Using DNI Forecasts provided by All Sky Imager to improve Control of Parabolic Trough Solar Fields

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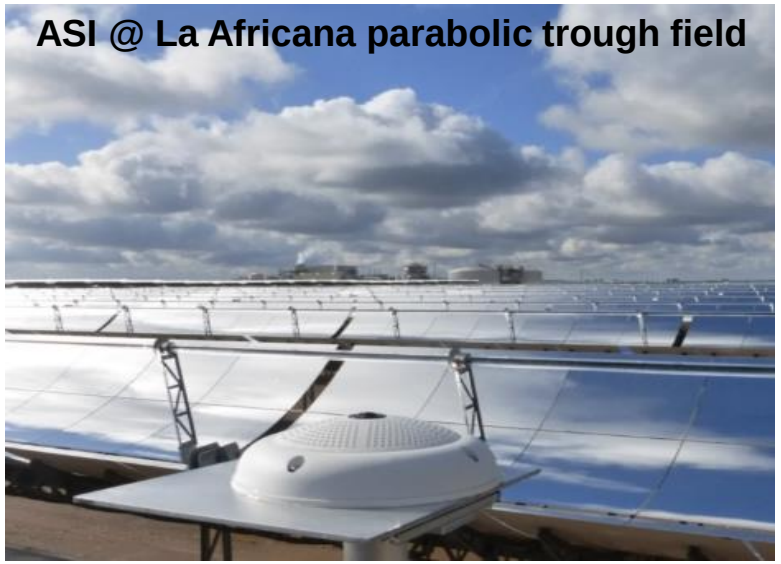
Motivation

- 6.1 GW of CSP plants are in operation worldwide. The large majority uses parabolic trough with oil as heat transfer medium. Control strategy implemented in commercial scale solar fields has not evolved much over the last decade.
- Developments in short-term irradiance forecasting by all sky imagers (ASI) offers new ways for improved control.
  - Use of spatial DNI distribution instead of pyrheliometer measurements to create a feed-forward control element for the field mass flow [1]
  - Use of cloud classes derived from DNI maps to trim feedback control parameters [2]
- Whereas the studies above make use only of the current value irradiation situation, **this study investigates the potential of predicted DNI values over 20 min horizon to improve the feedforward mass flow control of the field.**



[1] Noureldin, Kareem (2019) Modelling and Control of Transients in Parabolic Trough Power Plants with Single-Phase Heat Transfer Fluids. PhD thesis, RWTH Aachen
[2] Nouri, Bijan et all (2020) *Optimization of parabolic trough power plant operations in variable irradiance conditions using all sky imagers.* Solar Energy (198), pages

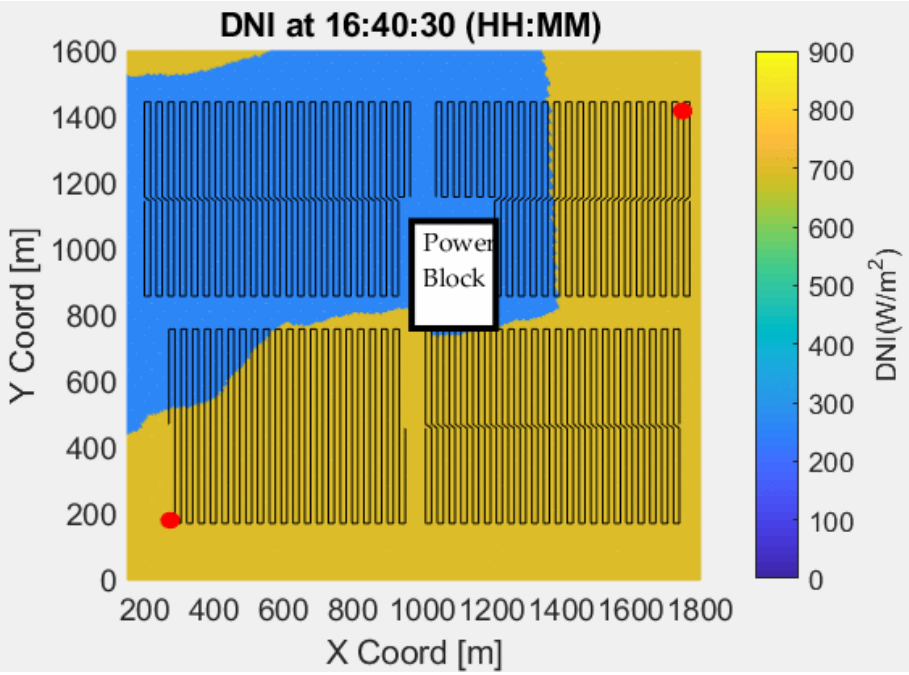
State of the art and approach

State of the art:

- A few pyrheliometers are installed in the solar field (usually 1 to 4)
- These point measurements of DNI are used to estimate the required mass flow (many plants even don't use automatic control of mass flow but manual setting by operator)

Our approach

- Use new system with all sky imagers (ASI) to get better average of DNI over the whole field
- Use transient field model to simulate different mass flow trajectories for next minute
- Choose best mass flow trajectory in terms of energy output and temperature stability
- Compare to reference control strategy



The Virtual Solar Field (VSF)

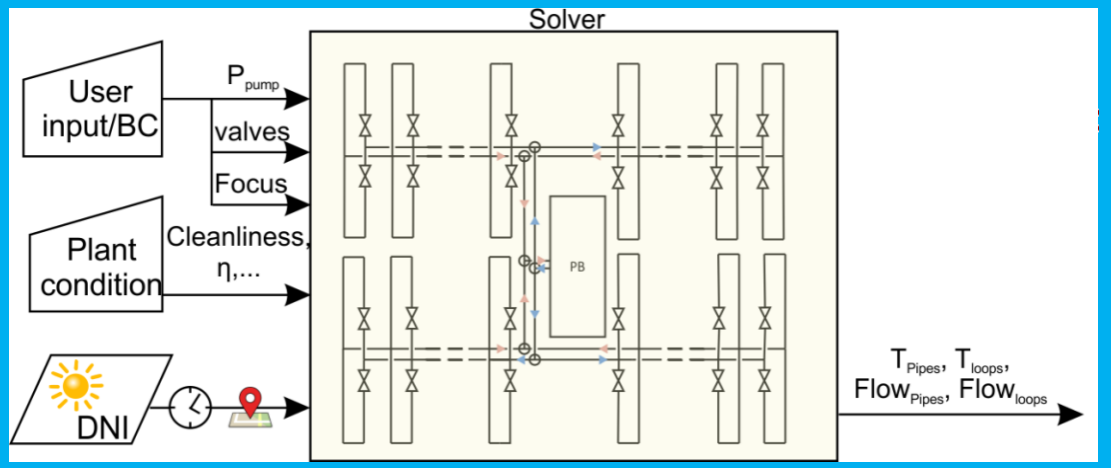
With the VSF we can simulate a whole parabolic trough solar field. In this study it is used

a) as solar field representation in absence of a real solar field
b) as tool to simulate the different trajectories in the feed-forward control block (“digital twin”)

La Africana power plant is used as example: (4 subfields, 4 collectors per loop, total of 168 loops)

Main features of VSF:

- Modelling the hydraulic network of the solar field
- Use of spatially resolved DNI maps as input
- Transient energy and mass balances to compute temperature, flow and pressure individually for every loop.



