Modelling an Automatic Controller for Parabolic Trough Solar Fields under Realistic Weather Conditions

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Motivation: why do we do this?

- Improve competitiveness of the technology
  →optimization of SF controllers
- New HTF used (e.g. Molten salt and Si-oil)
  → need testing

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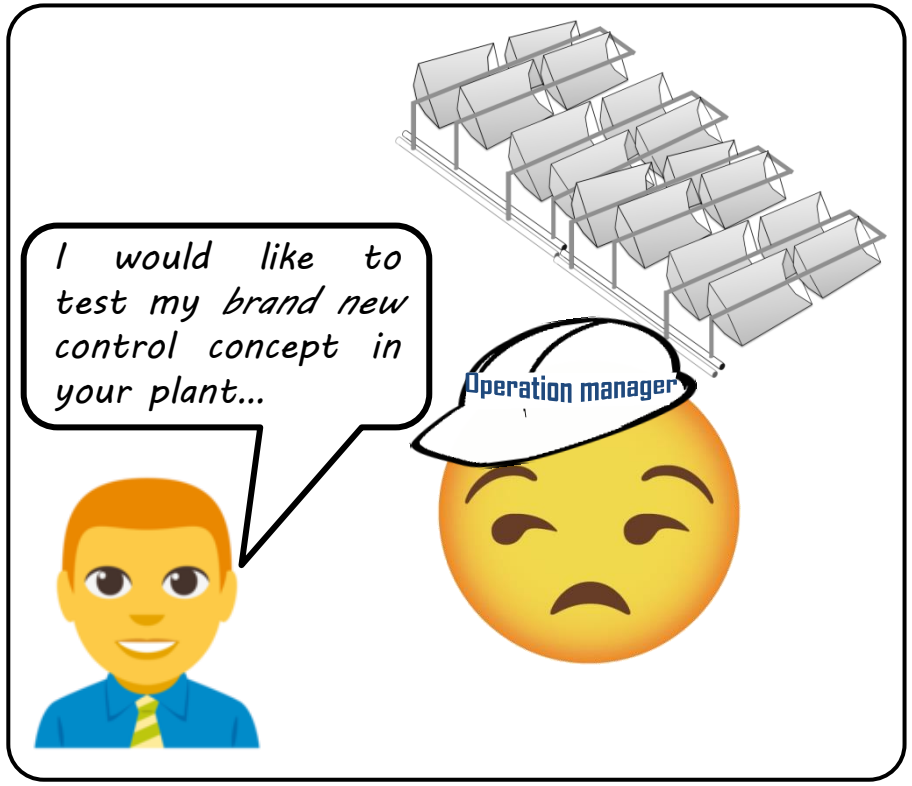

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However

1. Expensive to do it in real power plants.
2. Difficult to quantify the benefit/loss caused by the control concepts

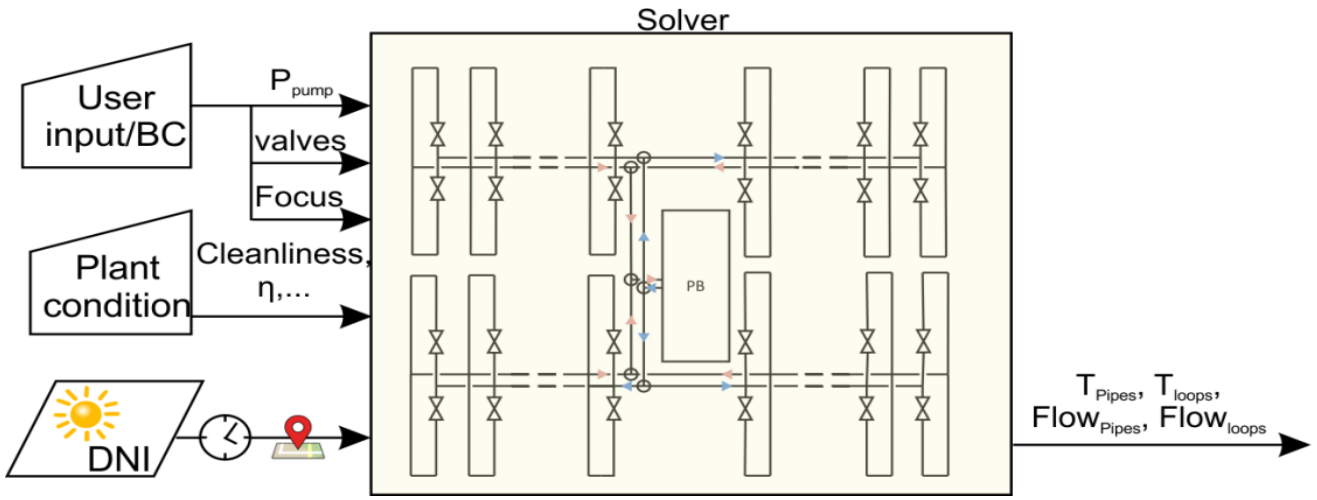
The Virtual Solar Field (VSF)

About:

An in-house dynamic simulation tool capable of representing a complete solar field in high level of detail using a computationally efficient implementation in C++.

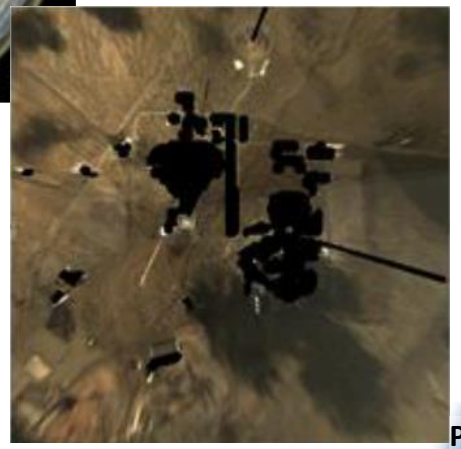
Main features:

- Compute flow distribution in the field according to the plant condition.
- Flexible plant layout and operation/ maintenance.
- Use spatially varying DNI.
- Add-on solar field and collector controllers.



Realistic weather conditions (DNI maps)

- Based on cloud or shadow cameras
- Resolution:
  Up to 5mx5m and 15s



Pictures from: P. Kuhn, B. Nouri, S. Wilbert, C. Prahl, N. Kozonek, T. Schmidt, Z. Yasser, L. Ramirez, L. Zarzalejo, A. Meyer, L. Vuilleumier, D. Heinemann, P. Blanc, and R. Pitz-Paal, EUPVSEC conference proceedings (2017), accepted for publication.

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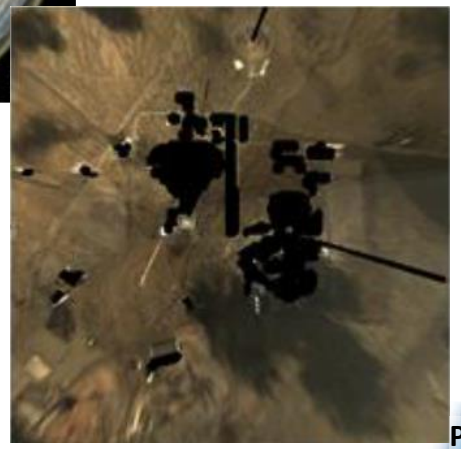
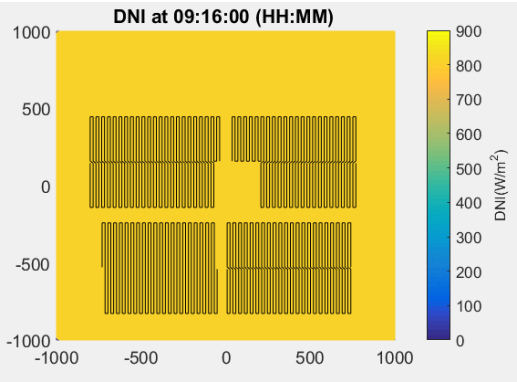
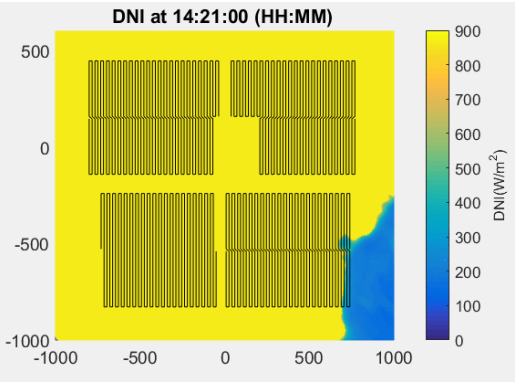
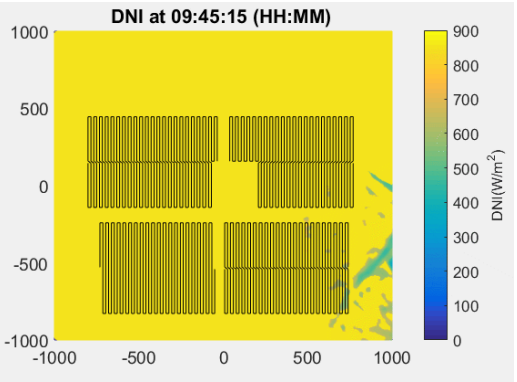
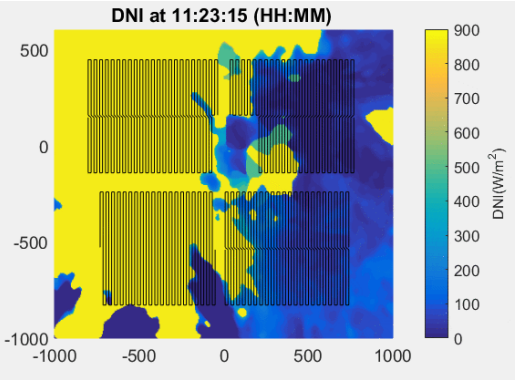
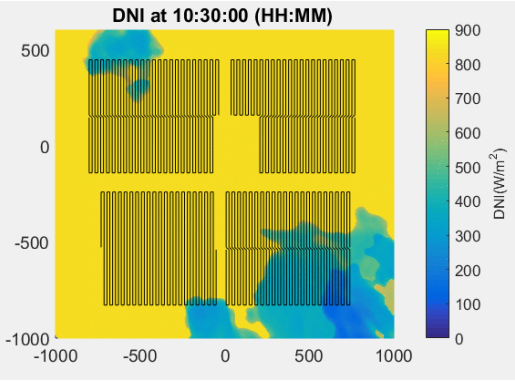


Clear-sky	Thick small clouds	Random quick clouds
		
Thick with holes	**Large thick**	
		

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Quantify controller performance

- Penalize off-design operation due to controller.
  - Defocusing instances due to over temperatures
  - Reduced PB efficiency
  - Reduced TES efficiency

  } due to reduced T_{out}

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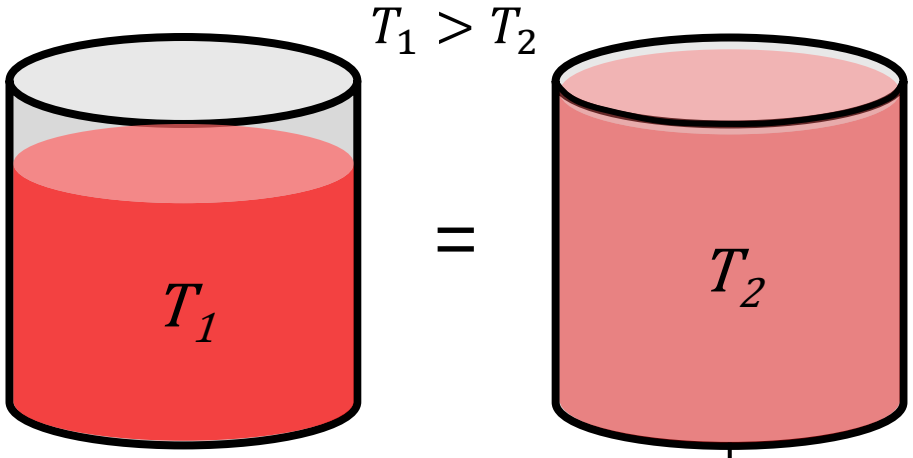

$Q_{TES,1} = Q_{TES,2}$ → Collectors defocus due to overload (OL)

Compute controller penalties

annual yield simulation

greenius
THE GREEN ENERGY SYSTEM ANALYSIS TOOL

$\eta_{\mathrm{PB,a}}$

$$\eta_{PB} = \frac{E_a}{Q_{PB,a}}$$

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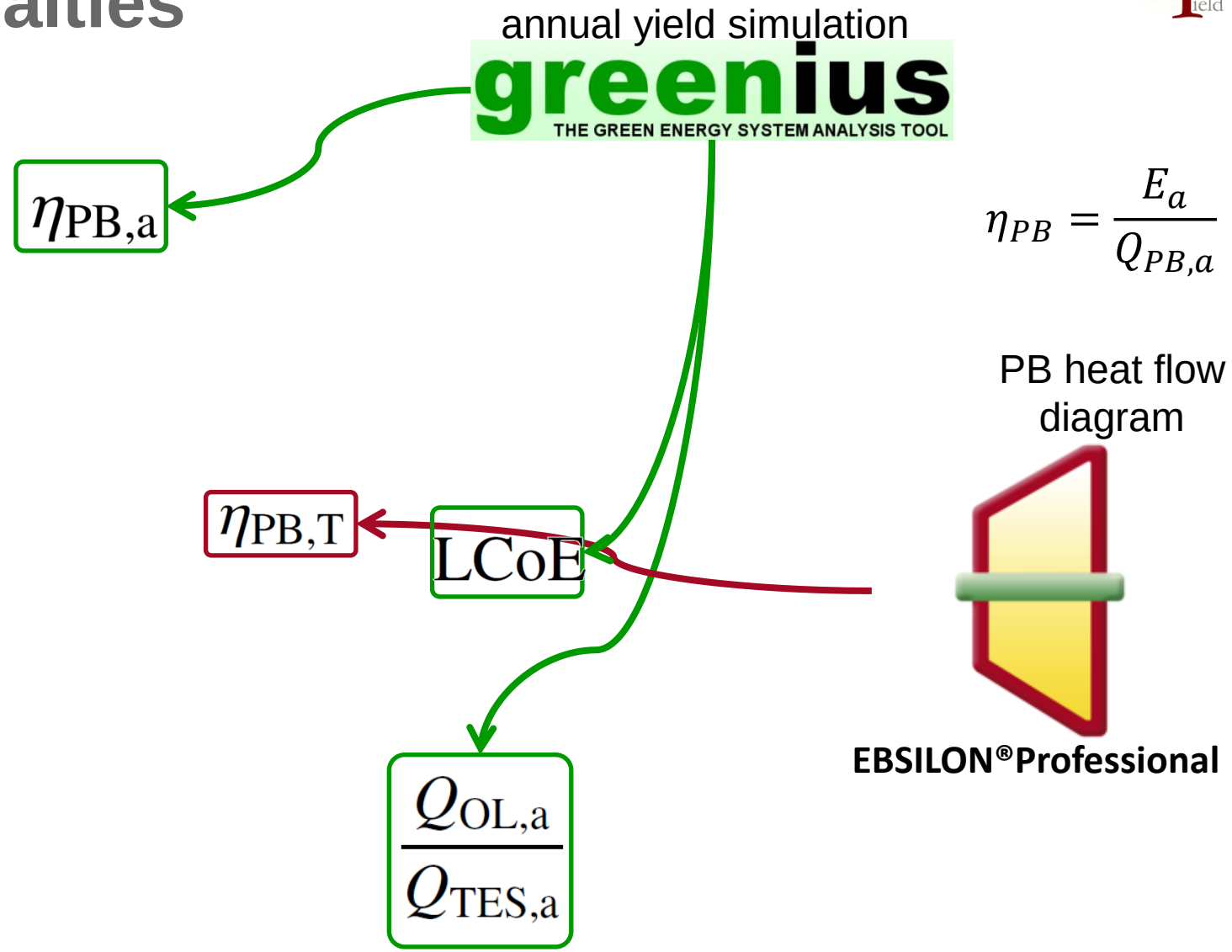

