Control System of the Spiral2 Superconducting Linac Cryogenic System (TUPV006)

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Architecture and functions of the control system

Home Page Cryo Supervision

Cryogenic automation allows the cryogenic operation of the cryomodules. It therefore takes into account the transfer of cryogenic fluids from their production (liquefier and its annexes) to their use (cryomodules), as well as the return of these fluids. It also manages the operation of Frequency Tuning Systems (FTS) in superconducting cavities, and interfaces with other systems for interlock functions.

Liquid helium production and routing, as well as the automated safeties and the controls of the helium liquid bath, are ensured by a PLC-based control system. Each cryomodule is controlled by a Programmable Logic Controller (PLC). The cryomodule PLC performs the following functions:

- Acquisition and processing of analog measurements of the valve box and cryostat.
- Management of the different operating modes of the cryomodule.
- Interlock with vacuum and RF PLCs.
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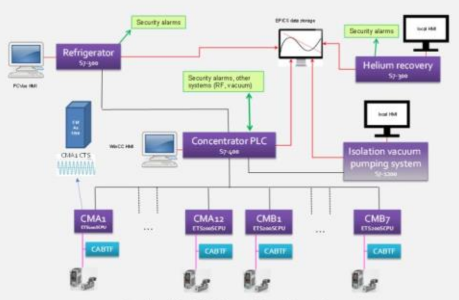
PLC cryogenic system architecture



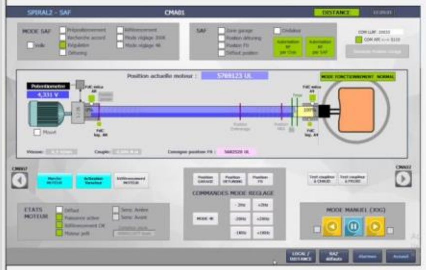
Developped by GANIL (except for refrigerator)

Linac's cryogenics control system is made up of a fleet of 20 PLCs, 3 supervisions, 1 workshop terminal, 26 brushless motors driving the Frequency Tuning Systems (FTS) of the RF cavities. In addition, there are nearly 70 instrumentation boxes for the control of temperatures, pressures and helium levels, vacuum pressures, heating supplies. The cryo network is completely autonomous with independent supervision. During power cuts, batteries make it possible to secure the cryogenic automated system (PLC, supervision and network) and to keep control at all times.

15 Control Bays

Frequency Tuning System Control / Simulation Supervision / Epics / Linac Vacuum

Frequency Tuning System



A particular function is to control the FTS device of the cryomodule. On type A cryomodule, a mechanical device resembling a pliers makes it possible to deform the cylindrical part of the RF cavity so as to vary its volume, this volume being directly linked to the resonance frequency of the superconducting RF cavity, in a manner to adjust its resonant frequency. On type B cryomodules, a mechanical device similar to a diver allows the volume of the resonant cavity to be tuned. Operating zones are defined for the FTS according to the active cryogenic mode. These software safeguards prevent any premature wear of the frequency tuning system and any mechanical deterioration. The LLRF gives the phase shift instructions to each of the cryomodule PLCs.

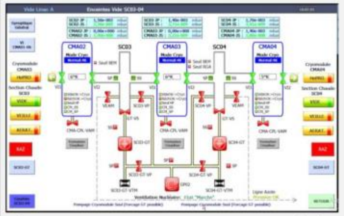
CMB Cryomodule Simulation

During the operation of the cryogenic system, a simulator in WinCC Pro supervision was used to check all program steps and verify all safety conditions. This simulator is also used after the maintenance period.

Epics

The Epics curves make it possible to visualize the archived process variables and to analyze the different cooldown sequences in order to better understand the operation.