Reference Controller for comparison: Structure

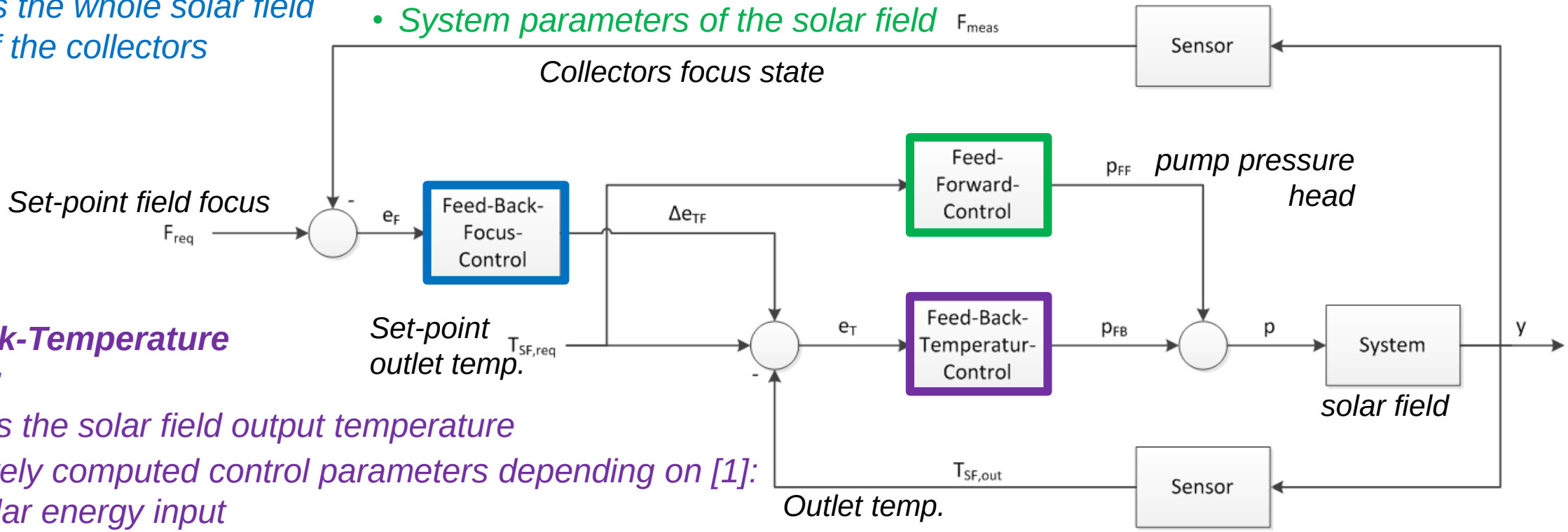
Feed-Forward-Control:

Computes a required mass flow depending on:

- *Current DNI Situation measured from 2 pyrheliometers*
- *System parameters of the solar field*

Feed-Back-Focus-Control:

Controls the whole solar field focus of the collectors

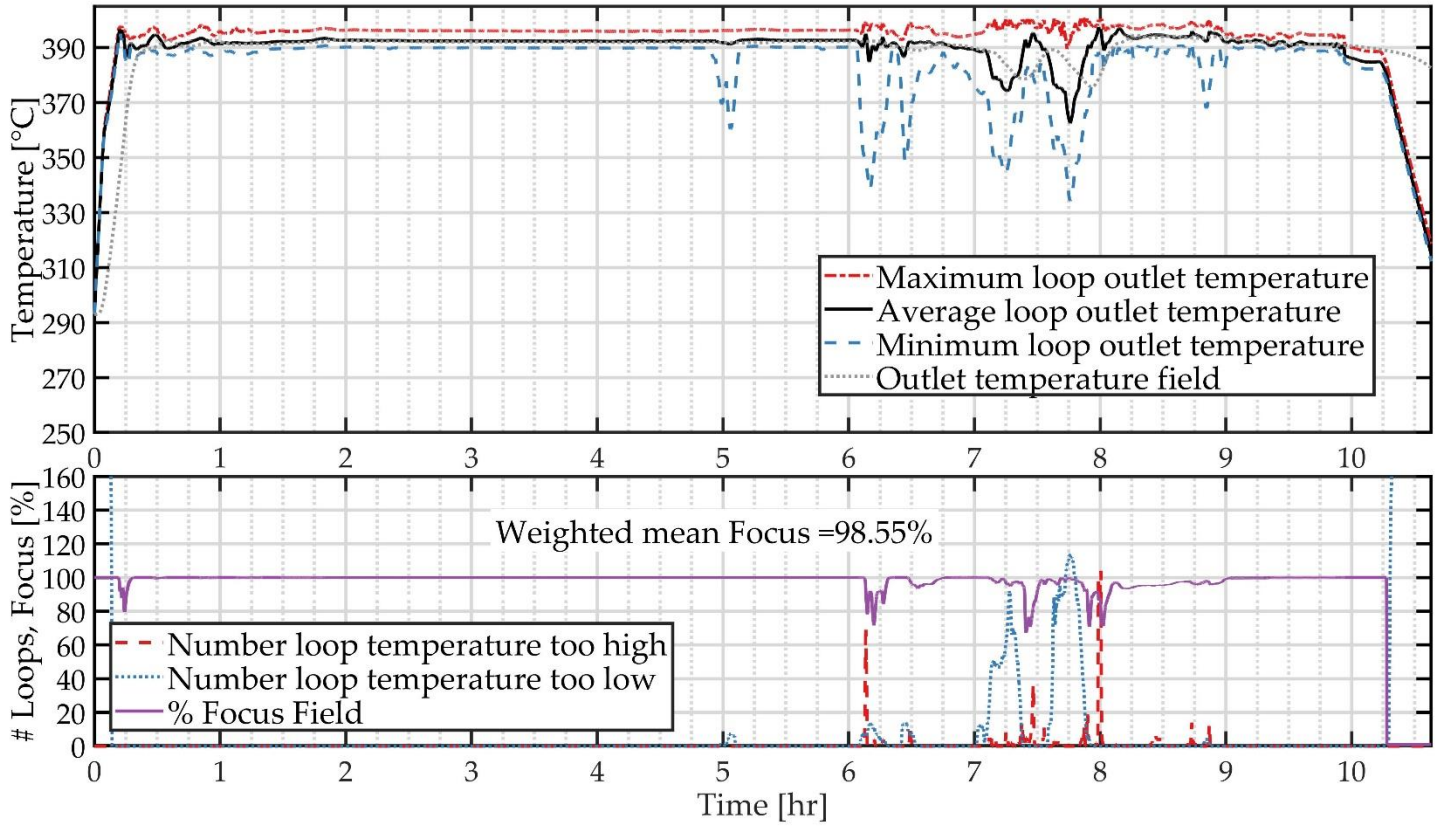


Feedback-Temperature -Control:

- *Controls the solar field output temperature*
- *Adaptively computed control parameters depending on [1]:*
  - *Solar energy input*
  - *Solar field thermodynamics state*

[1] Noureldin, Kareem (2019) Modelling and Control of Transients in Parabolic Trough Power Plants with Single-Phase Heat Transfer Fluids. PhD thesis, RWTH Aach

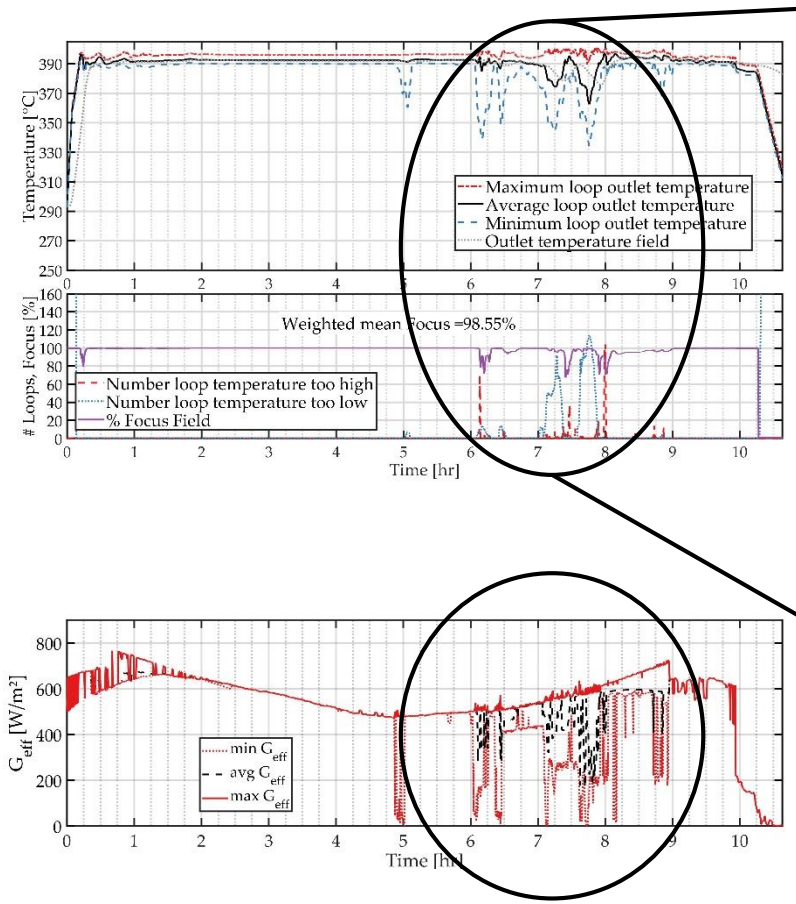
Reference Controller for comparison: Simulation Result