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$$p_{\mathrm{def}} = Q_{\mathrm{def}} \cdot \boxed{\eta_{\mathrm{PB,a}}} \cdot \mathrm{LCoE}$$

$$\eta_{PB} = \frac{E_a}{Q_{PB,a}}$$

$$Q_{\mathrm{def}} = \int \dot{Q}_{\mathrm{th,SF}}(t) \cdot \frac{1-f(t)}{f(t)} dt$$

- PB efficiency

$$p_{\mathrm{dT}} = Q_{\mathrm{th,SF}} \cdot \eta_{\mathrm{PB,a}} \cdot \left(1 - \frac{\boxed{\eta_{\mathrm{PB,T}}}}{\eta_{\mathrm{PB,T_0}}}\right) \cdot \boxed{\mathrm{LCoE}}$$

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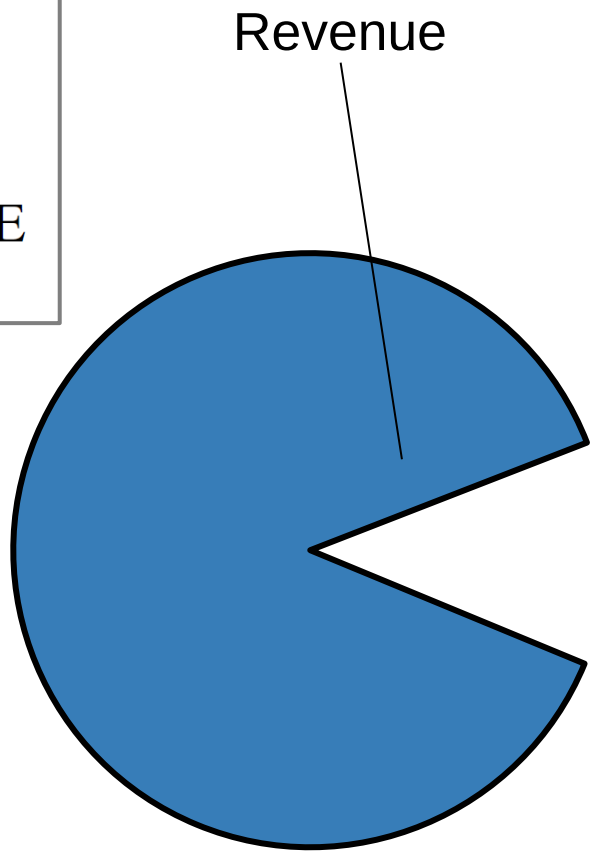

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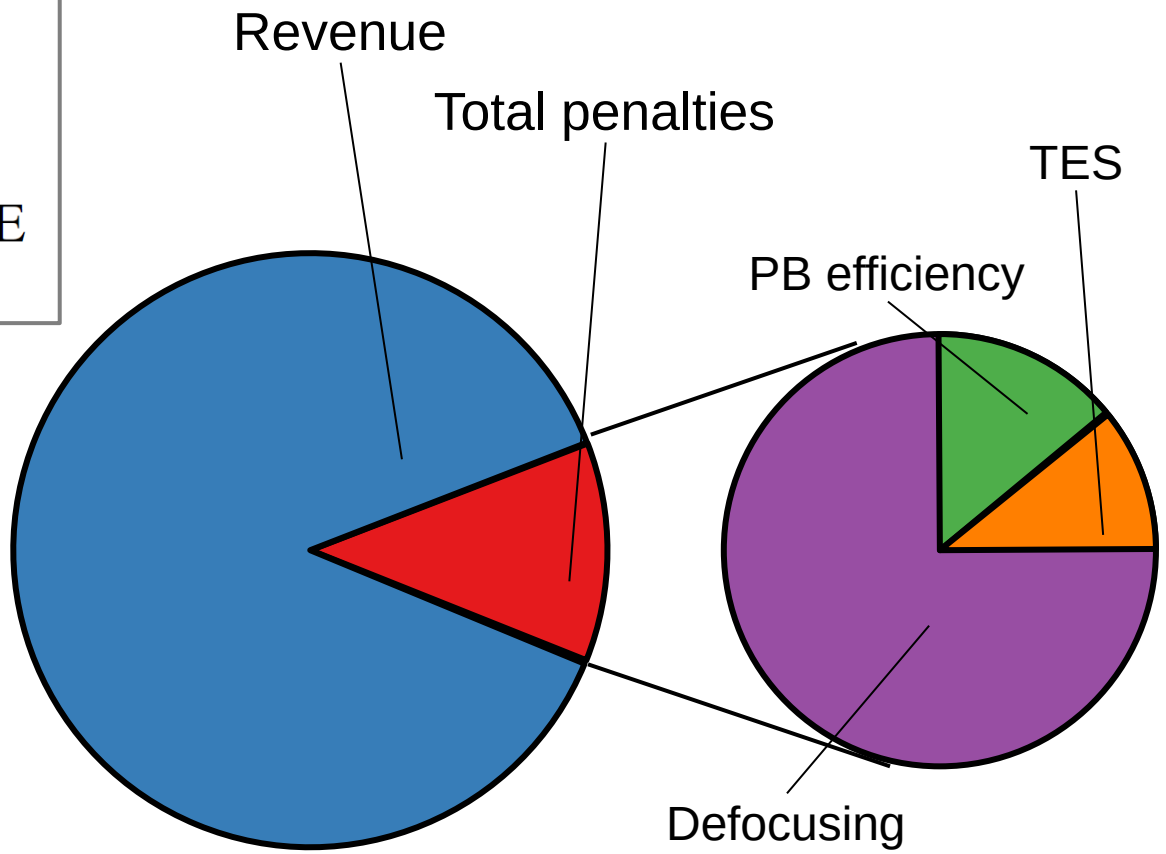

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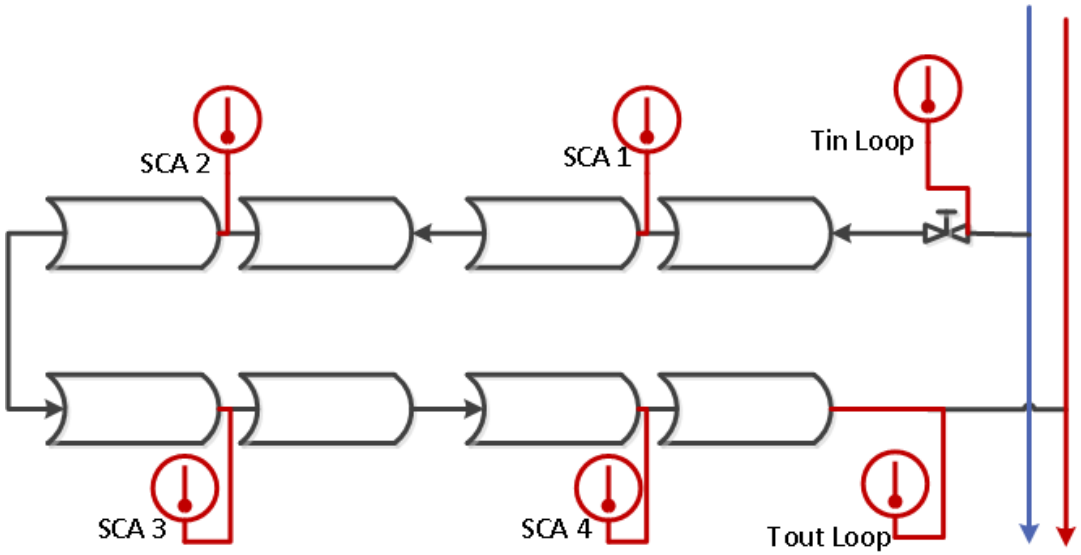
Basic control elements in VSF – Collector focus

Controller input



Local PI Controllers

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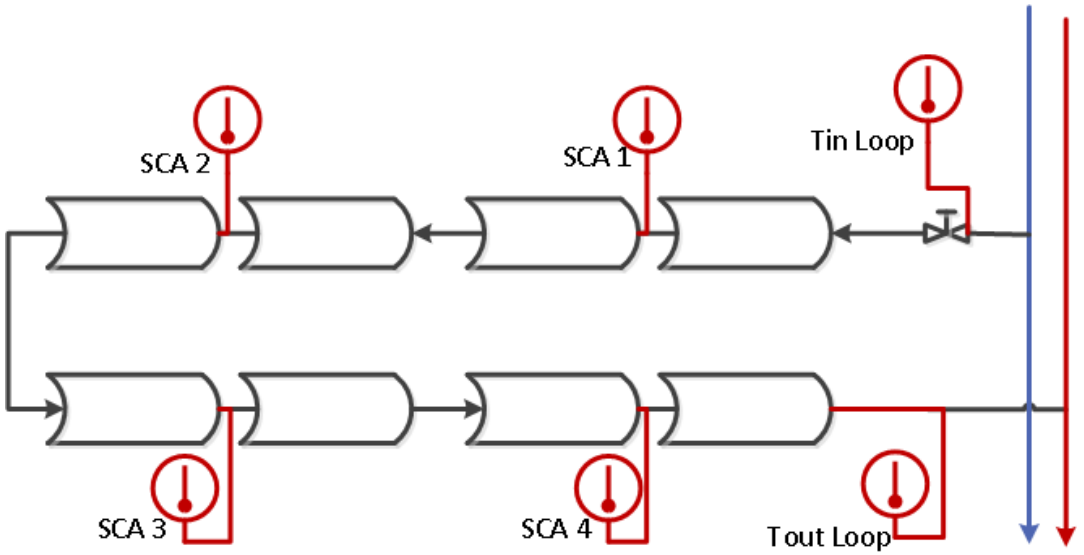

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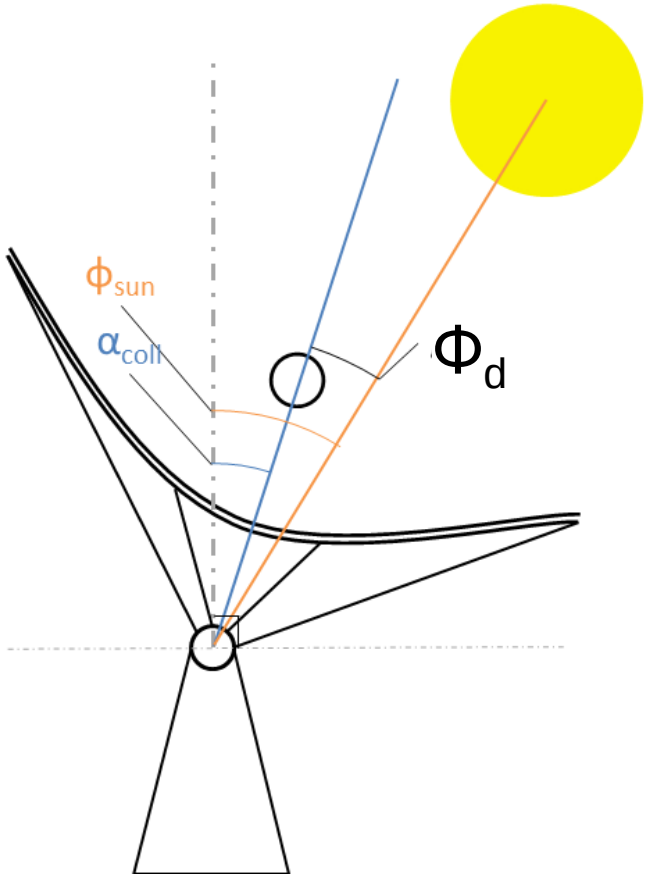

Basic control elements in VSF – Main flow

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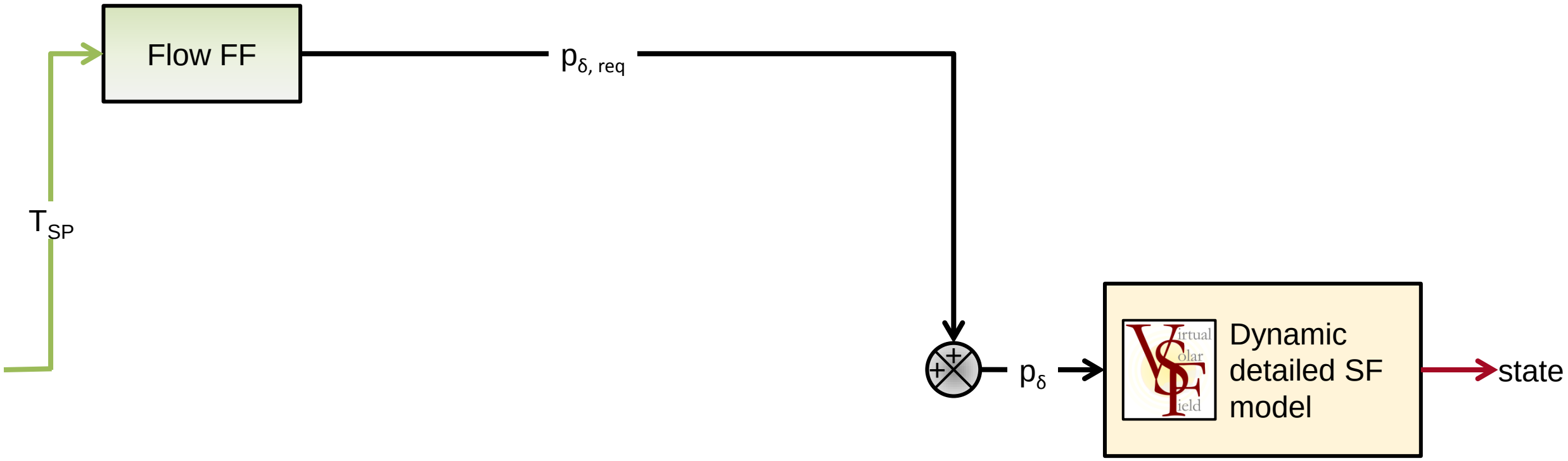

