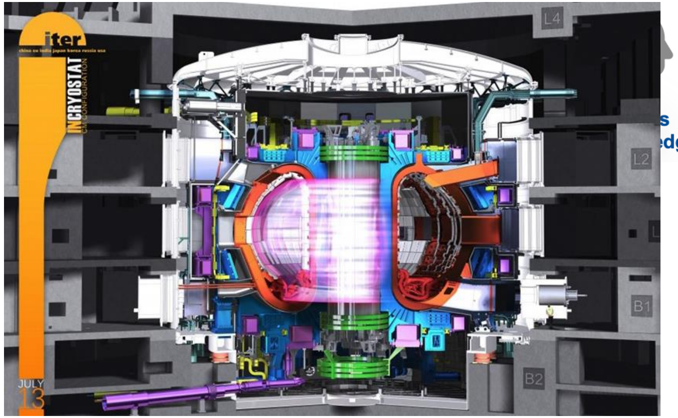
Process knowledge

ITER project

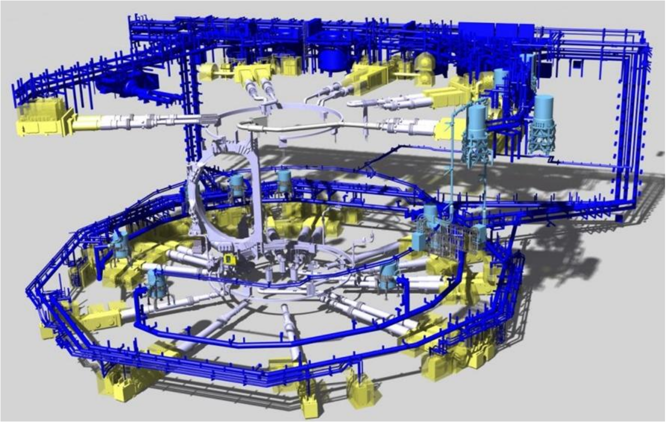
the first **fusion** device to produce **net energy**.

The ITER magnets will be cooled with supercritical helium at 4 K (-269°C) in order to operate at the high magnetic fields necessary for the confinement and stabilization of the plasma.

The ITER cryogenic system will be the **largest concentrated cryogenic** system in the world with an installed cooling power of 75 kW at 4.5K (helium) and 1300 kW at 80 K (nitrogen).