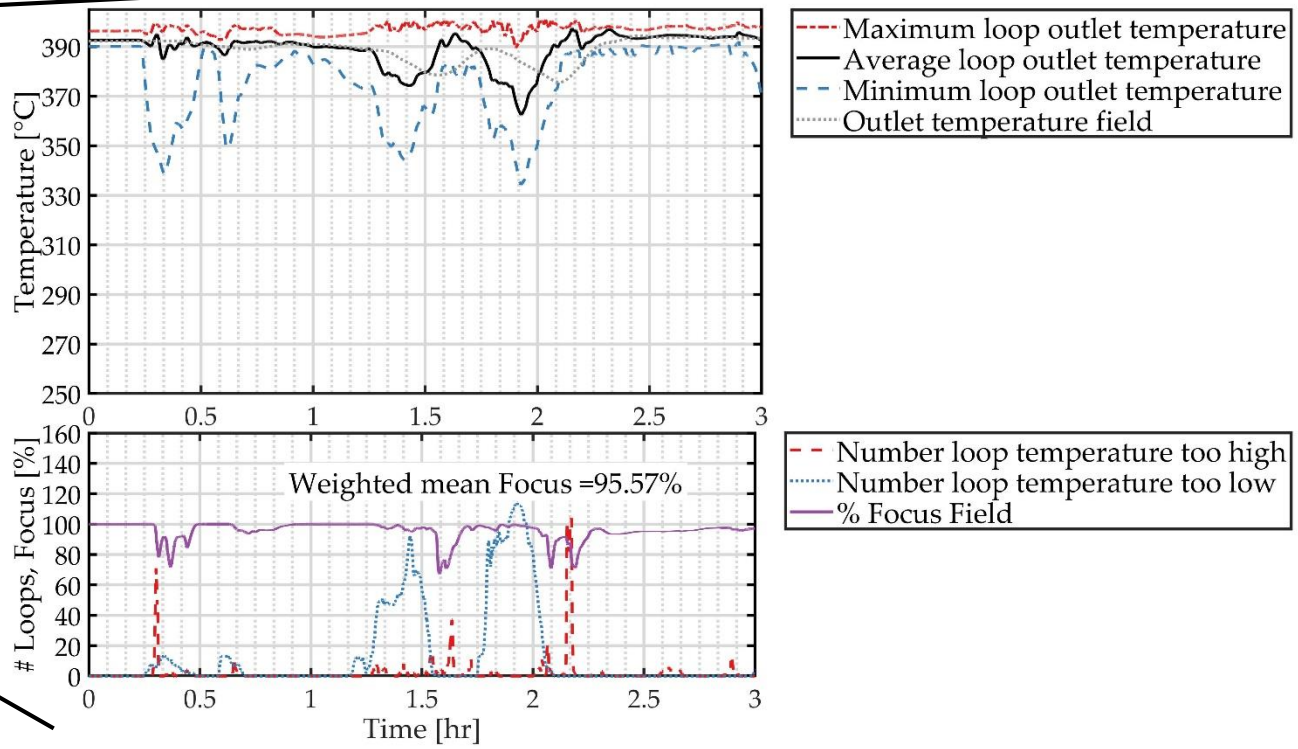


Reference controller can adjust the output temperature and field focus in the first 6 hours during clear sky conditions