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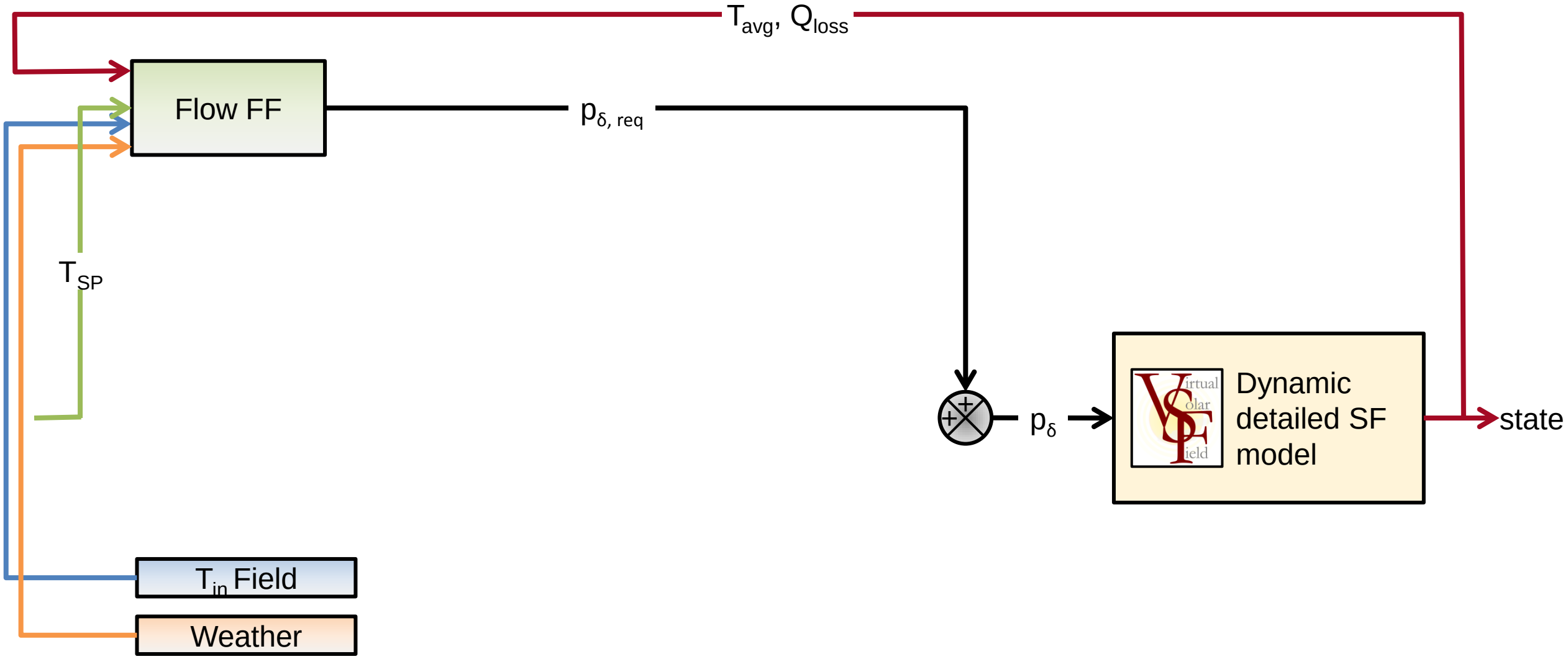

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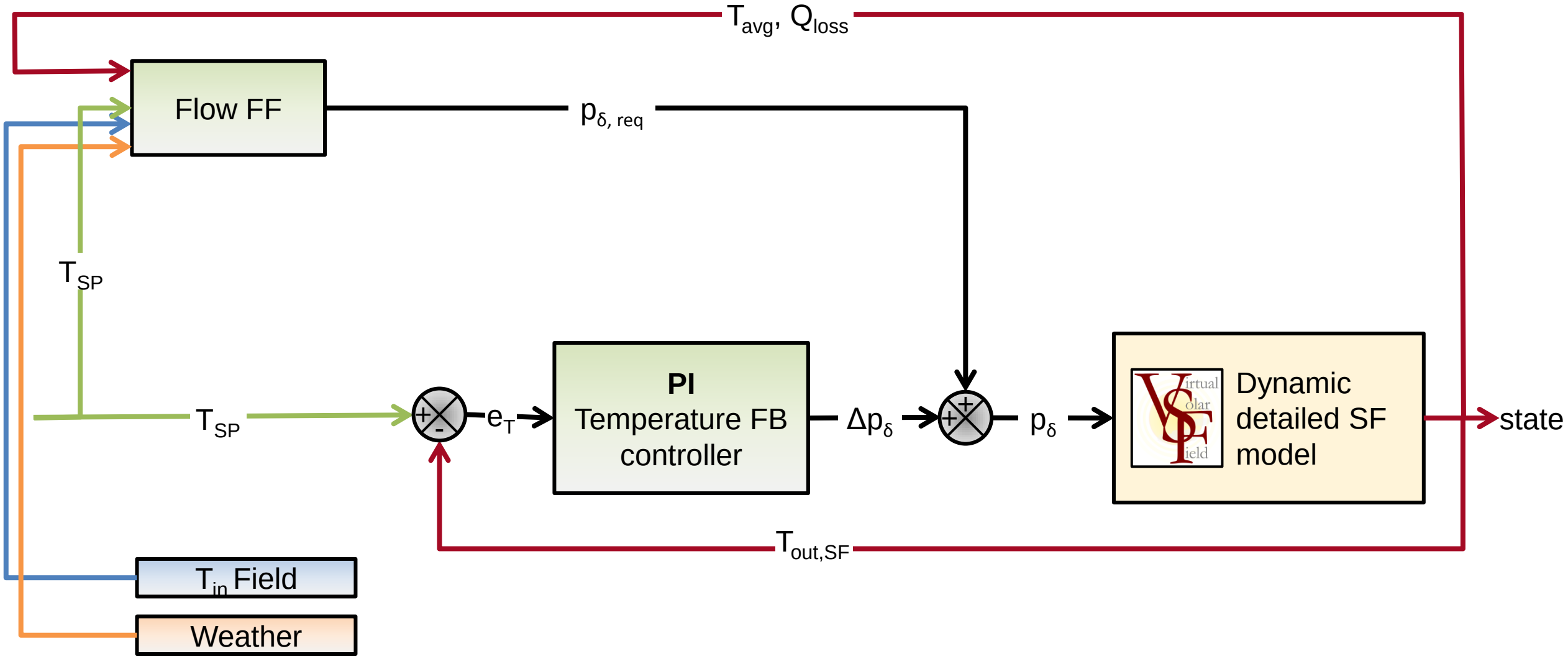

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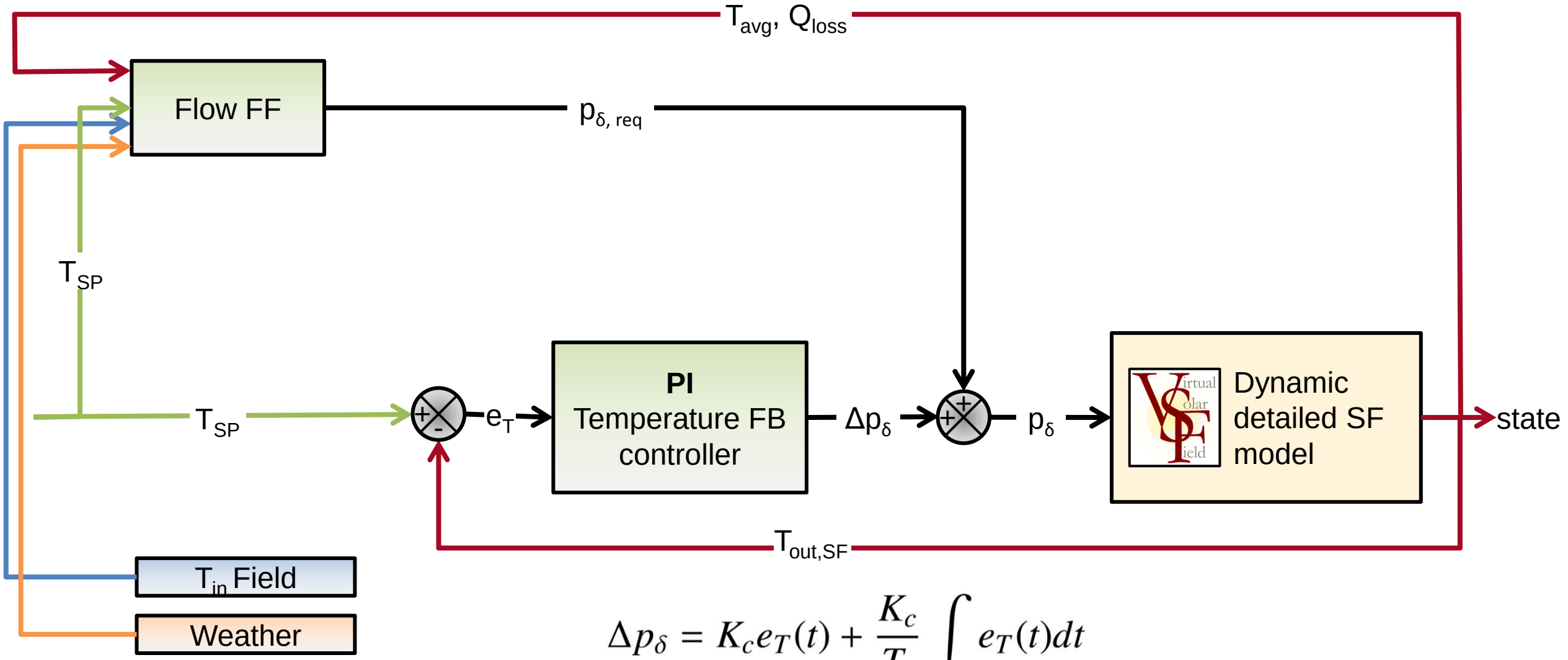
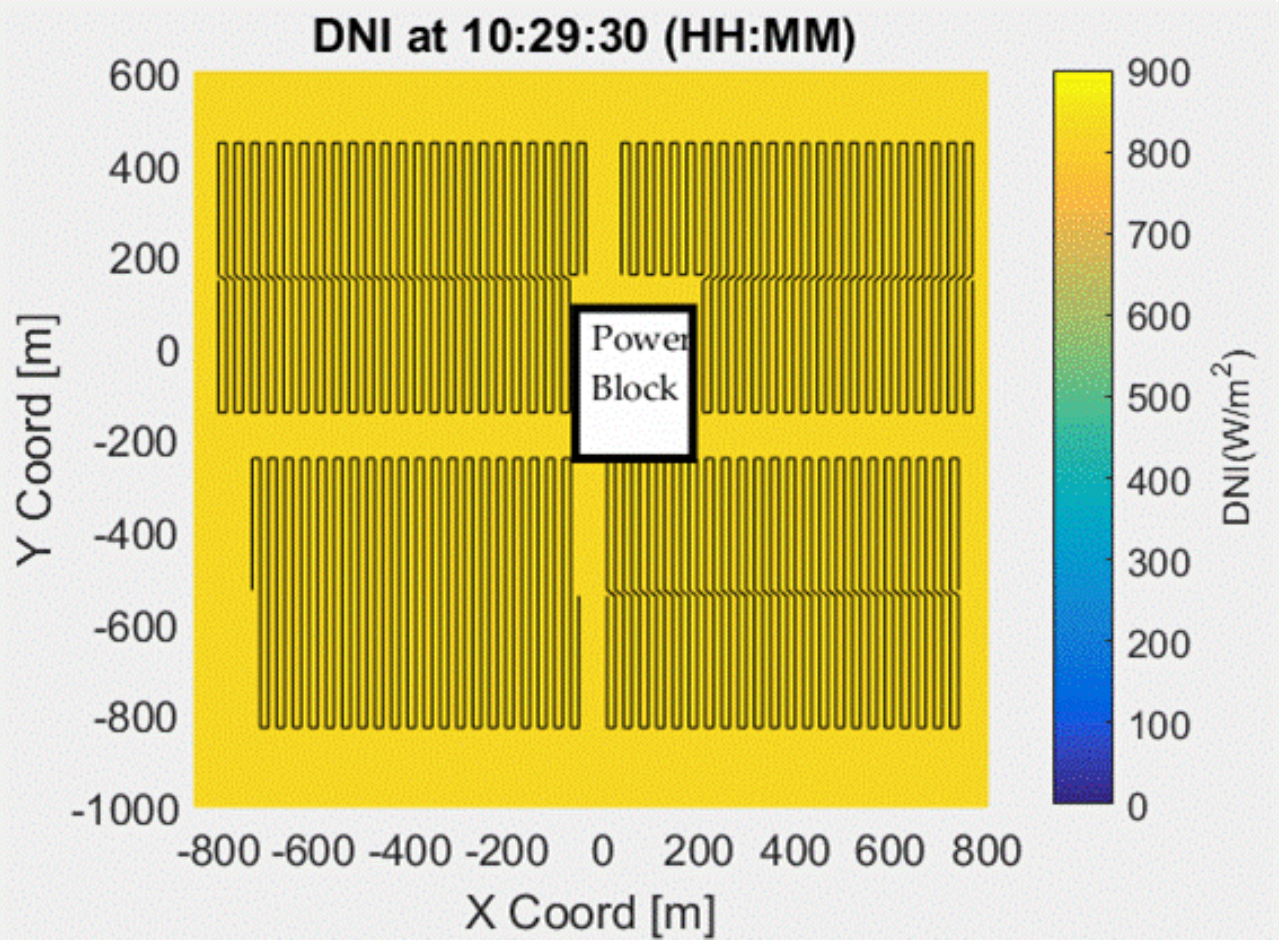