Tokamak


Cryogenics system

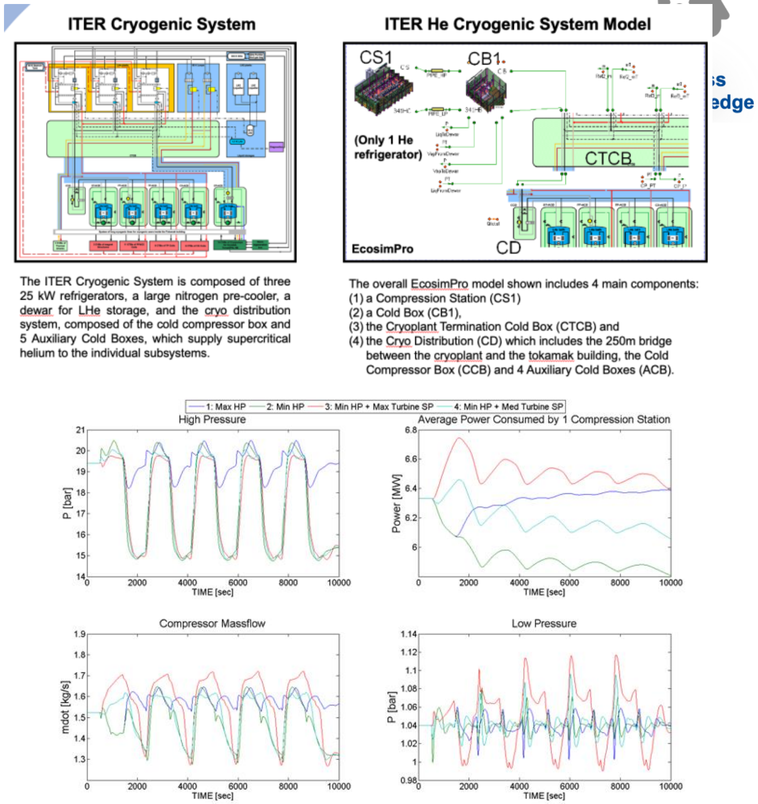
Process knowledge

ITER cryo model

designed to perform dynamic simulations of the overall ITER cryogenic process during the short and long plasma **pulses (plasma operation)**

3 x 25 kW refrigerators

The dynamic simulation of the ITER helium cryogenic system has demonstrated the ability of the **preliminary design** to meet the operation requirements.



Publication at ICEC24 – ICMC 2012

Operators training

Training of operators

- The operator sits in a "virtual" control room that emulates the real one. The experts/trainers can have full access to any action on the simulated process and may recreate malfunction or instruments failure to check the responsiveness of the operators.

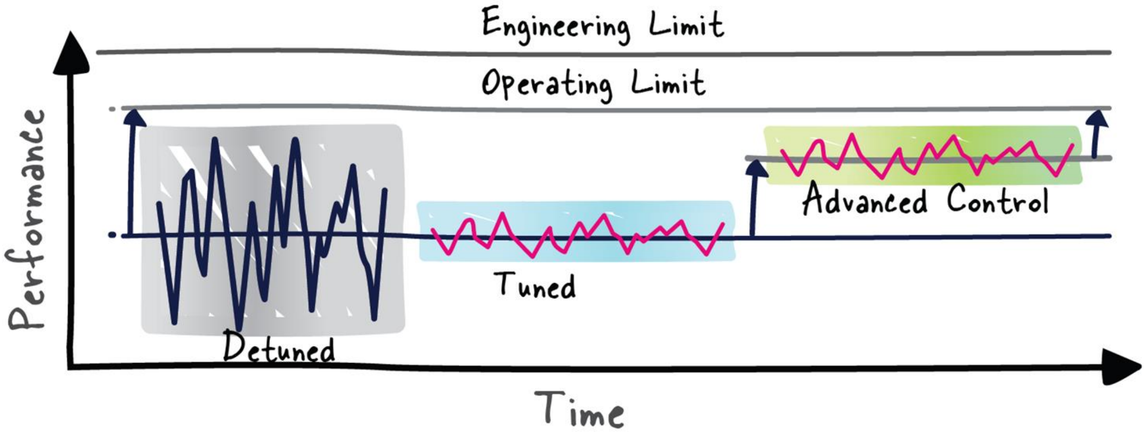
- The plant control strategies and operator interface should be used **without change** when create the training system.