Cryomodule Cavity Vaccum



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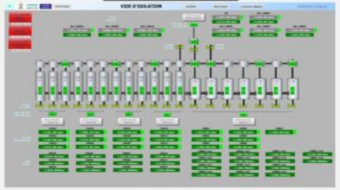
Linac Isolation Vaccum



The permanent pumping of the isolation vacuum of cryomodules and transfer lines helps to absorb helium leaks and maintain a correct vacuum level.

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PLCs Functions

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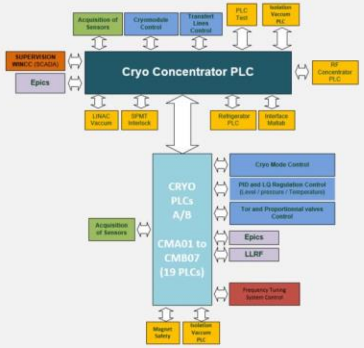
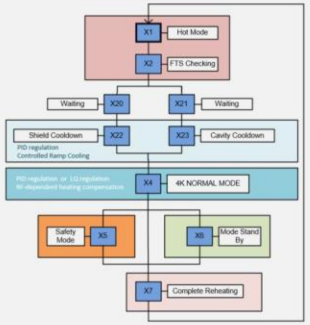


SFC: Order of the Cryomodule Mode

The general principle is that the step change request is made manually at the supervision level. Since the supervisors are connected to the concentrator PLC, a mode change order is sent to the PLC of each cryomodule via the private network to authorize this mode change. Each cryomodule manages its "security" mode. Following a fault, the cryomodule goes into safety and informs the concentrator controller of its state.



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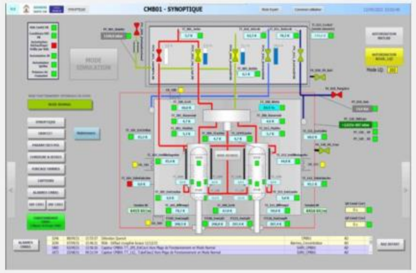

The supervision of cryogenics makes it possible to display all the data necessary for driving the process and the associated commands of the connection box, from transfer lines to cryomodules. It is made up of around 200 pages and 6000 variables. The alarms are archived. The photo above represents the block diagram of a type B cryomodule.

The cooldown of the Linac is completely controlled with the application of a sliding temperature setpoint. The descent is slowed down from 300K to 150K and then accelerated from 150K to 4K in order to limit the time in the critical temperature range 150-50K.

An independent pumping system provides a sufficient vacuum level in the cryomodules to ensure thermal insulation.

LQ Regulation / Heat Load Estimator

The type-A and type-B cryomodules were modelled using the Simcryogenics library on MATLAB/SIMSCAPE environment. In order to be simple enough to be usable with a PLC, the cryomodule model is linearized to provide the state space equation, linking the opening of the valves and the liquid helium bath state.

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$
$$x = [\rho \; e]^T$$
$$u = [CV002 \; CV005]^T$$
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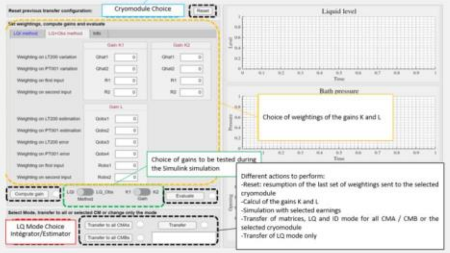
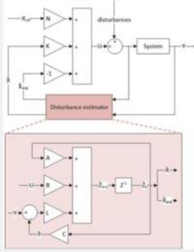


Graphic Interface Matlab: LQ Controller Parameter



Linear–Quadratic controller with a disturbance estimator

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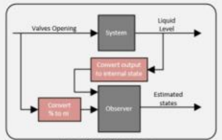
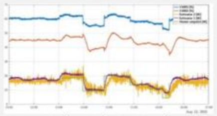


Load Estimator

Tests showed that this estimator is correct but too dependent on the valves opening value, which are disturbed by thermo-acoustics oscillations. Others strategies are being studied to mitigate the weight of those disturbances, for instance the estimator 2 also aims at computing the error of the output mass flow.