Example: 02.10.2015, 9 am - 6 pm

Reference Controller for comparison: Simulation Result





Strong deviations in outlet temperatures under cloud passage

Strong defocusing induced by over-temperatures

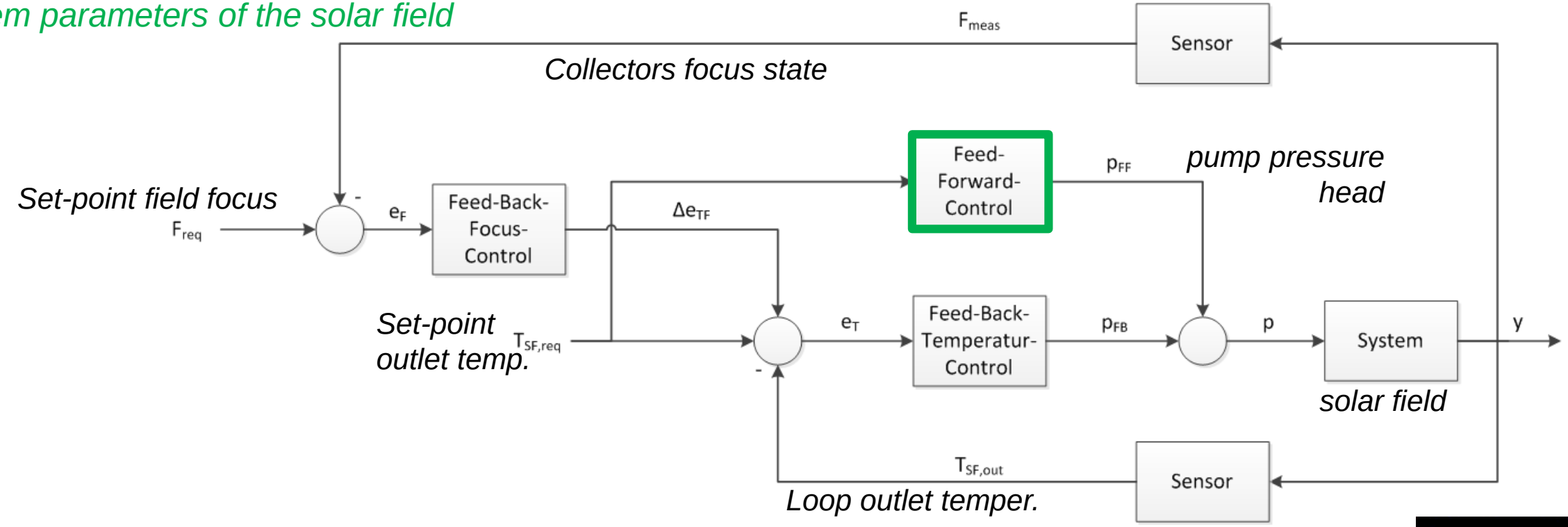
Example: 02.10.2015, 9 am - 6 pm

New approach for the feed-forward block

Feed-Forward-Control:

Computes a required mass flow depending on:

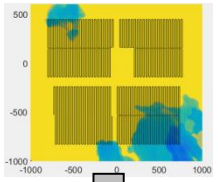
- *Current DNI Situation* ⟶ **NEW: Use current & predicted DNI situation from ASI system**
- *System parameters of the solar field*



New Approach: Digital twin to simulate next minute

Time series calculation in VSF (in absense of a real field)