CERN CRYO Central Control Room

CERN CRYO **Virtual** Control Room

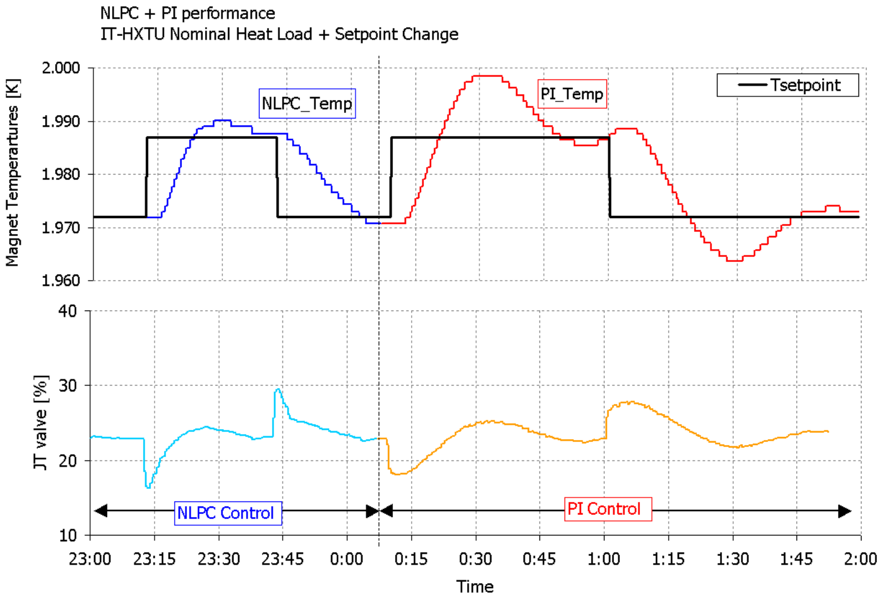
Advanced Control

- Controller tuning
- New control approaches
- Model based controls

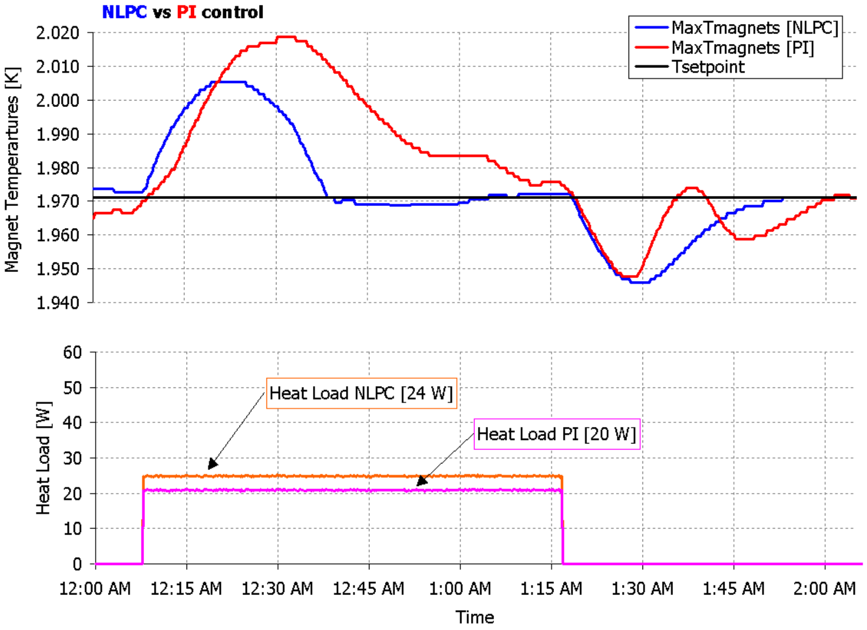


NLPC vs. PID: heat load change

Advanced Control



NLPC vs. PID: set point change



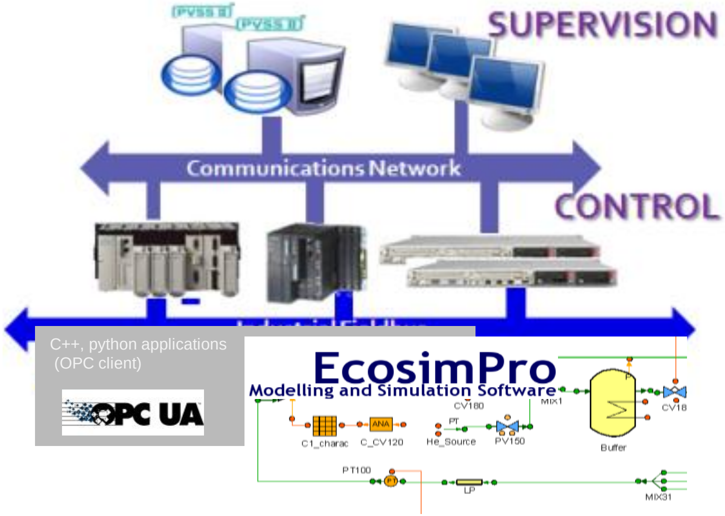
NLPC vs. PID: heat load change

Virtual commissioning

Adopting the **Virtual Commissioning** concept reduces installation launch time and increase the control system quality by testing, validating, and debugging the system before physical commissioning

