VIRTUAL CONTROL COMMISSIONING FOR A LARGE CRITICAL VENTILATION SYSTEM: THE CMS CAVERN USE CASE

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Goal

Performance problems?

Availability?

9 YEARS OF RUN

Safety issues?

Obsolescence?
Goal

- LHC has been operational since 2008, no major improvement has been done for 9 years on ATLAS and CMS HVAC plants:

  ![Diagram](image)

  - Performance problems?
  - Availability?
  - Safety issues?
  - Obsolescence?

  **9 YEARS OF RUN**

- Decision to upgrade the ATLAS and CMS HVAC Plants control systems during LHC Long Shutdown 2 (LS2) in 2019 in order to:
  - Solve obsolescence problem: current SCADA (Wizcon) is not supported anymore; PLCs are at end-of-life
  - Migrate the control to the CERN UNICOS framework
  - Take into account the experience gained during the LHC operation and improve the control & availability when necessary (e.g. lot of manual actions are currently necessary)
**Constraints**

- CMS Ventilation plant is running 24h/7d
- Critical during LHC run:
  - Maintain stable under-pressure for safe operation
- Critical immediately after run: purge before interventions
- Critical during interventions (technical stops): air flow
- Limited intervention time (<3 months)
- Q: how best to ensure smooth upgrade?
  - Virtual Commissioning
Virtual Commissioning

- Offline, no impact on installation
- Dynamic simulation model to validate new:
  - control strategies
  - switching between operation modes
- Operator training
Approach

Process & Equipment analysis → HVAC library development → HVAC library Validation → "Simple" HVAC Plants Model building/simulation → CMS Cavern Physical Model building

Physical Model Building

... → Control Model building and A.F. → Simulations, improvement and upgrades → Implementation → Virtual-Commissioning
Overview CMS buildings surface and underground
Overview CMS buildings surface and underground

Ventilation Units at the Surface

CMS Experiment Cavern (UXC55)
Overview CMS buildings surface and underground

Ventilation Units at the Surface

CMS Experiment Cavern (UXC55)
Process & Equipment Analysis

EDMS & EN/CV inventory

P&IDs, Equipment datasheets, HVAC Maintenance reports, GA Drawings, Duct routing, ...

RELIAL INPUT DATA

“As Built” Sub-Contractor doc.: A.F., I/O Lists, PLC programs, Alarms Lists, HVAC Commissioning reports
HVAC Library Development

- EcosimPro™
- CERN-developed library of HVAC components
HVAC Library Development

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Physical Model Building

Process & Equipment analysis

HVAC library development
Fan Component Development

Fan efficiency correction factor

Example of fan curve (Fläktwoods)

Pressure drop across the fan

Fan efficiency

Fan rotation speed

Fan airflow

Fan model

Fan operating point

<table>
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<th>Fan characteristics</th>
<th>Motor characteristics</th>
<th>Initial conditions</th>
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</table>
Fan efficiency correction factor

Example of fan curve (Fläktwoods)

Pressure drop across the fan

Fan rotation speed

Fan airflow

Fan model: Ideal fan + Electrical heater

Airflow power: \( \Delta P \times Q \)

Fan shaft power

Motor shaft power

Motor load factor

Motor efficiency

Fan efficiency (linearization)

Fan losses

Transmission losses

Motor losses

Motor electrical consumption

Fan Component Development

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Typical component basic check

- “blind tests” - components internal equations not supposed to be known.
- Basic thermodynamic evolutions can be easily followed with a Psychrometric diagram
- Example: heater
  - Dry temperature
  - Specific enthalpy
  - Relative humidity
  - Absolute humidity
- Same principle for other components
- CERN Computing Centre (Building 513) – R401 UPS Physics
  - Simple ventilation system
  - Similar components
  - Data available to validate model
  - Control studies
Simple HVAC Plant Model: Modelling
One fresh air inlet with:
- temperature sensor
- RH sensor

One recirculation duct with:
- temperature sensor
- RH sensor

Blown air measurements:
- temperature
- RH sensor
- Air speed

UPS room:
- One air inlet
- One air outlet
- Two (2) room temperature sensors
One fresh air inlet with:
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- Shut-off damper
- Exhaust duct
- Shut-off damper
- Filter
- Cooling coil with its 2-way valve
- Centrifugal fan

Control elements are not depicted

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- Control elements are not depicted

Simple HVAC Plant Model: Modelling
5-days simulation: dampers authority settings

As control loops are activated, this discrepancy is not necessarily due to the dampers settings, e.g. room heat load variation.