Estimated Heat Load

Future improvements :
-Mitigation of the thermos-acoustics phenomena
-Implementation of estimators in every cryomodule
-Variety of estimators working in parallel with different accuracy and response time

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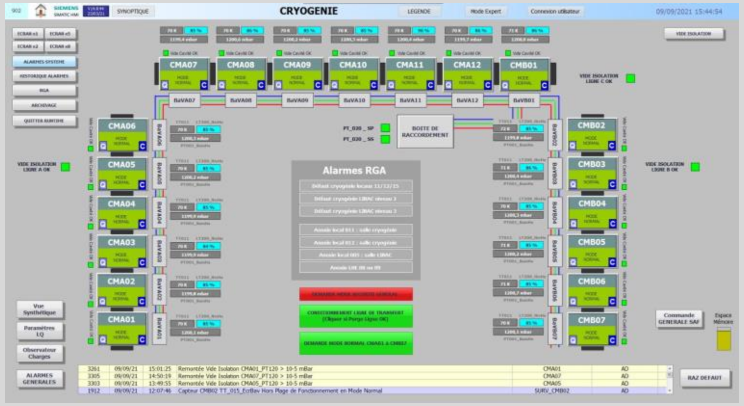

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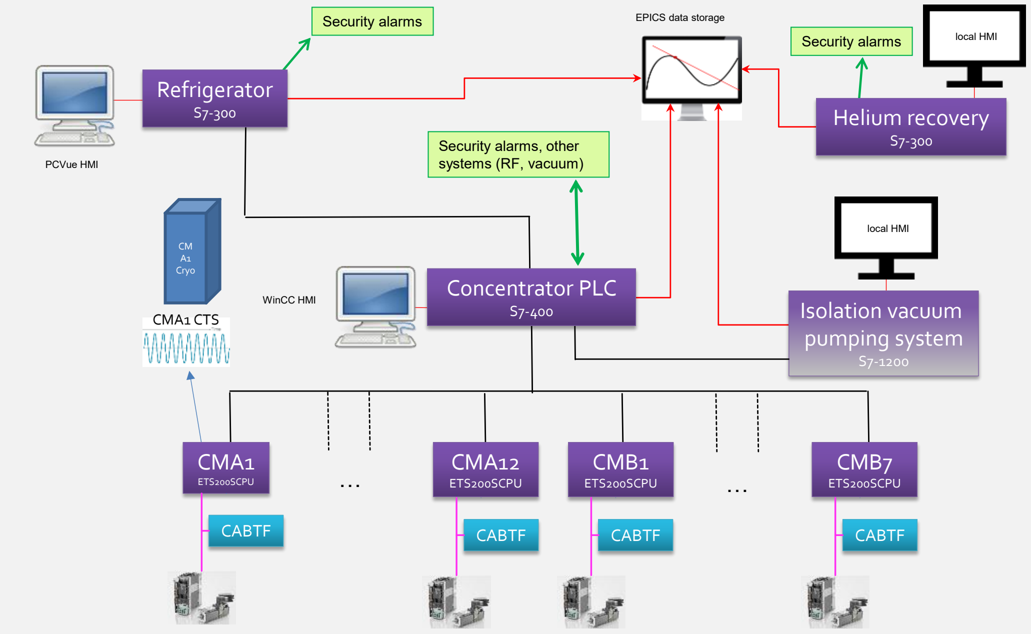