HIL: Hardware in the loop: PLCs

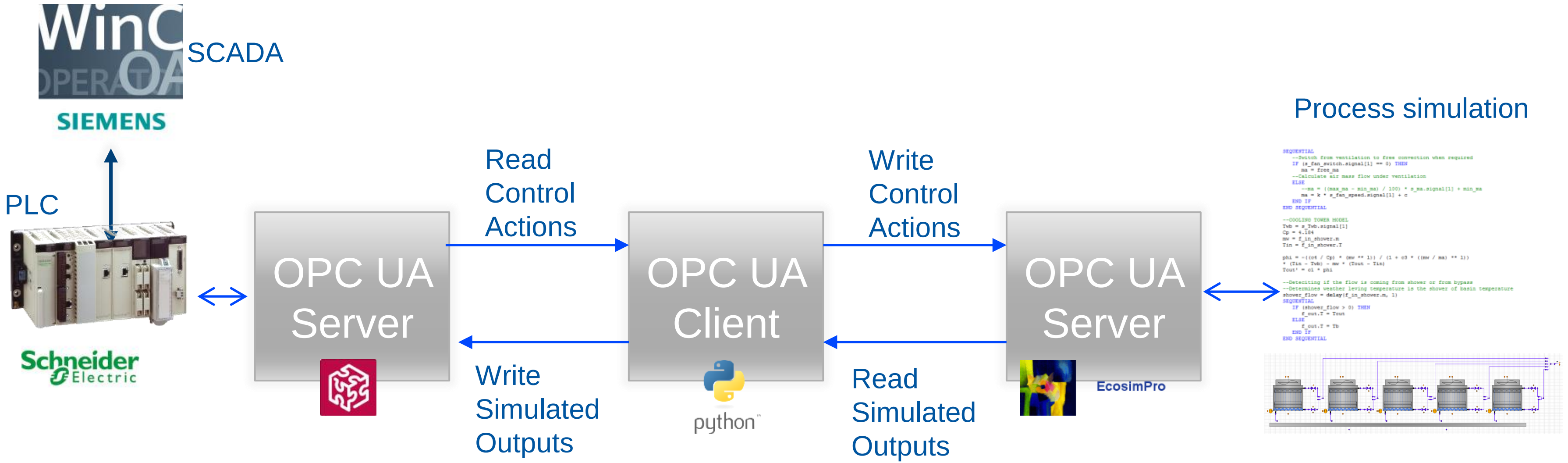
SIL: Software in the loop: PLC Simulators



Virtual commissioning

Virtual Commissioning

Architecture and workflow

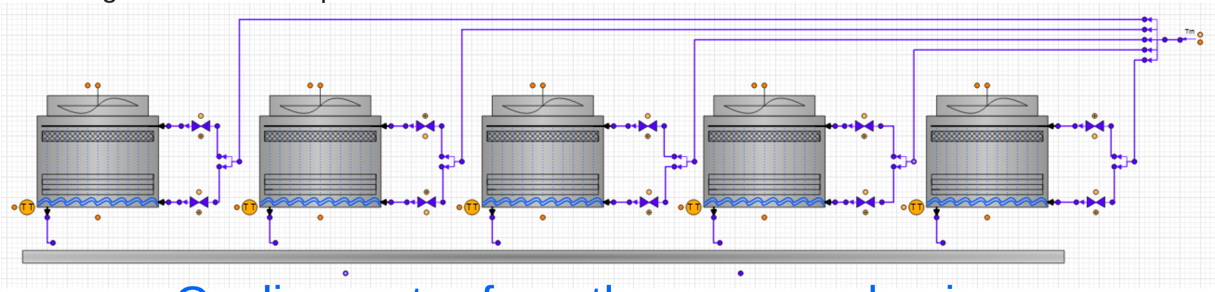


Courtesy of Brad Schofield

Waste heat recovery in LHC point 8

Virtual Commissioning

Cooling towers of LHC point 8



Cooling water from the common basin

22 °C

Clients of cooling of LHC point 8 (e.g. LHC Cryogenics)