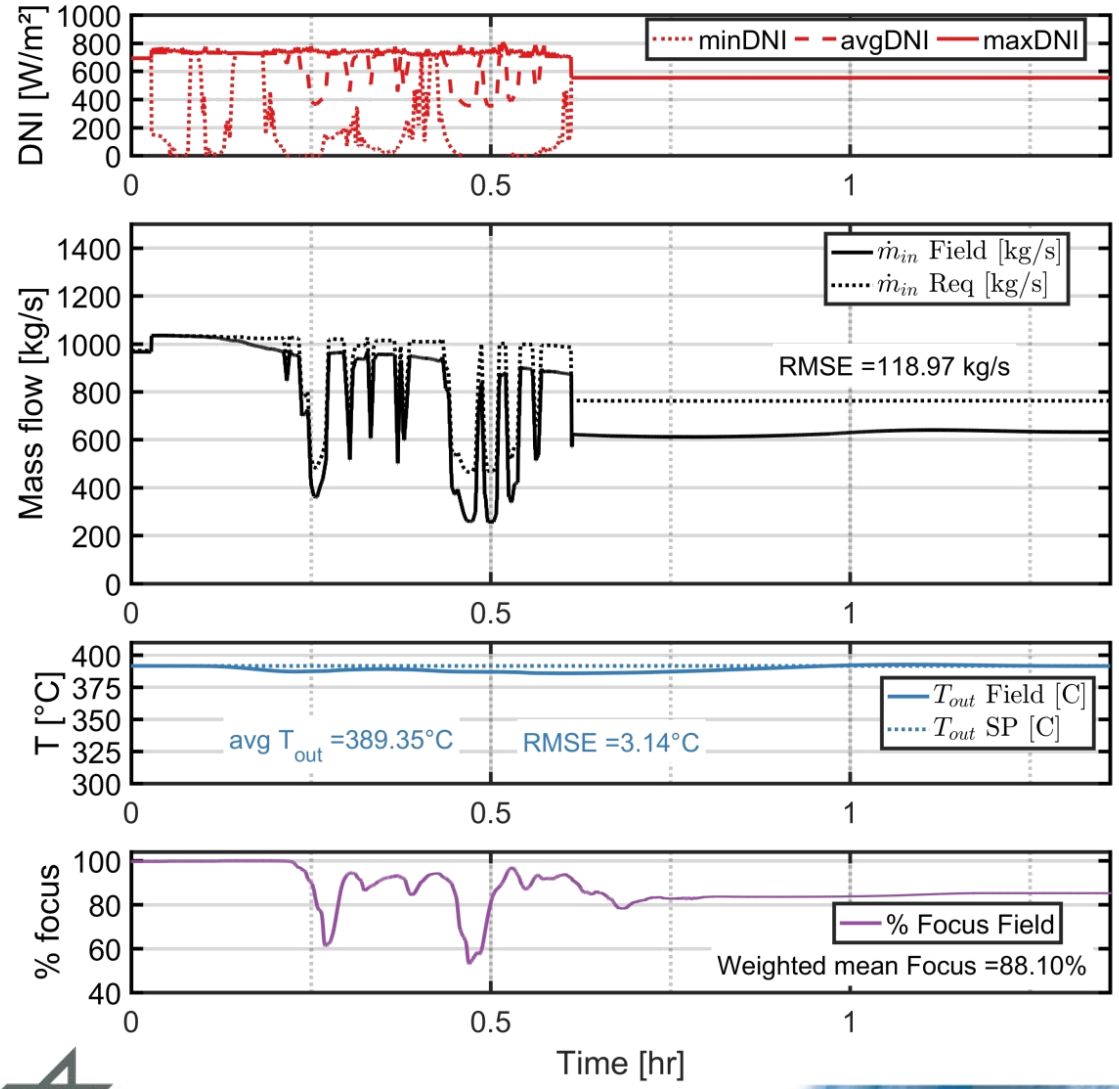
$$\Delta p_\delta = K_c e_T(t) + \frac{K_c}{T_i} \int e_T(t) dt$$

Test case

- La Africana power plant
- 168 loops in 4 subfields
- DNI from shadow cameras in PSA, Almería
- Clouds category: Large thick



Basic flow controller



T_{SP} = 391.5°C

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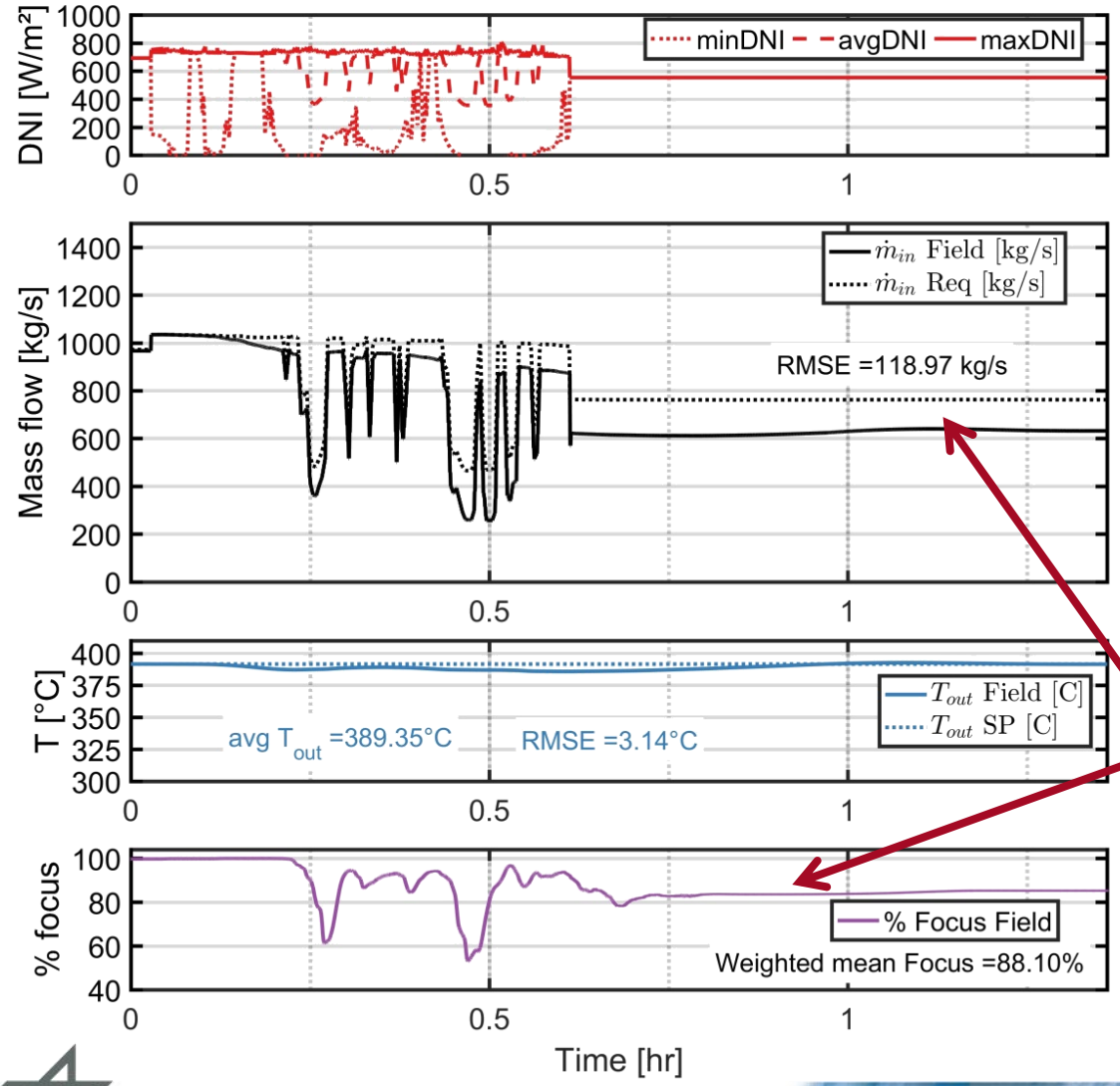

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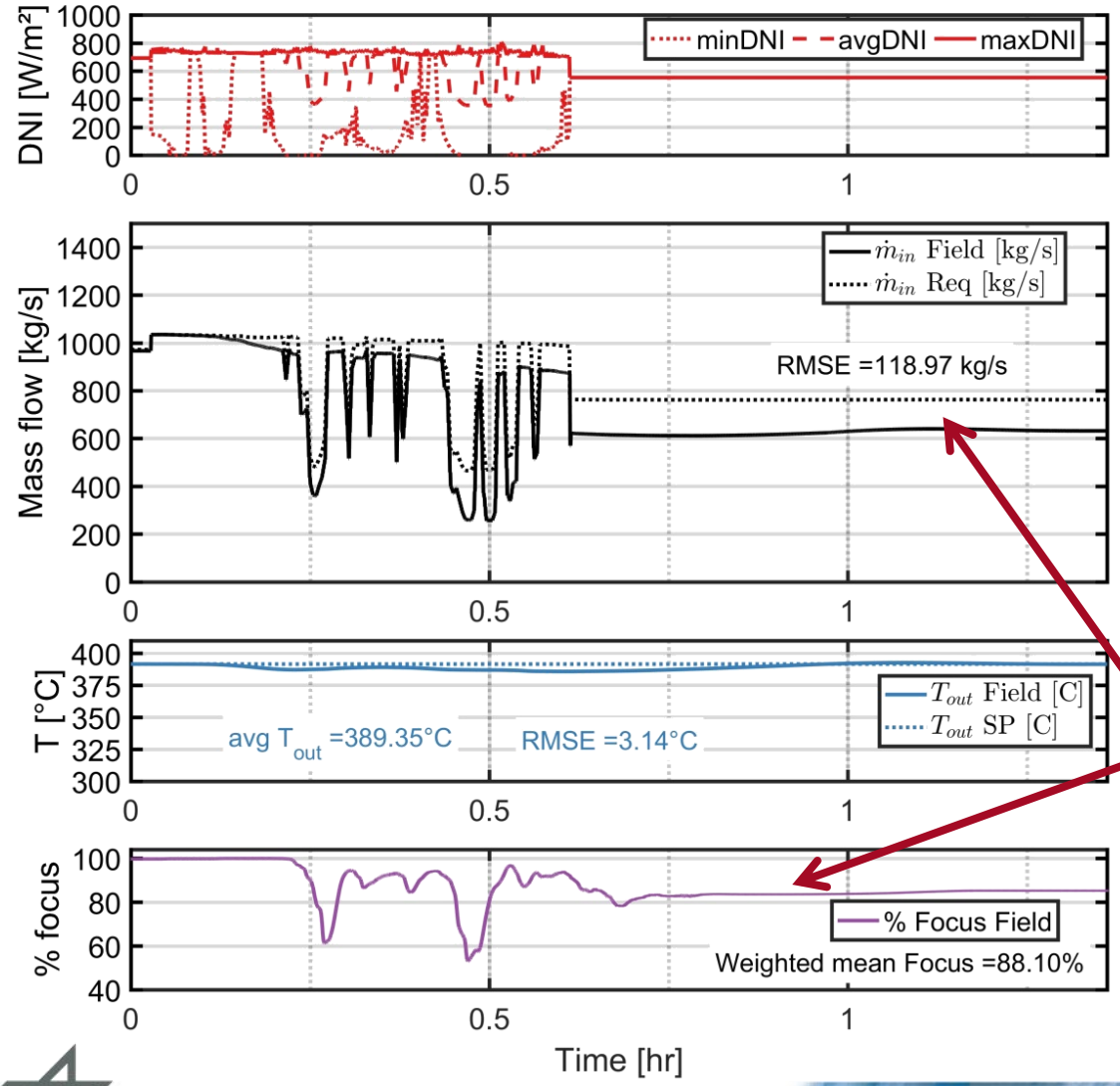

In power plants:

manual operator → forces more flow

→ collectors get back to focus

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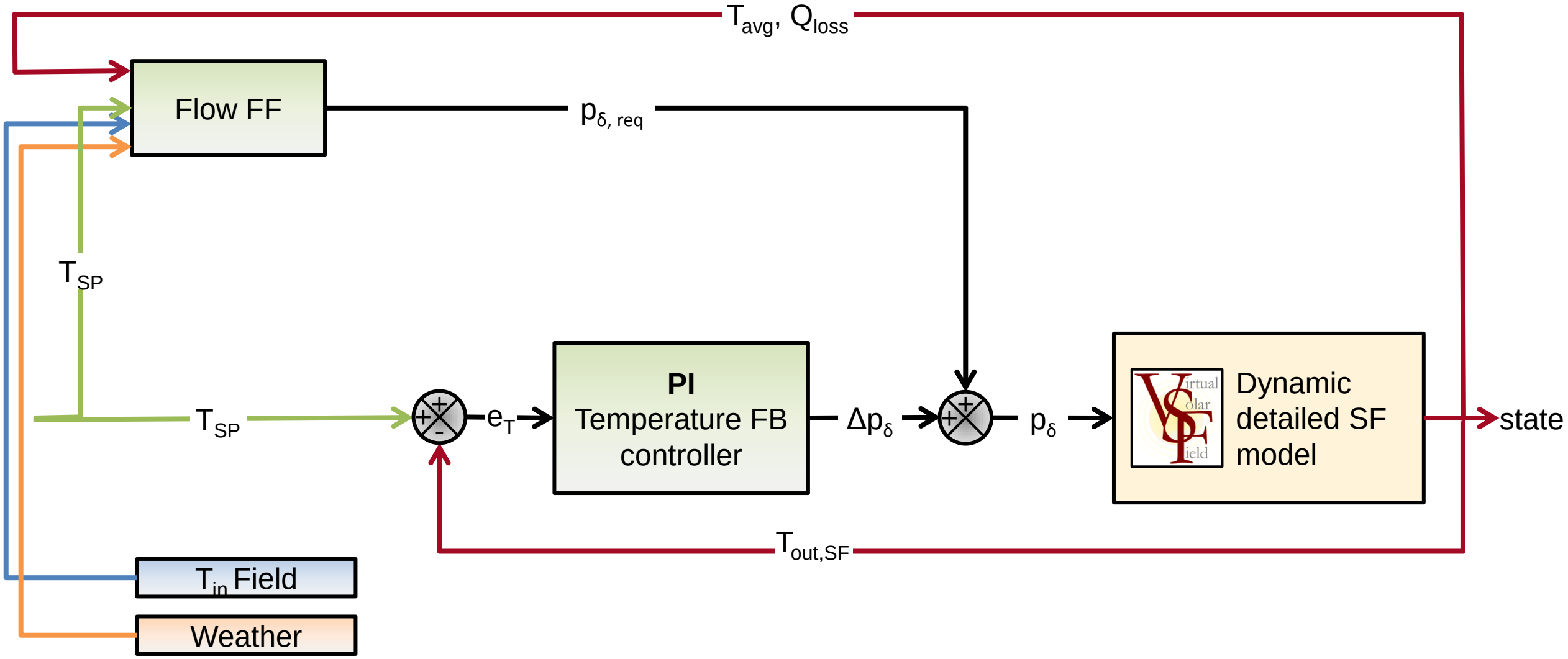
Automatic Flow controller