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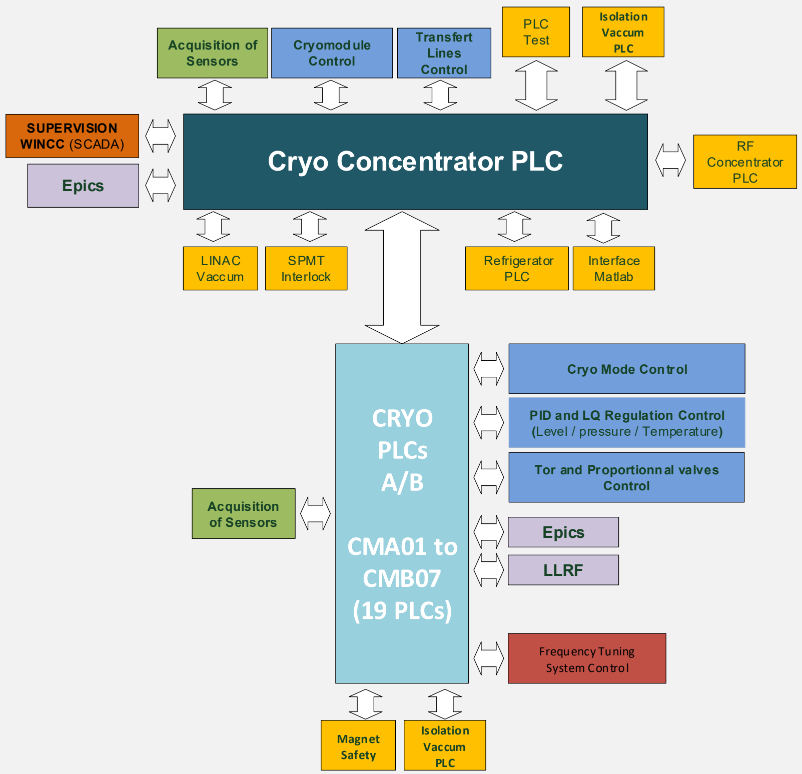

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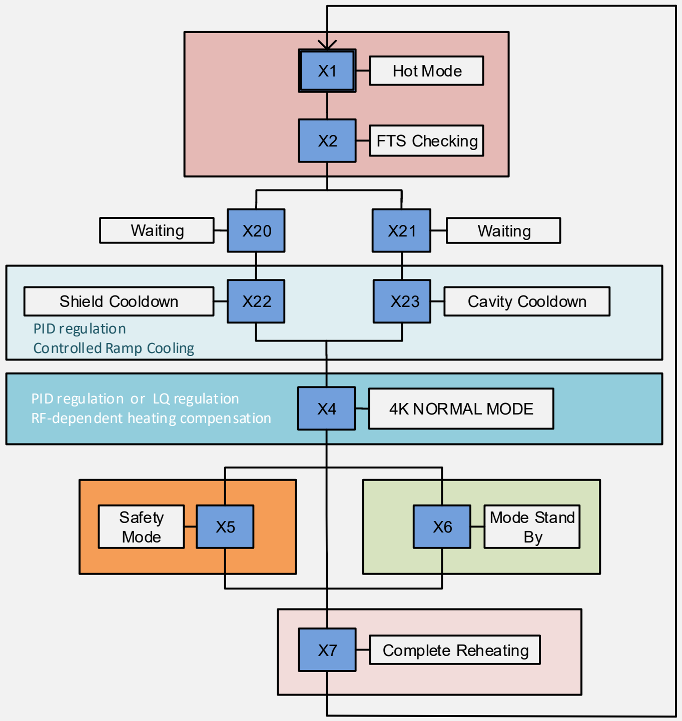