Average ~30 C°

Entering cooling water

Average ~30 °C

With the heat exchanger: ~25-28 °C

Circulation from the city

Heat Recovery Heat Exchanger

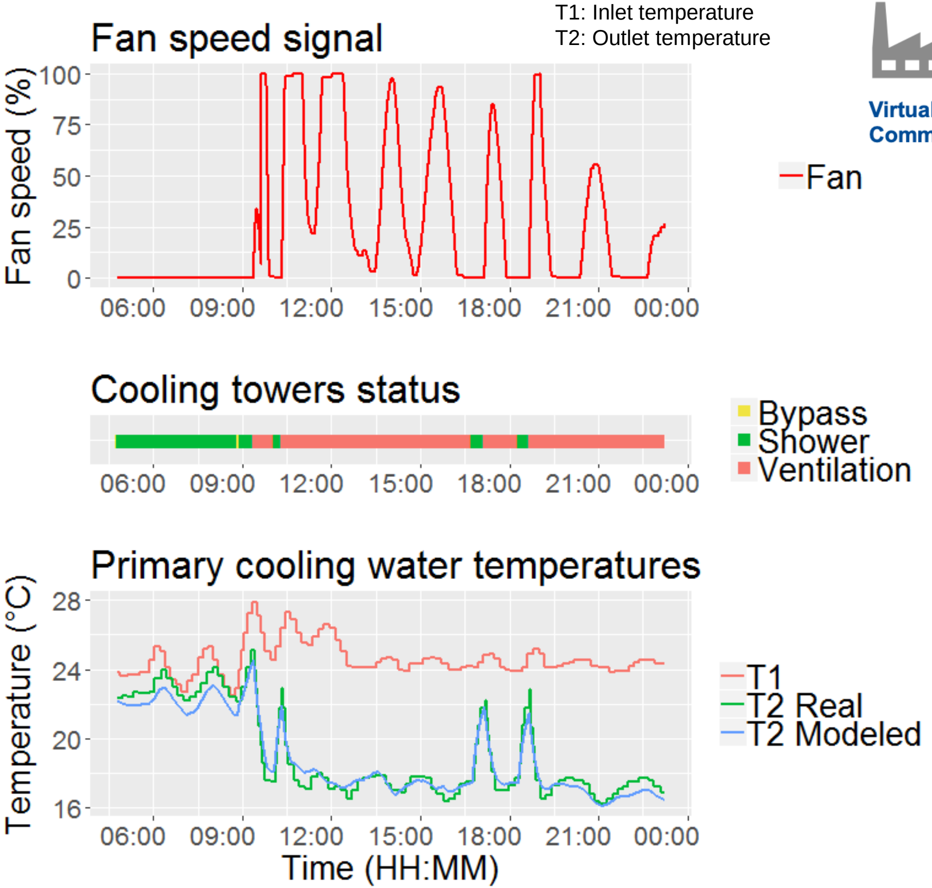
Circulation to the city

Courtesy of Matias Peljo

Model validation

Dynamic