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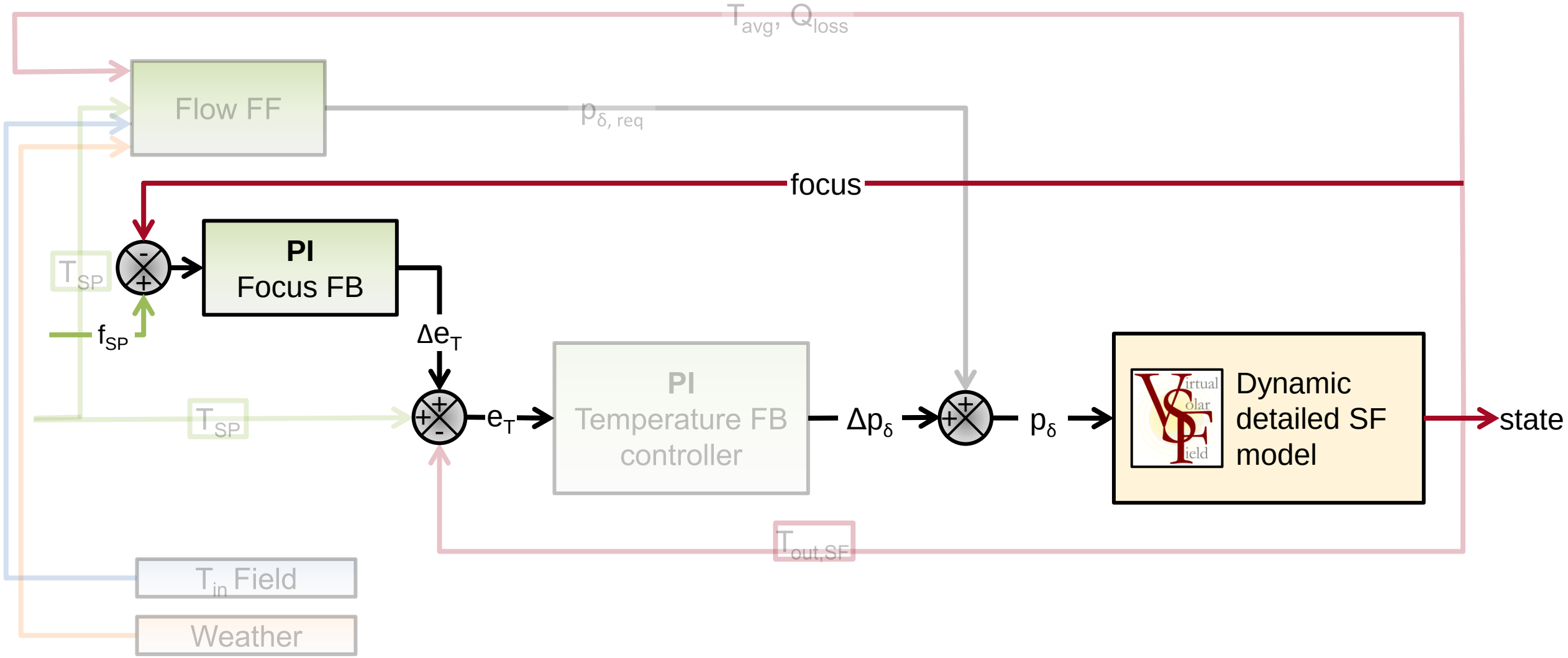

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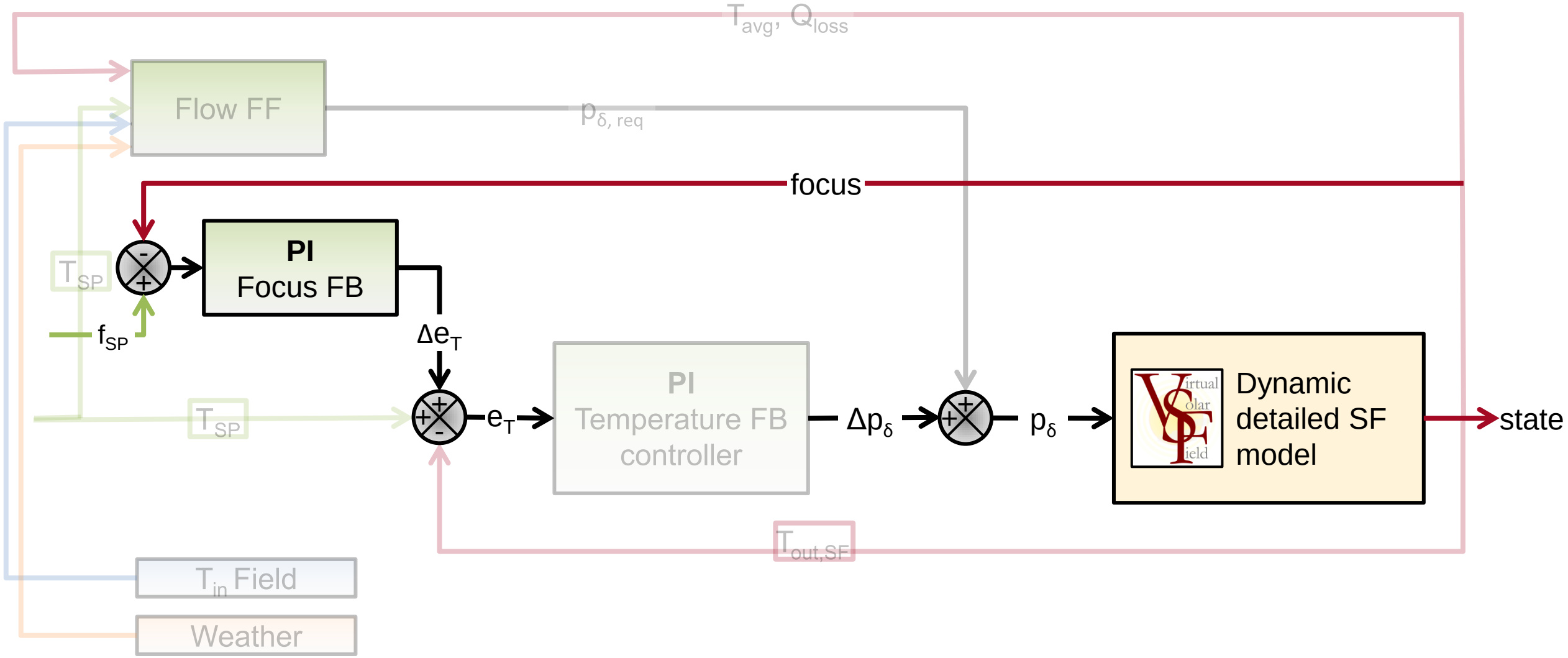
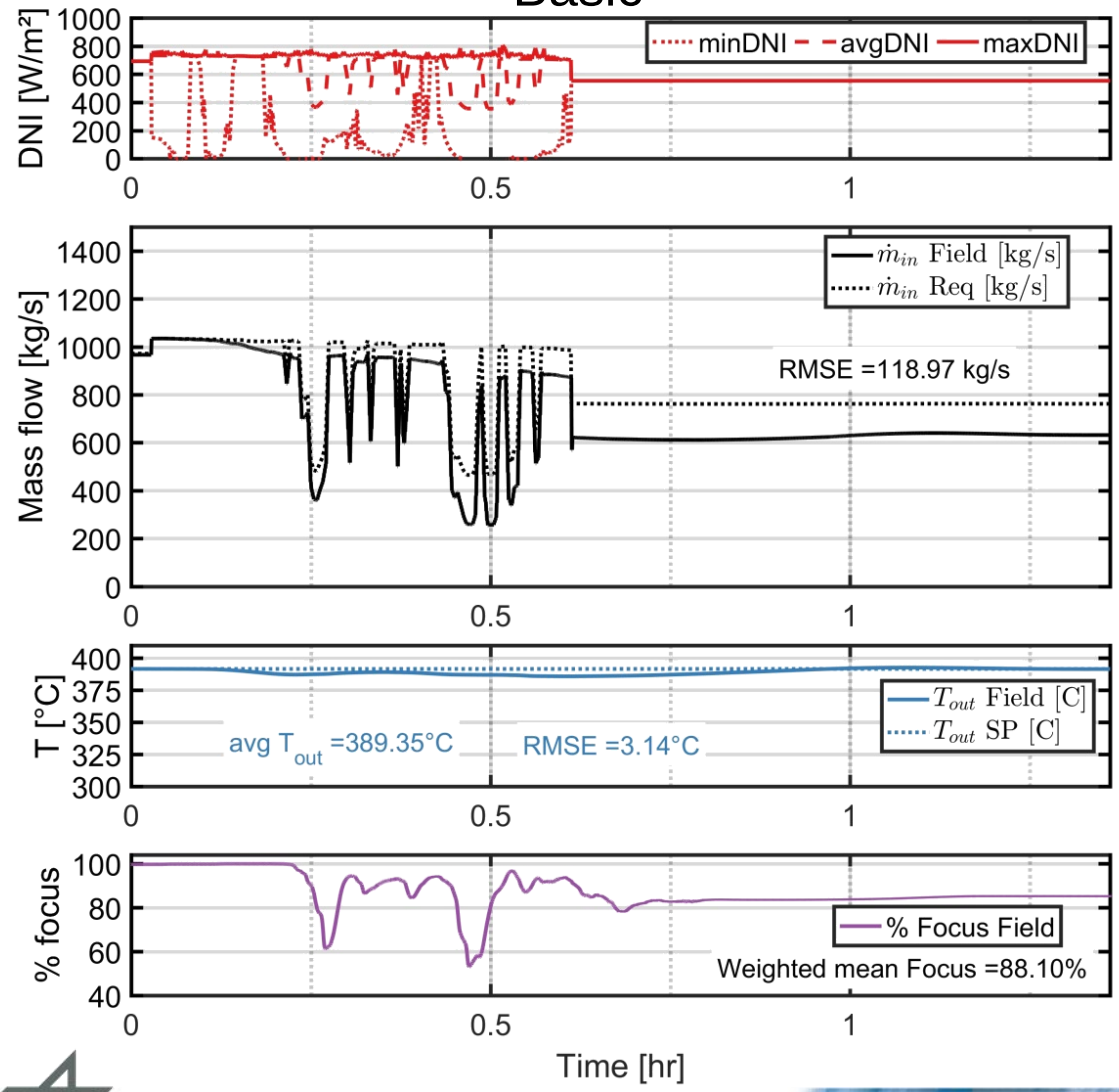


Benefit of automatic flow controller

Basic



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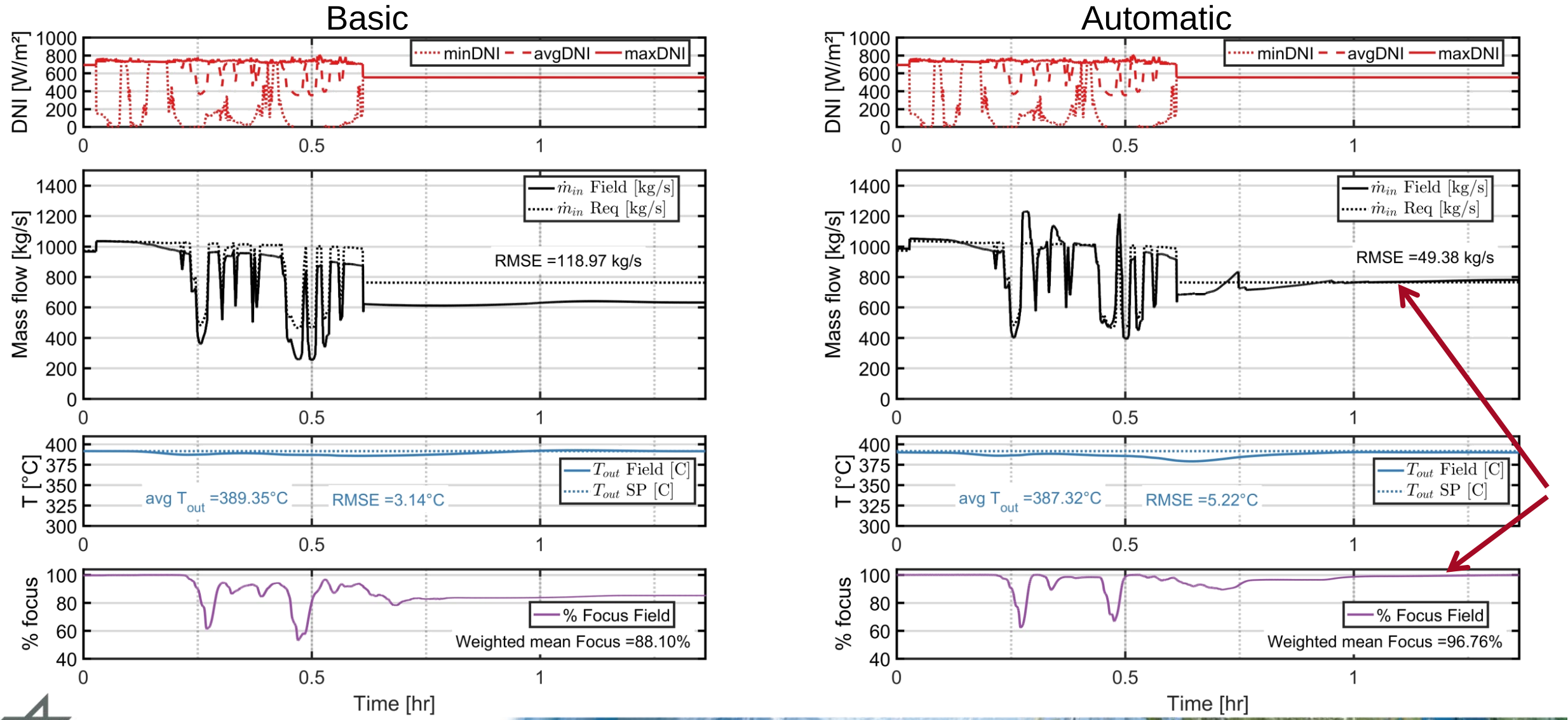

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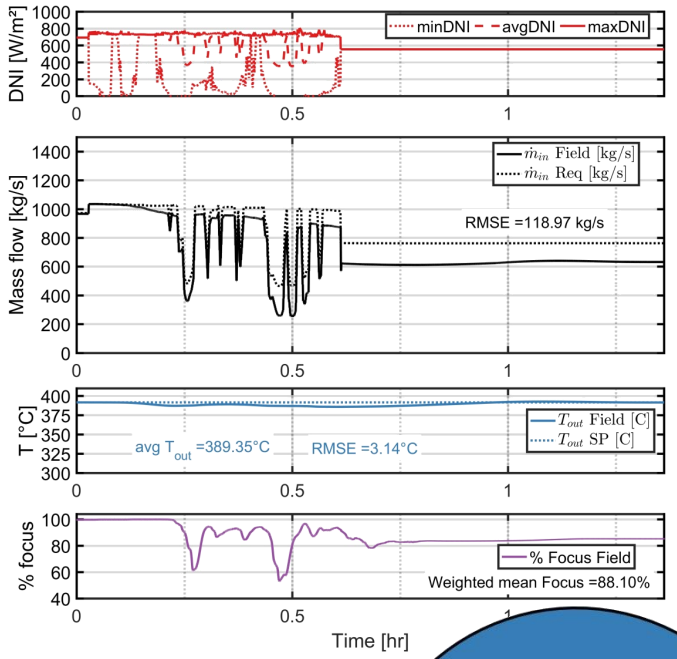