5-days simulation: comparison between simulation and measurements
Simple HVAC Plant Model: Simulation Results (2)

![Graph showing UPS Room absolute pressure (Pa, outdoor at 1013 hPa)]
Simple HVAC Plant Model: Simulation Results (2)
Valve characteristics and cooling coil characteristics found by trial and error
Heat load / water evaporation modified “by hand”
CMS Experimental Cavern Ventilation System: Process & Instrumentation Diagram

Process & Equipment analysis

HVAC library development

HVAC library Validation

"Simple" HVAC Plants Model building/simulation

CMS Cavern Physical Model building

Physical Model Building

FARSUPEC: supplies air into the cavern

FAREXTEC: extract air from the cavern

FGMEXTEC: Gas mixture extraction / underpressure

UXC55 cavern
CMS Experimental Cavern (UXC55) Ventilation System: EcosimPro Model

**UXC55 EcosimPro model:**

- **FARSUPEC:** supplies air into the cavern
- **FAREXTEC:** extract air from the cavern
- **FGMEXTEC:** Gas mixture extraction / underpressure
- **Handling air leakage with USC55**
EcosimPro Model Supply Units

UXC55 EcosimPro model:
UXC55 EcosimPro model:
EcosimPro Model Supply Units

UXC55 EcosimPro model:
UXC55 EcosimPro model:

UAPE 515 and UAPE 516 AHUs

Equivalent model of
EcosimPro Model: Main Supply Air Handling Unit

UXC55 EcosimPro model:
EcosimPro Model: Main Supply Air Handling Unit

UXC55 EcosimPro model:
EcosimPro Model: Main Supply Air Handling Unit
Control Model Building and Simulation

- Control Model building and A.F.
- Simulations, improvement and upgrades
- Implementation
- Virtual-Commissioning

### Control Model building and A.F.

- Functional Analysis Re-writing:
  - UNICOS approach
  - Improvements
Example: Start-up Gas detection in UXC55 – Cap Open

→ In this case, both UAPE AHU are running:

- Exhaust through the cap
- Both AHU blow at 45,000 m³/h
- Start-up time
- Outdoor air: 20°C
- Blown air temperature increase due to the motor load
- UXC55 walls T°C: 18°C, without sensible/latent heat load for this simulation → Temperature slightly increase.
Example: Start-up Gas detection in UXC55 – Cap Open

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Example: Start-up Gas detection in UXC55 – Cap Open

In this case, both UAPE AHU are running:

- Exhaust through the cap
- Both AHU blow at 45 000 m³/h
- Interlocks: the AHU fan cannot start when the modulating dampers are not open
- Initial room absolute pressure
- Typical case where additional data are required to set the absolute pressure amplitude variation
- Spring-return actuator
Dynamic Simulation with PLCs in the Loop
Conclusions

- EcosimPro HVAC library improved and validated
- Small HVAC plants modelled, good comparison with data
- EcosimPro CMS Cavern Physical Model:
  - All the technical inputs are now known or estimated (damper size, fan curve, duct pressure drops, ...)
  - UXC55 HVAC Plant model is built
  - Most simulation issues (convergence, simulation time) resolved
- Simulations with simple model control for various operating scenario
- Model hooked up to 3 PLCs in the lab for manual simulations
- Development of control system is ongoing, in collaboration with Cooling and Ventilation team at CERN
- Then Virtual Commissioning
Thank you for your attention