Comparison against real data on 15.8.2014,

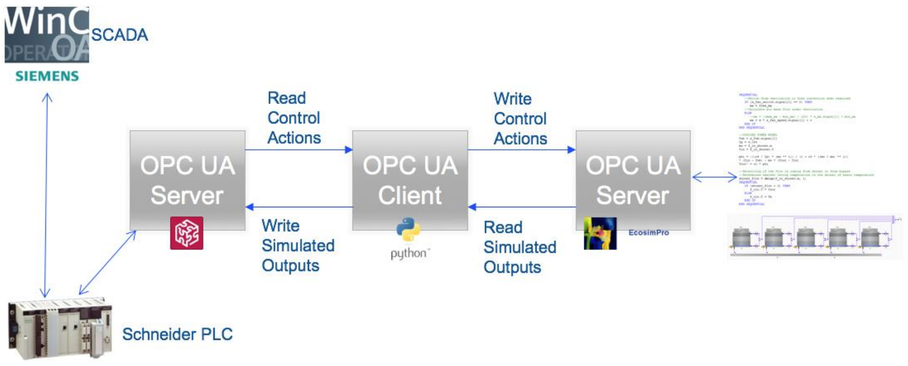


Virtual Commissioning

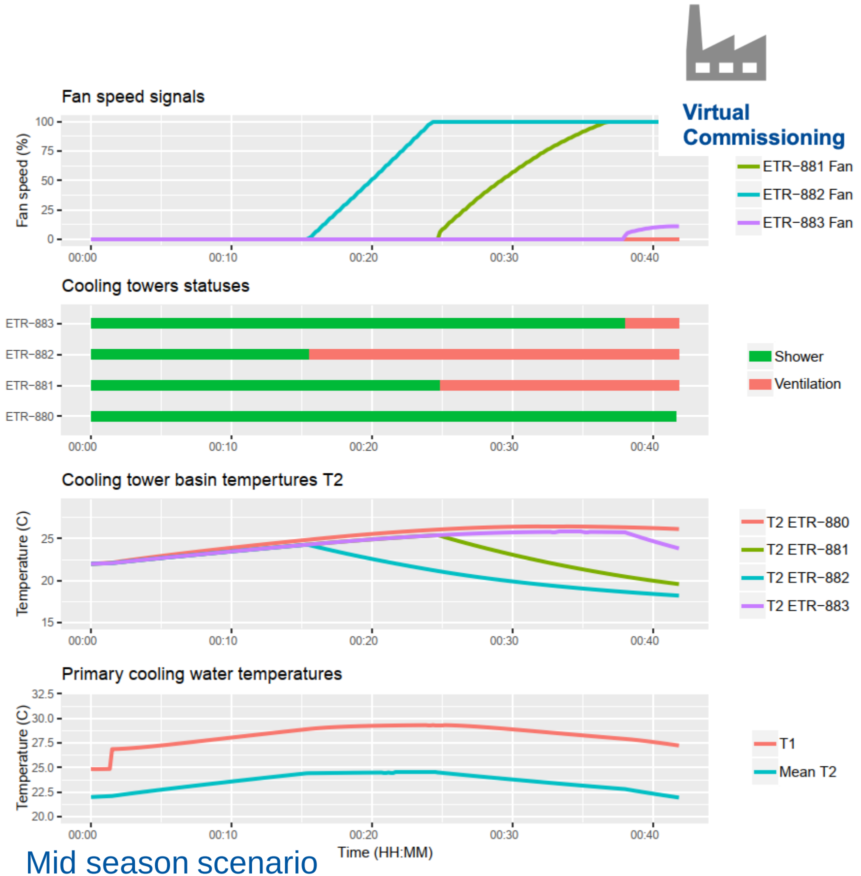
Courtesy of Matias Peljo

Virtual commissioning

- Does my control system behave as expected?
- Could it cope with unexpected scenarios?