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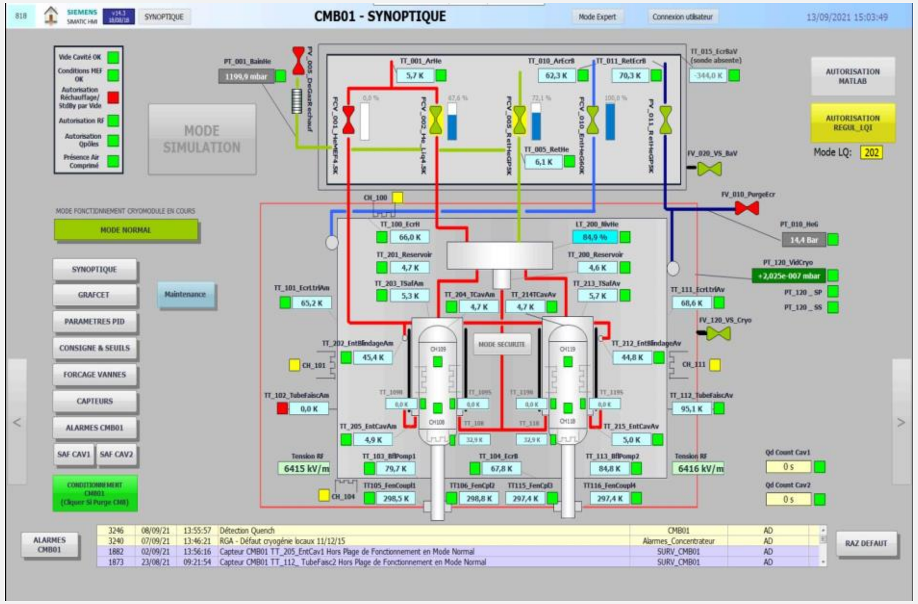

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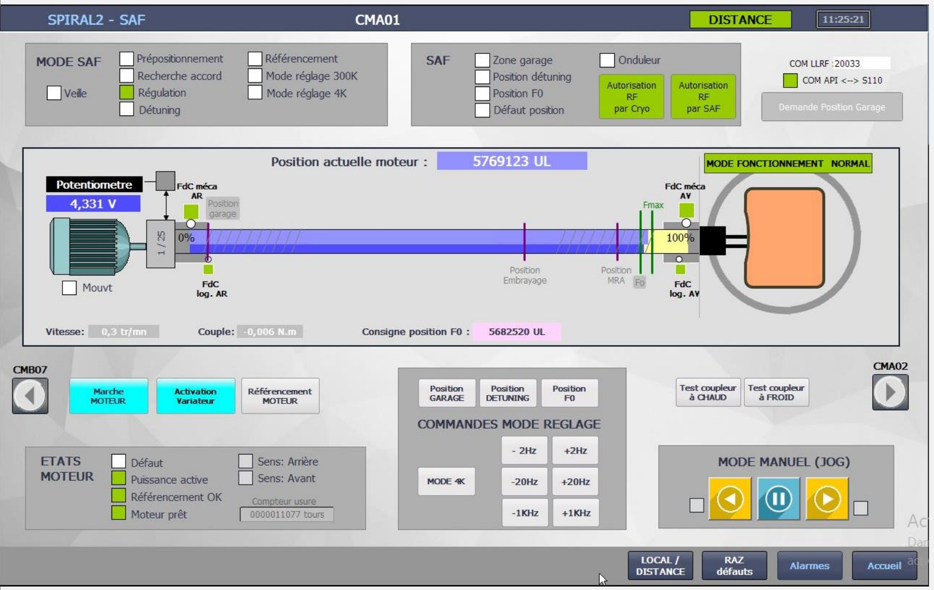

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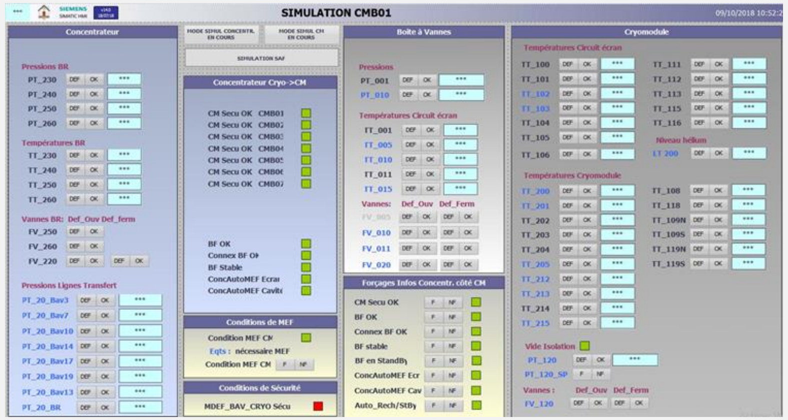