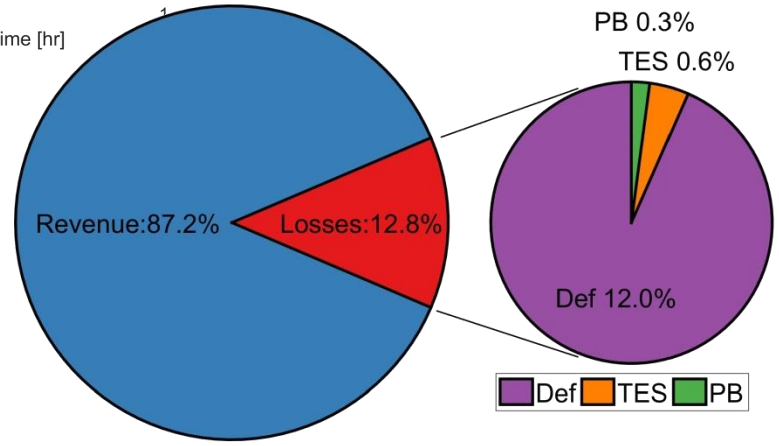

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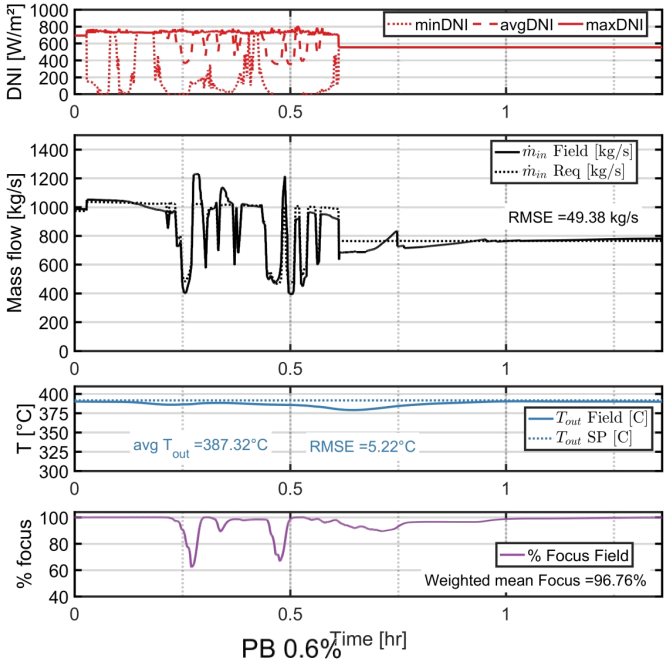

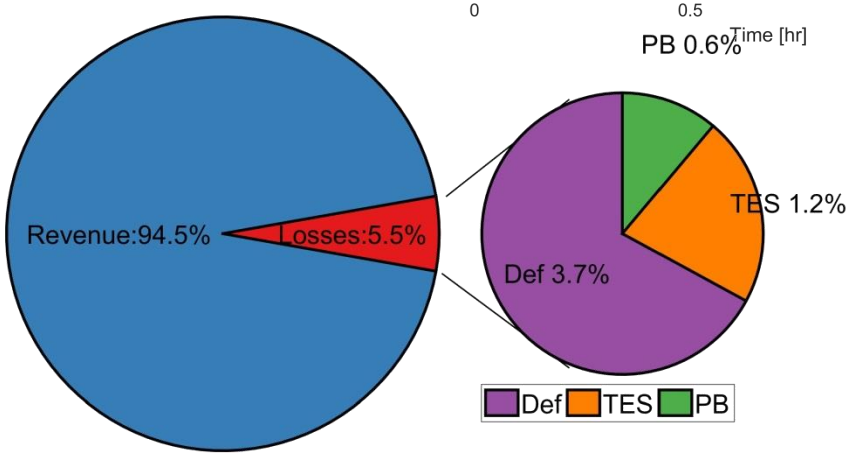

Some sources of errors in FF controller

$$\dot{m}_{req} = \frac{\dot{Q}_{sol} - \dot{Q}_{loss}}{\bar{c}_p\left(T_{out,req} - T_{in}\right)}$$

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- Spatial variation of DNI
- Uncertainty of mirror cleanliness
- Dependence on maintenance program of loops (e.g. loop shut-down)
- Broken absorber glass
- Errors in measurements

Dealing with errors in FF controller

- systematic +10% error in FF controller

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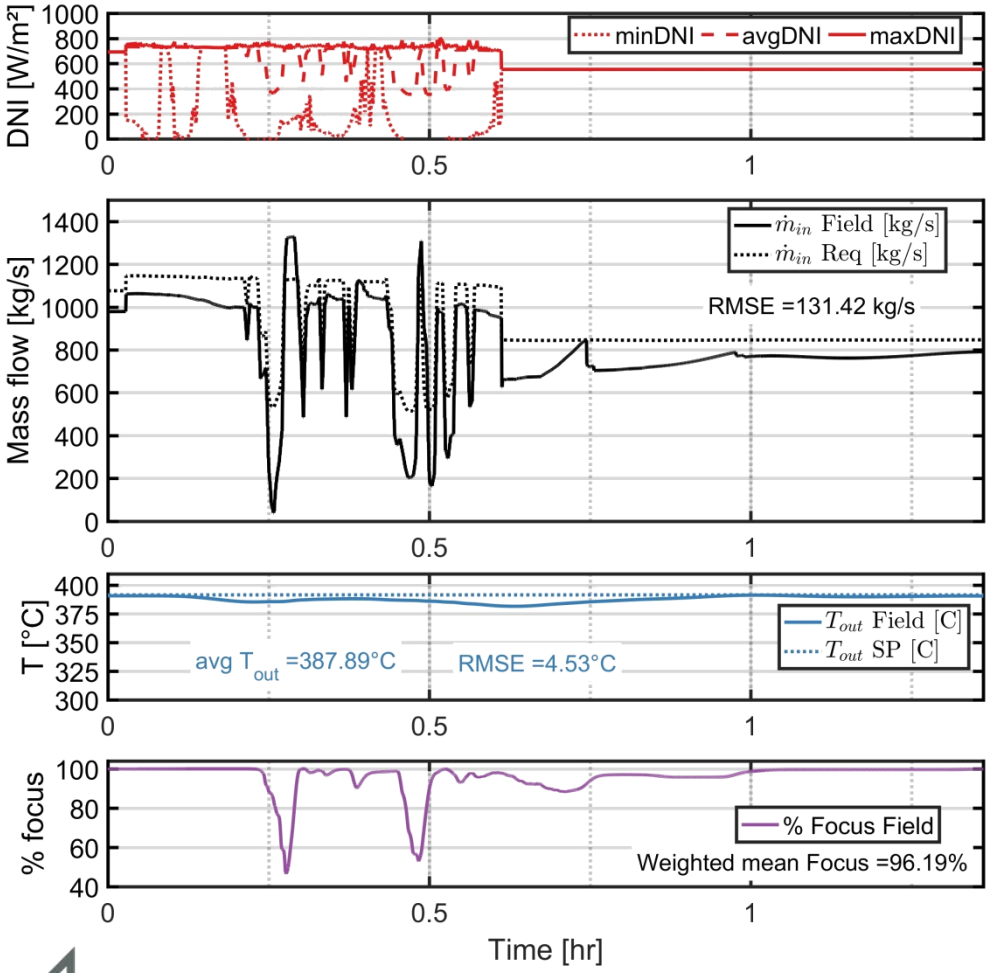

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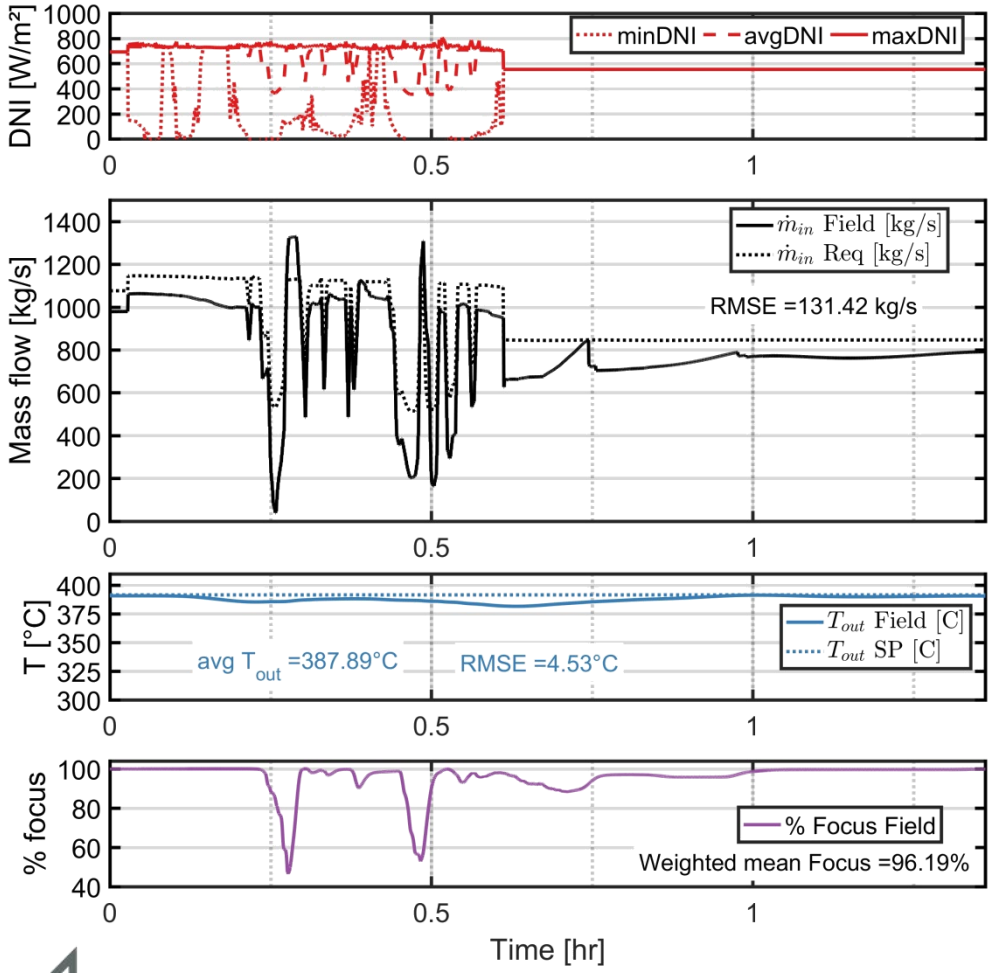