Virtual commissioning architecture



Mid season scenario

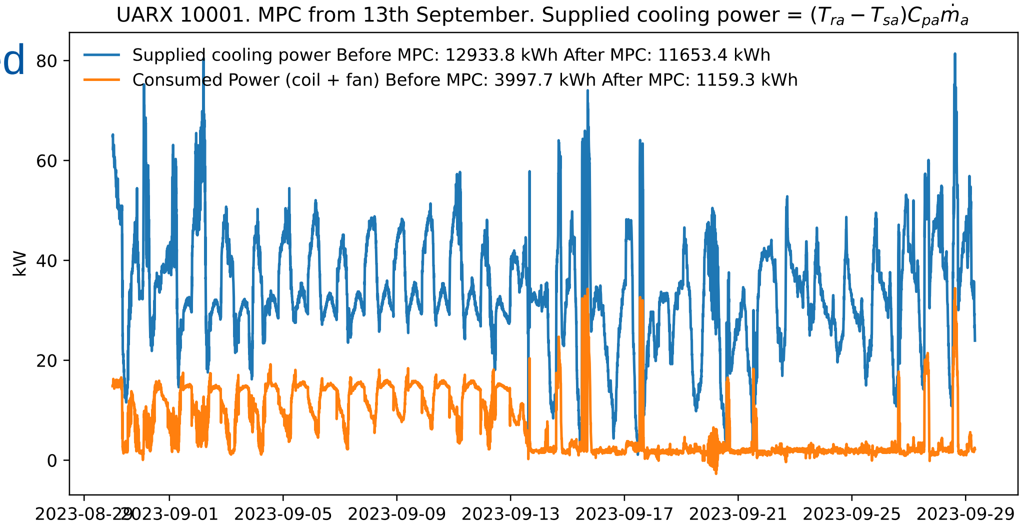
Courtesy of Brad Schofield

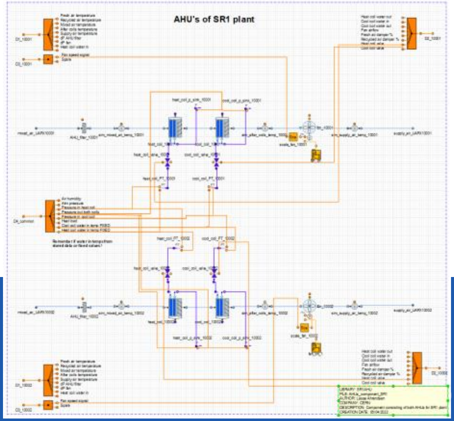
MPC for Air Handling Units

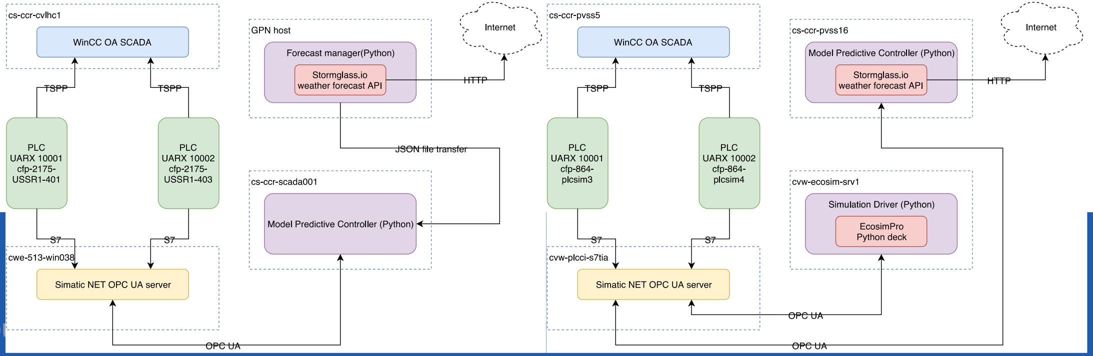
Advanced Control

Virtual Commissioning

- An MPC controller was recently deployed in an HVAC system
- Extensive Virtual Commissioning using the Ecosim Process model meant that deployment was seamless (~2 hours)
- Objective of the controller is energy optimization; so far the results are promising







Digital twins: Process simulation

Conclusions

- **Digital Twin** technology improved design, engineering & operational efficiency and safety through a combination of simulation and experimental data.
- So far the simulation **fidelity** comes at a cost: deep knowledge of the process and the ability of producing first-principles models and high-resource demands.
- Advances in **machine learning** may help to enable fast modelling with physical data streams leading to rapid prediction tools

Current Challenges

- I/O feeding with process model
- Variable simulation speed
- Integration with the control system (fault detection and degraded operation based on models)

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