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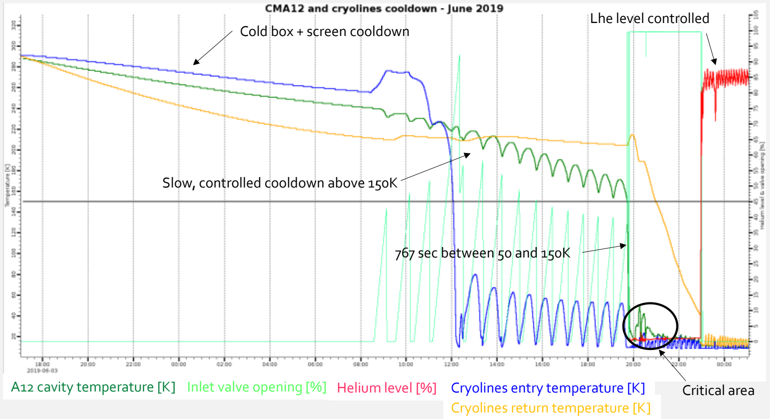

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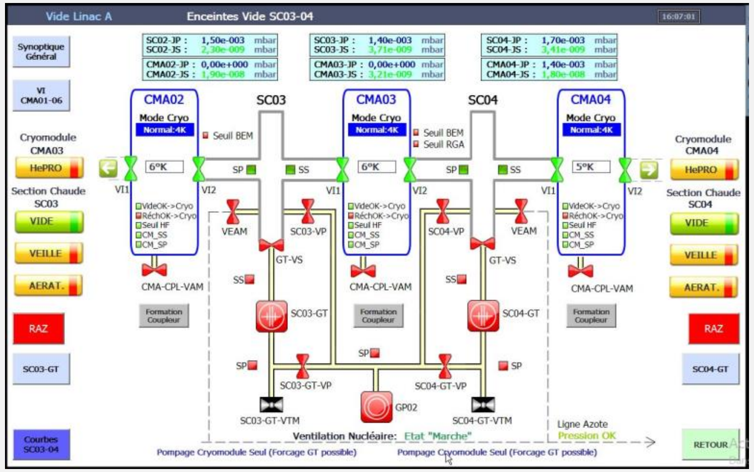

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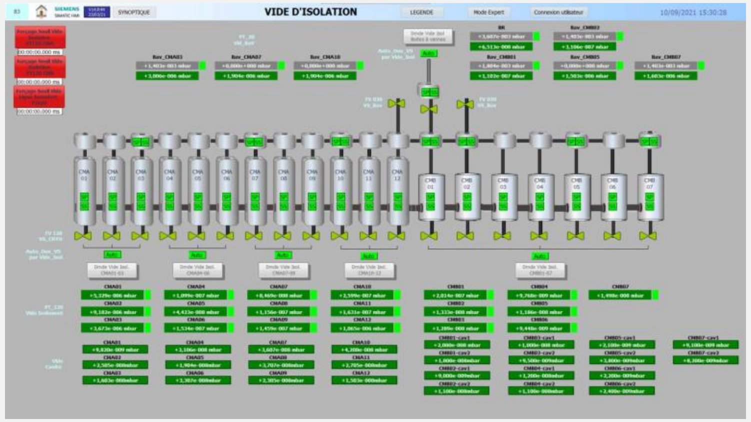

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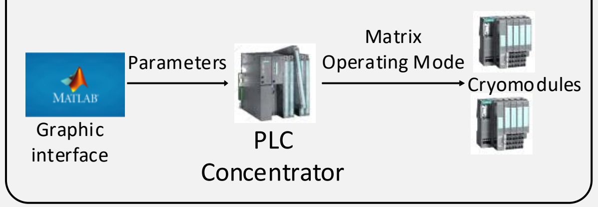