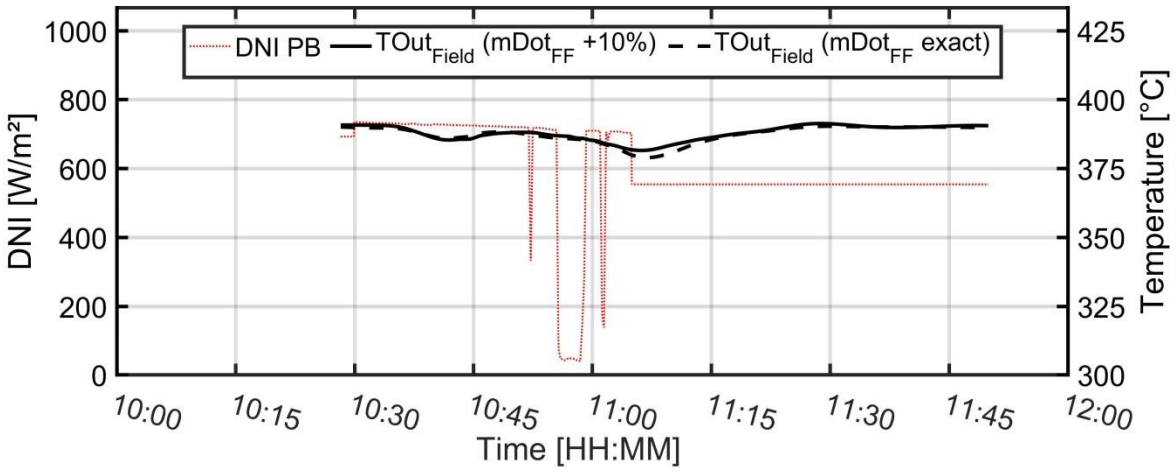

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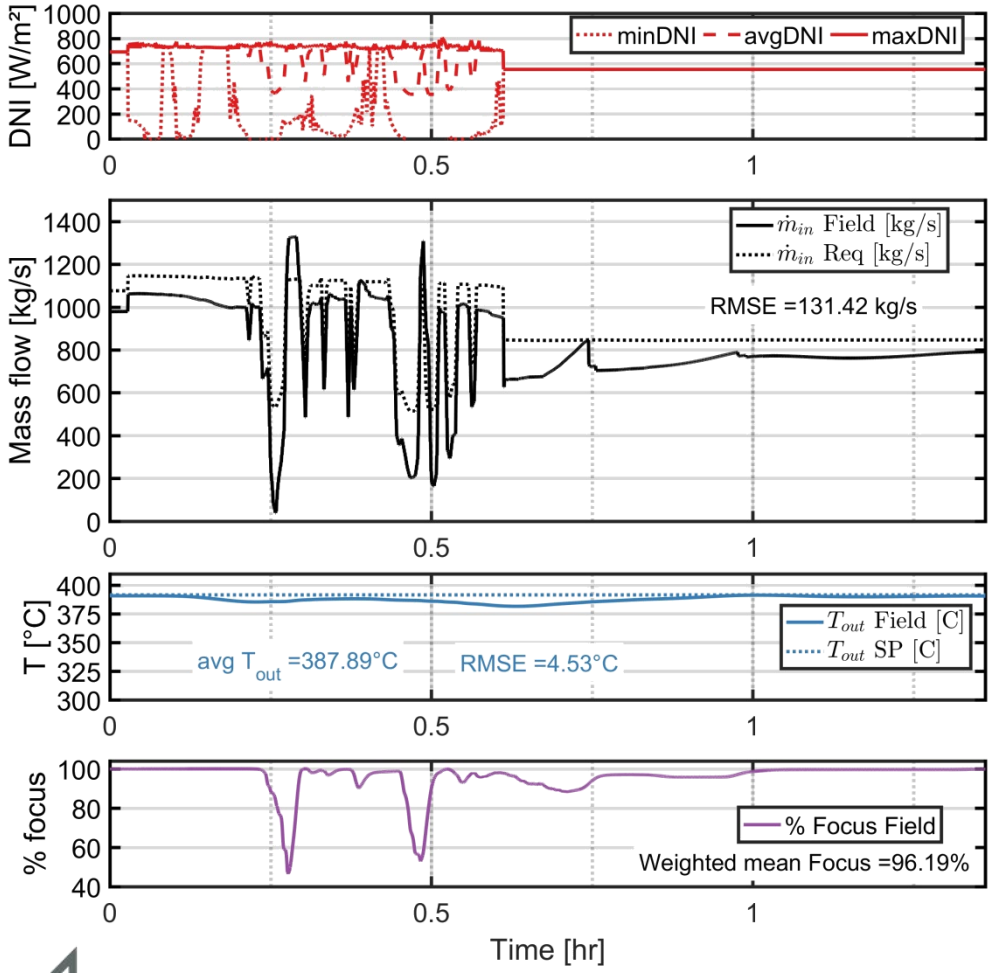
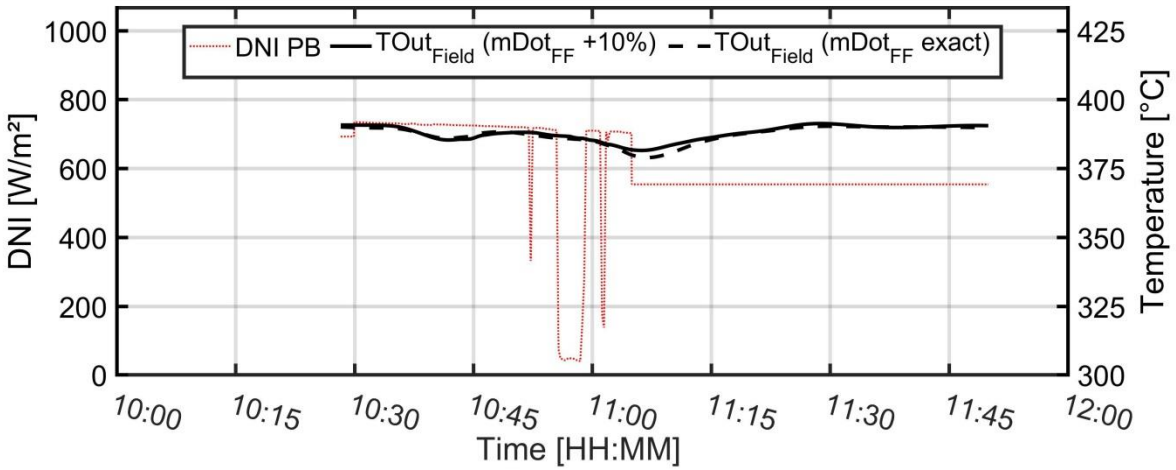
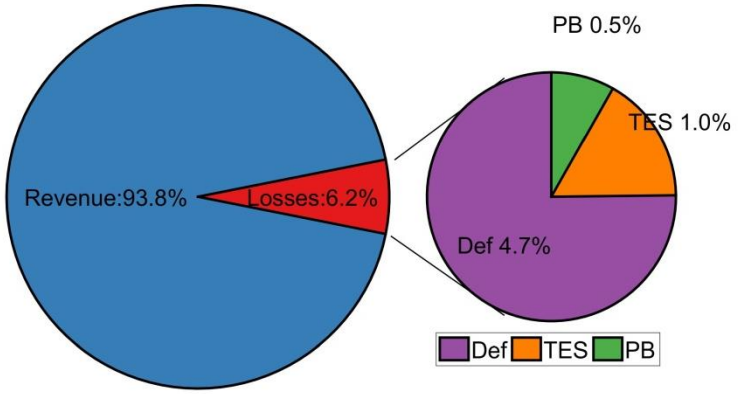
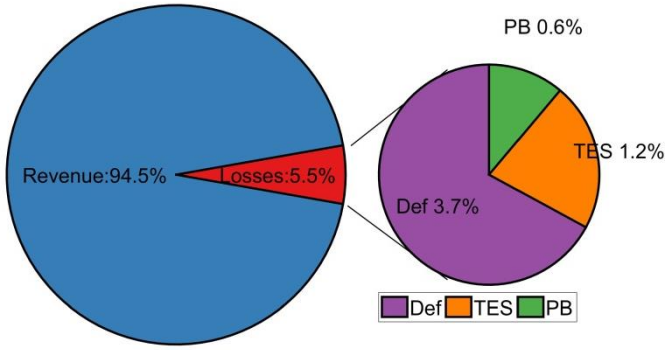