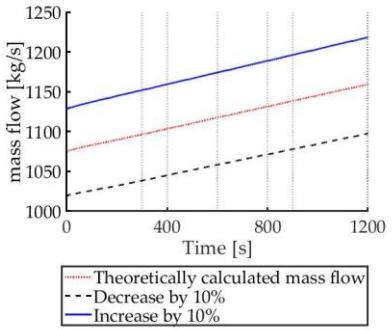
t_i



current DNImap + forecast

1. Step
Estimate state of solar field for the digital twin based on actual measurement values

2. Step
Define 3 mass flow trajectories for the upcoming minute



3. Step
Simulate behaviour for the upcoming minute with the digital twin

Virtual Solar Field –

4. Step
Evaluate simulations using:
- Output temperature
- Solar field focus

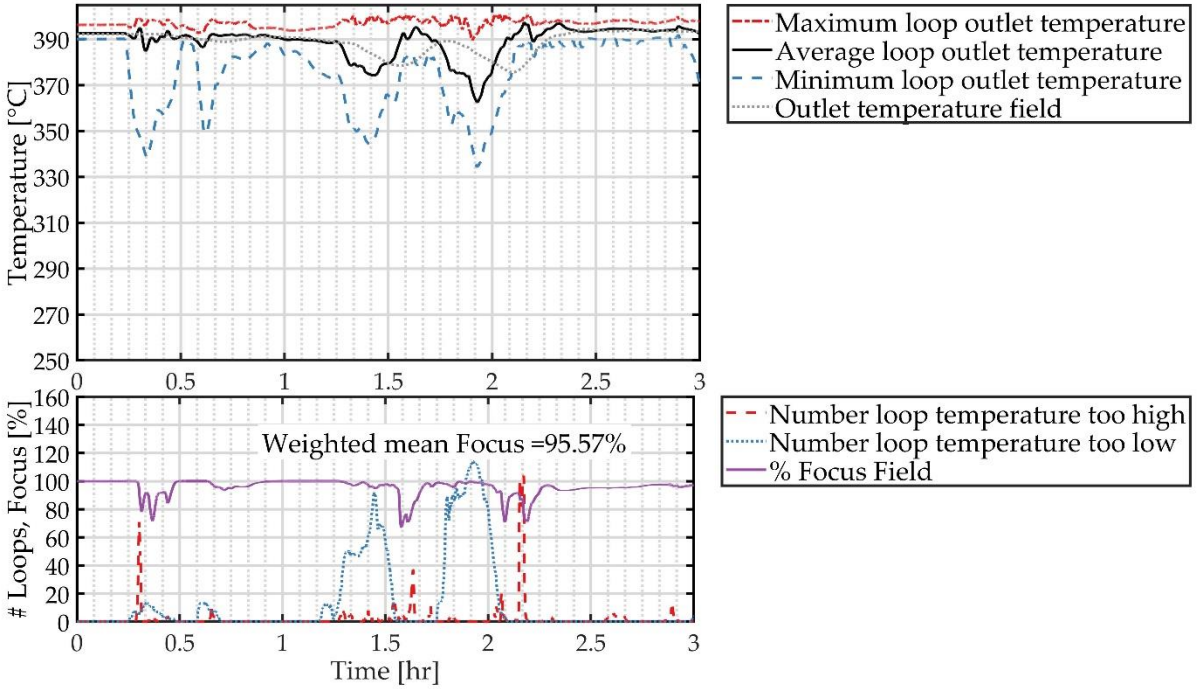
and select best mass flow trajectory for the next step

t_{i+1}

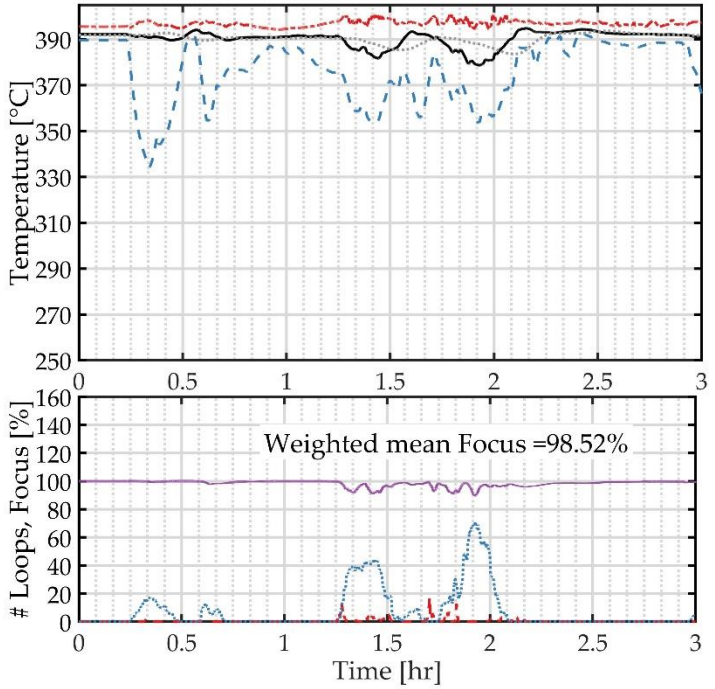
Update mass flow trajectory for next time step(s)