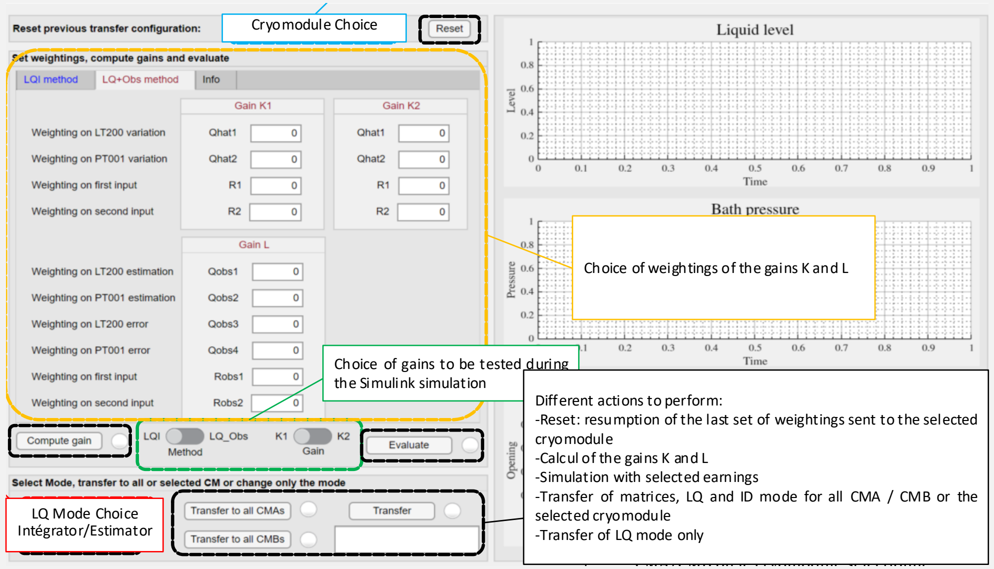

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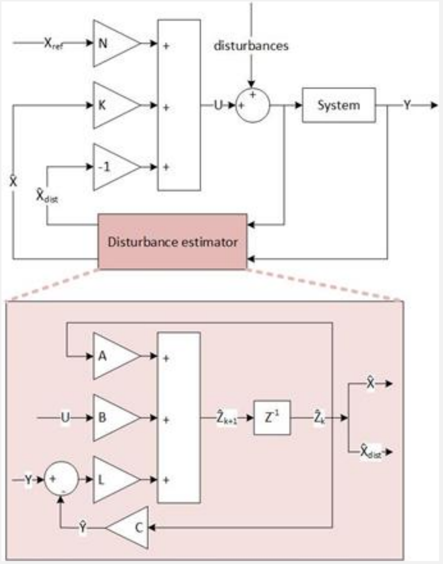

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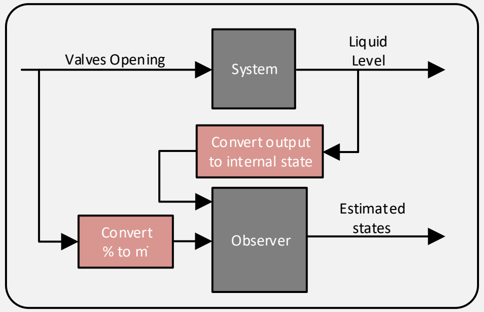

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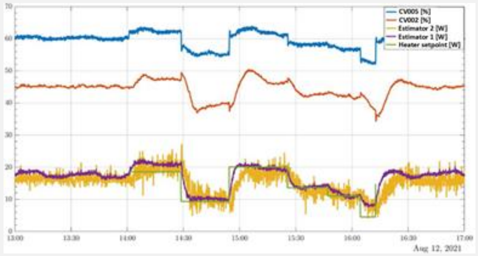

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