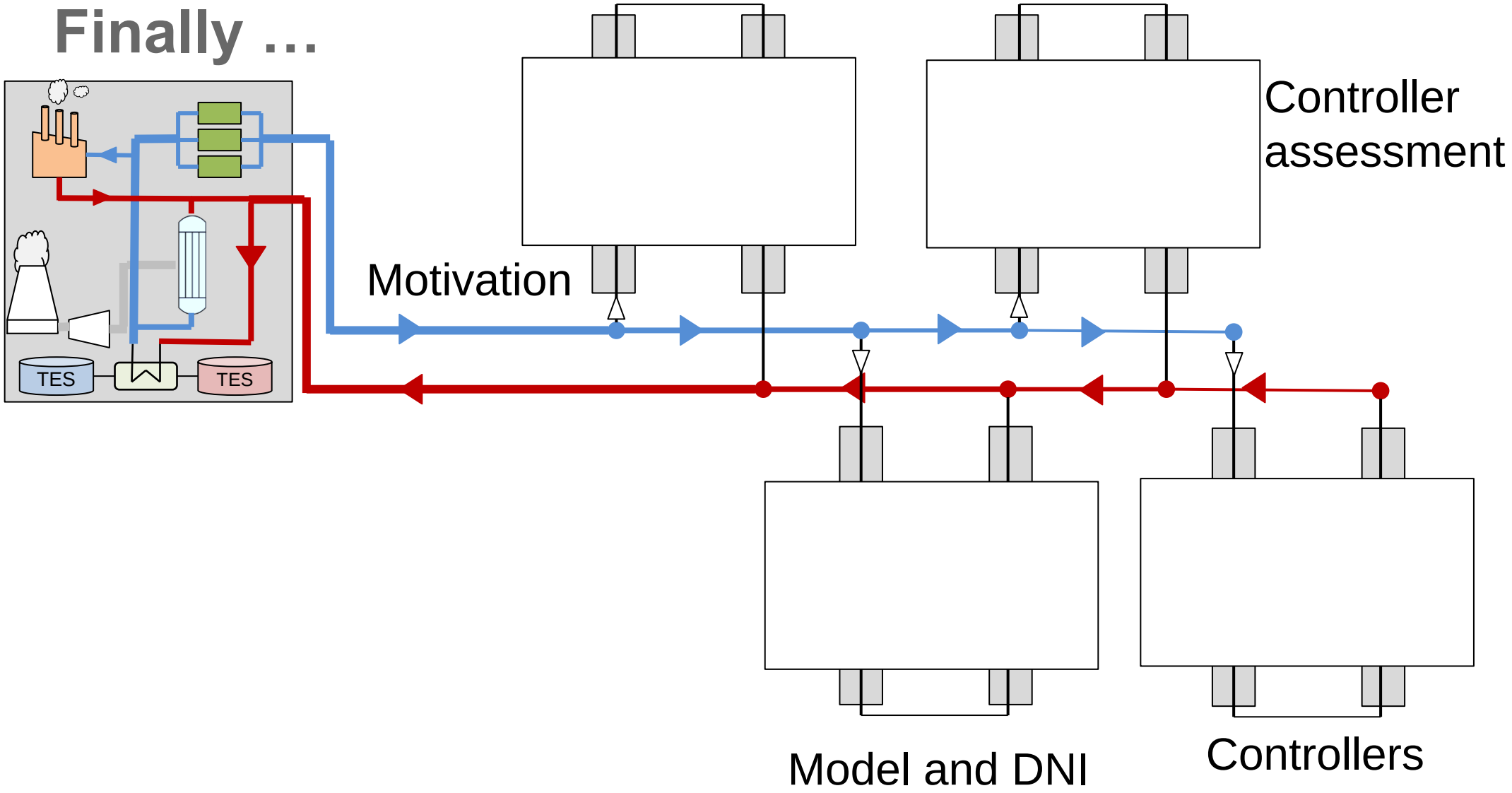


+10% error

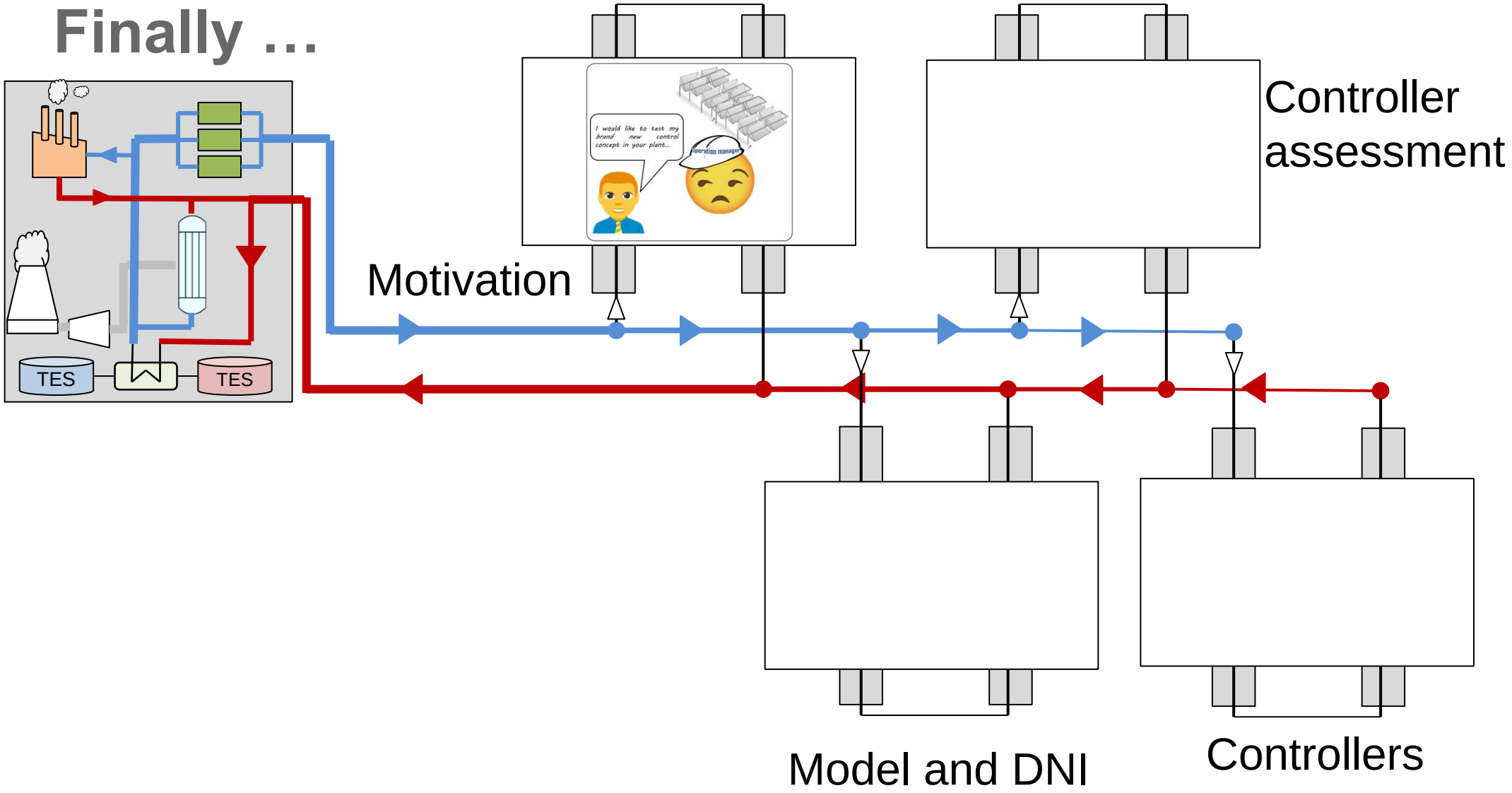


Exact FF

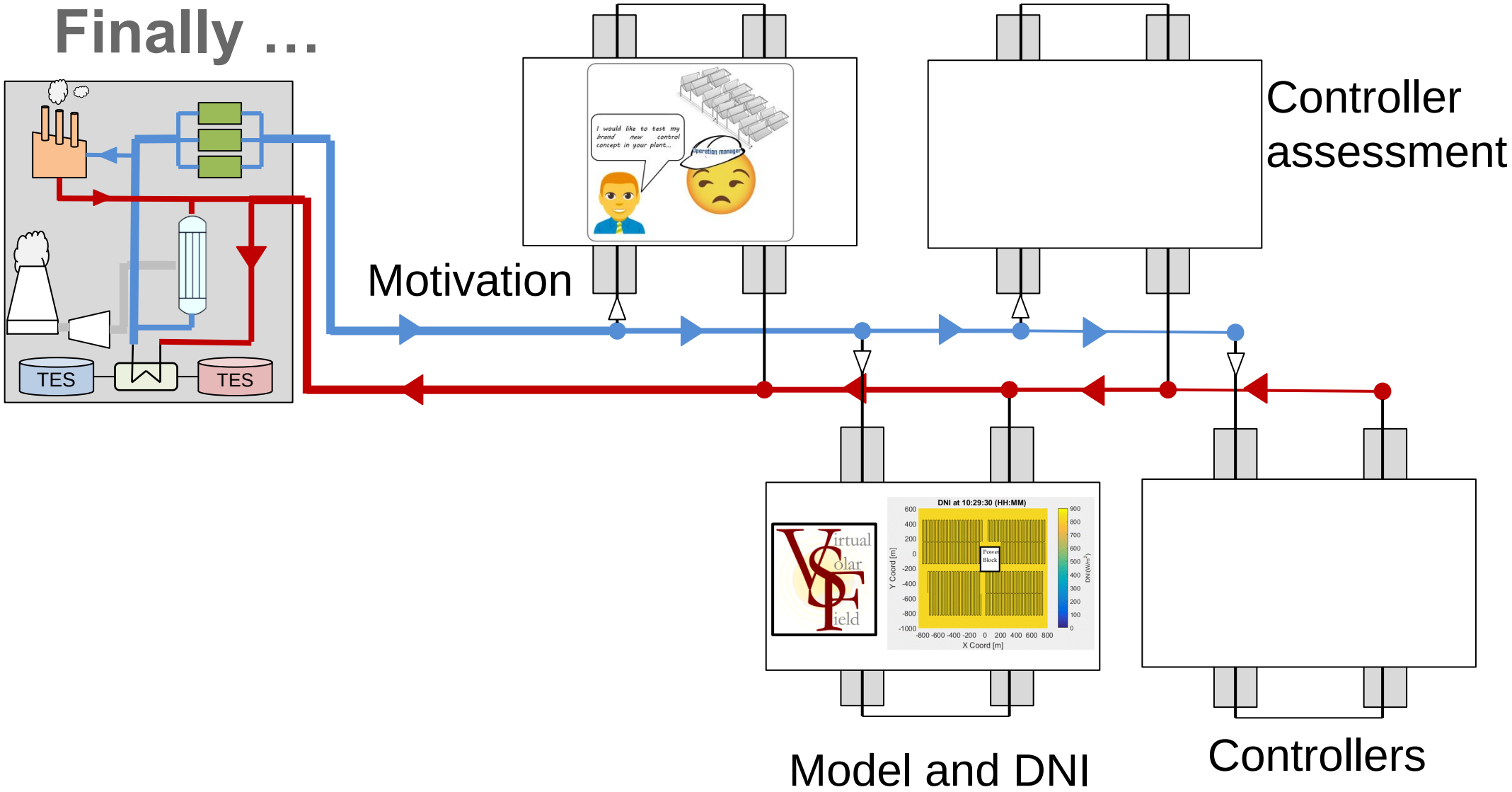
Finally …


TES
TES
Motivation
Controller assessment
Model and DNI
Controllers

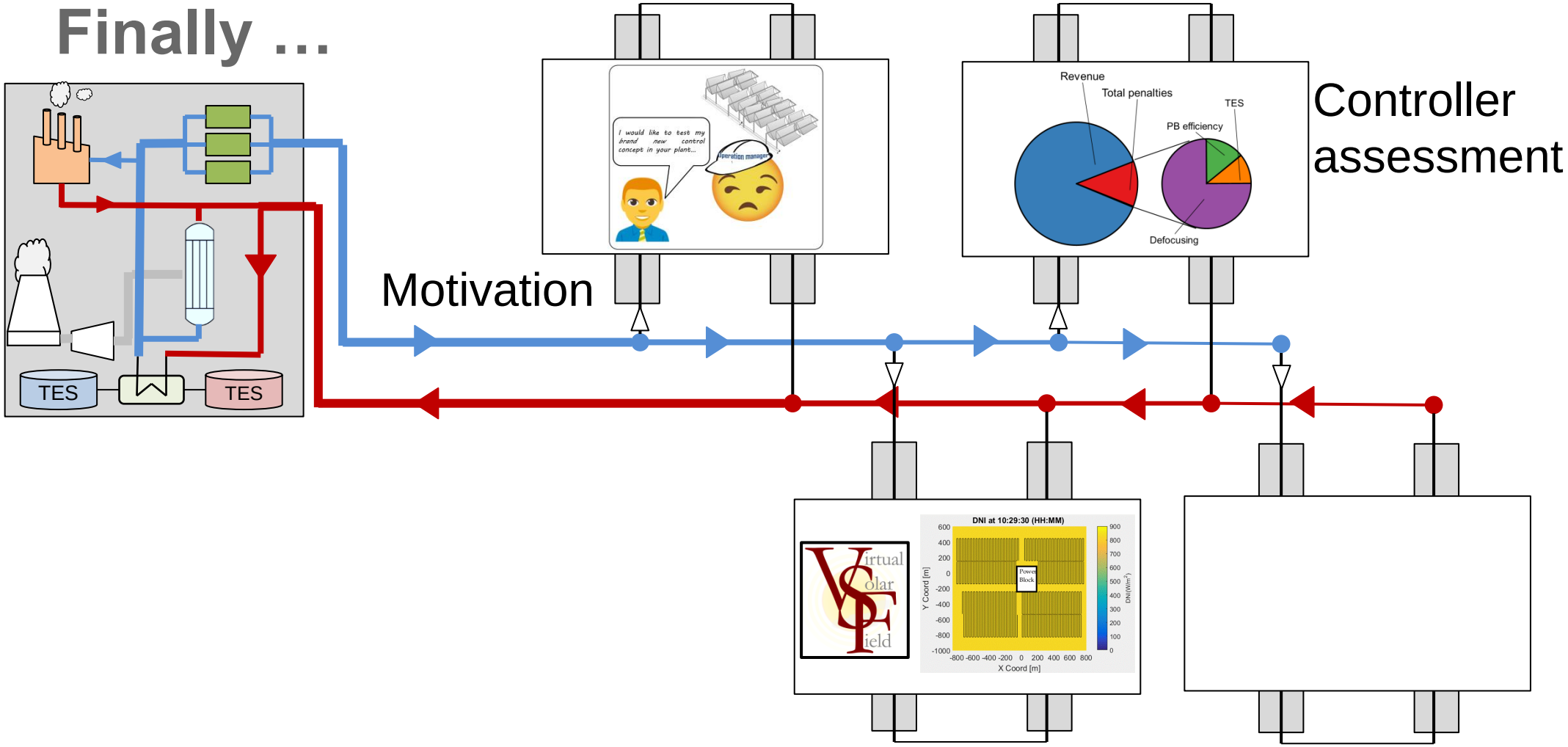
Finally …


TES
TES
I would like to test my brand new control concept in your plant...
Operation manager
Motivation
Controller assessment
Model and DNI
Controllers

Finally …


TES
TES
I would like to test my brand new control concept in your plant...
Operation manager
Motivation
Controller assessment
DNI at 10:29:30 (HH:MM)
Power Block
Y Coord [m]
X Coord [m]
DNI(W/m²)
Model and DNI
Controllers

Finally …



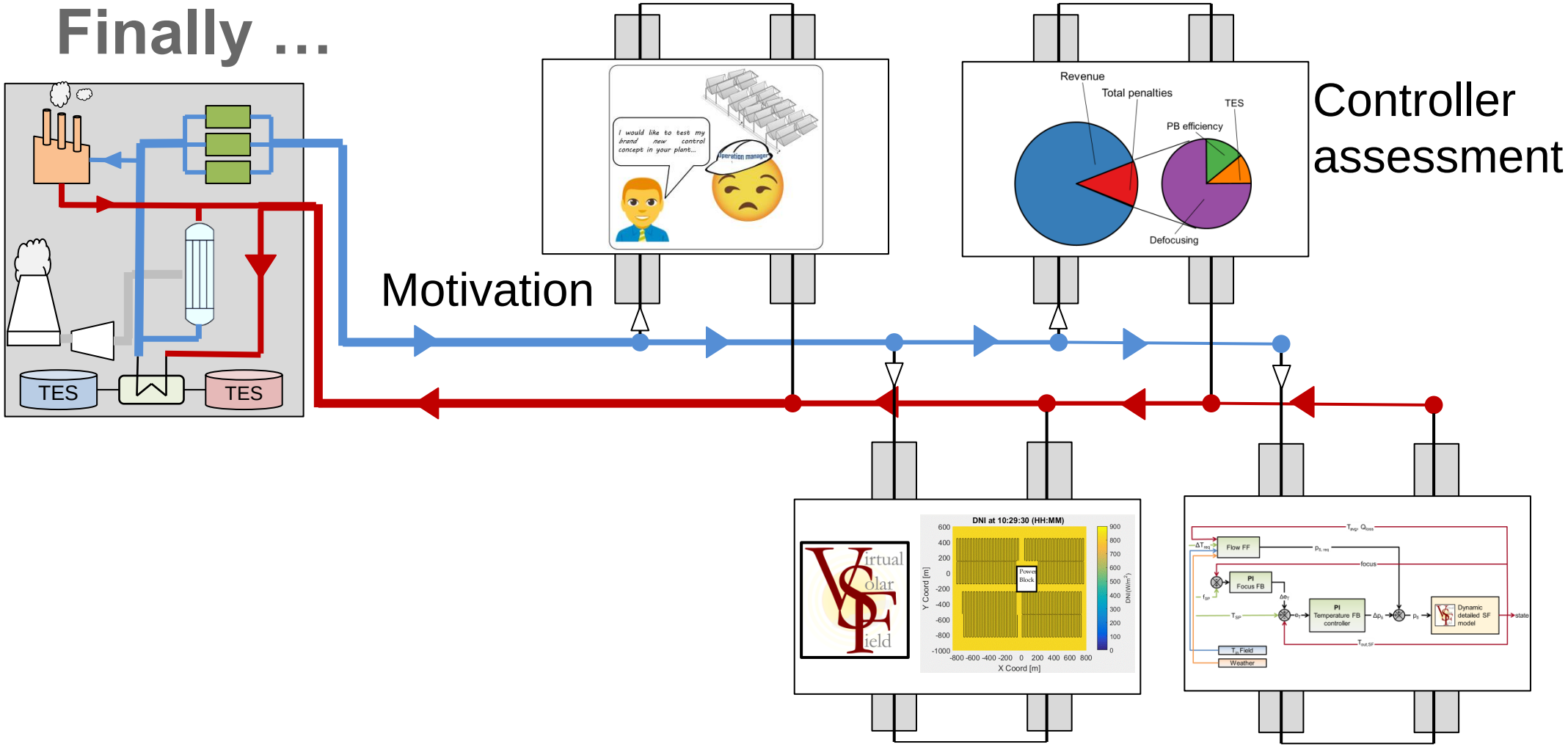
Motivation

Controller assessment

Model and DNI

Controllers

Finally …



Motivation

Controller assessment

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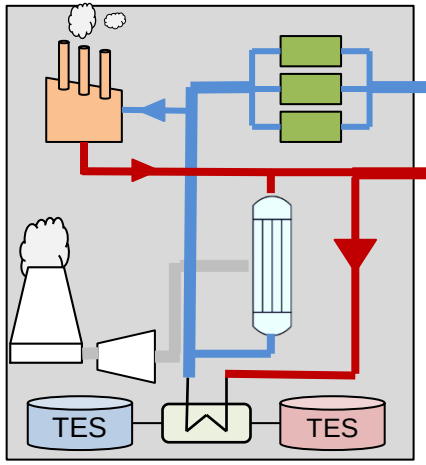
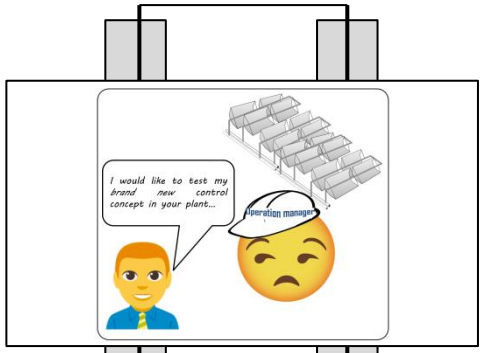
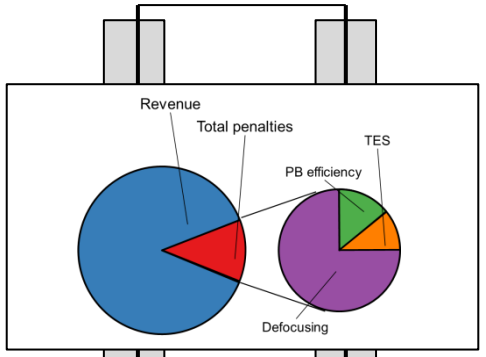
Controllers

Finally …

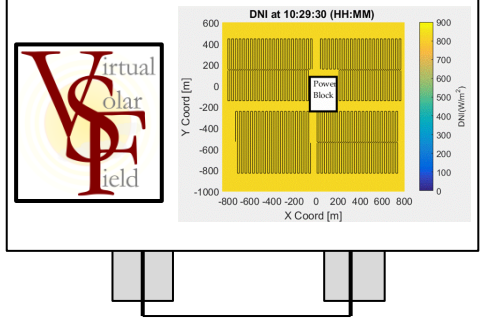




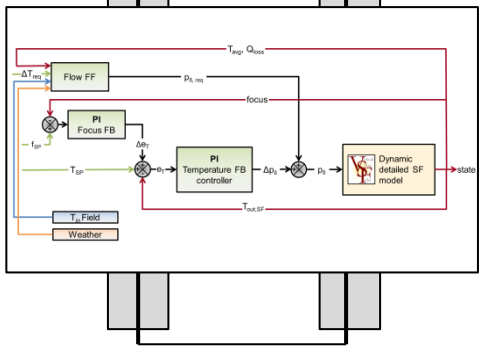
Motivation



Controller assessment



Model and DNI

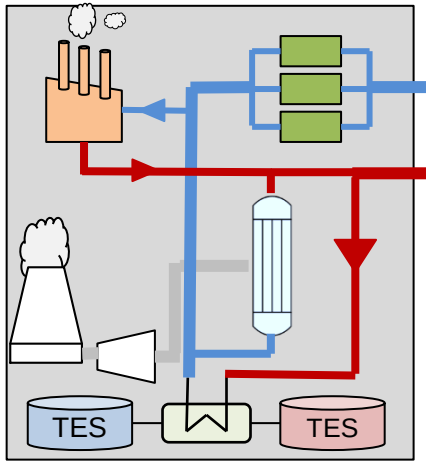


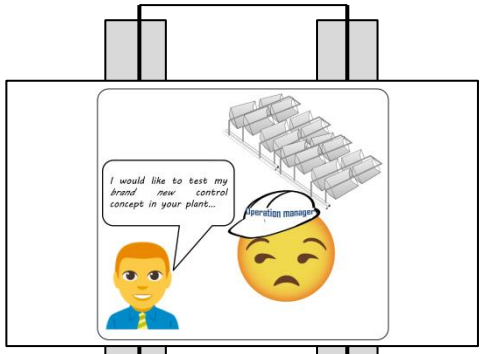
Controllers

Outlook and Conclusion

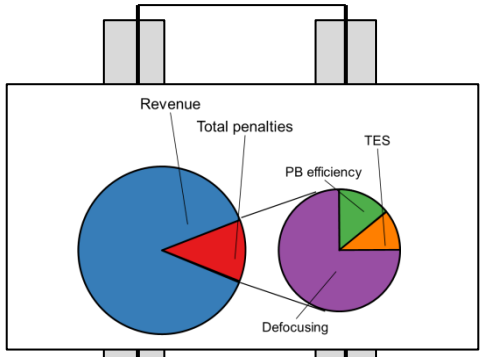
- A step towards SF control automation.
- A controller benchmark to compare with novel control concepts and prove their benefit/robustness.

Finally …

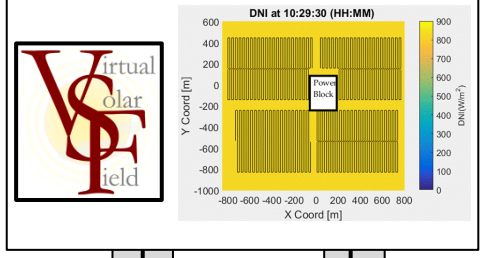




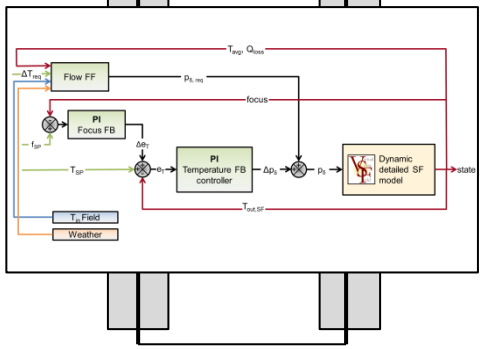
Motivation



Controller assessment



Model and DNI



Controllers

Outlook and Conclusion

- A step towards SF control automation.
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Thank You For Your Attention ☺