New Approach: Results compared to reference controller

Reference control



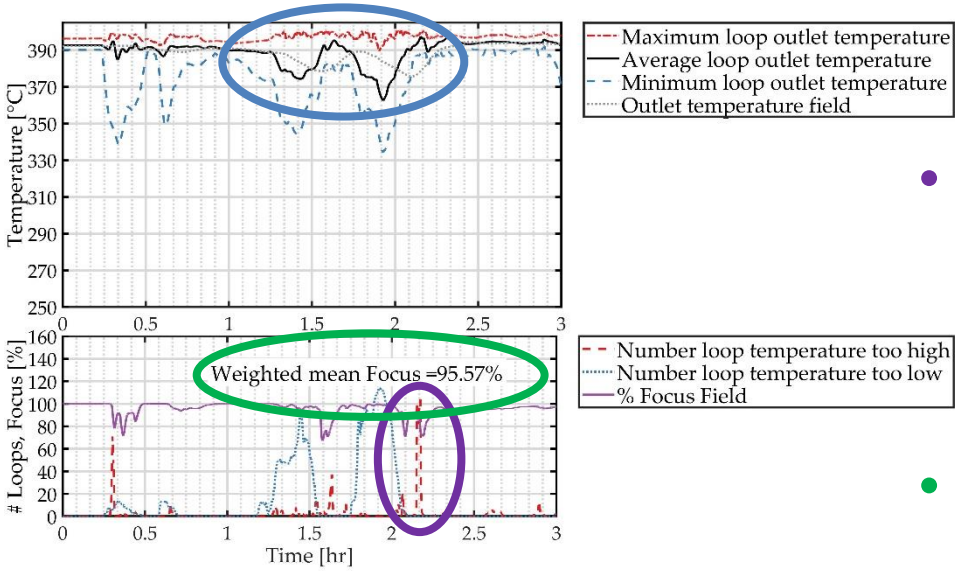
Digital twin



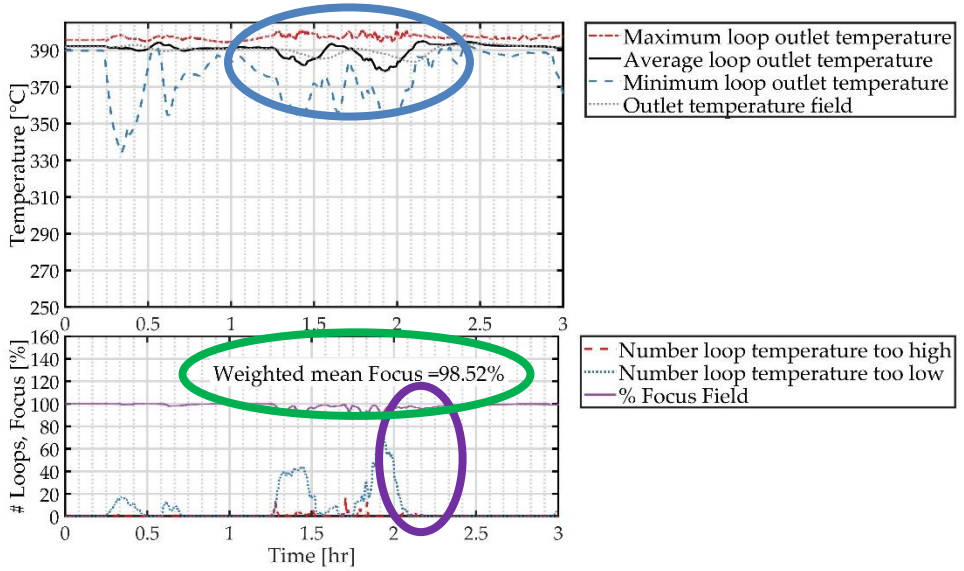
Example: 02.10.2015, 3-5 pm

New Approach: Results compared to reference controller

Reference control

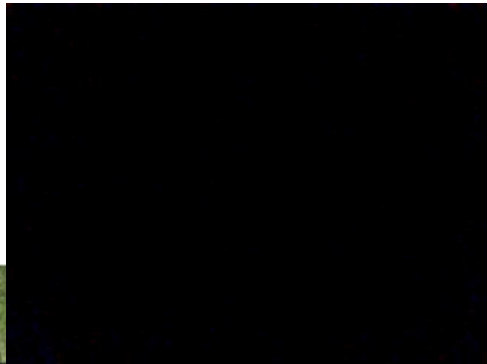


Digital twin



- Reduction of high peak temperatures of individual loops
- Increase of the total solar field focus
- Increase of the average output temperature

Example: 02.10.2015, 3-5 pm

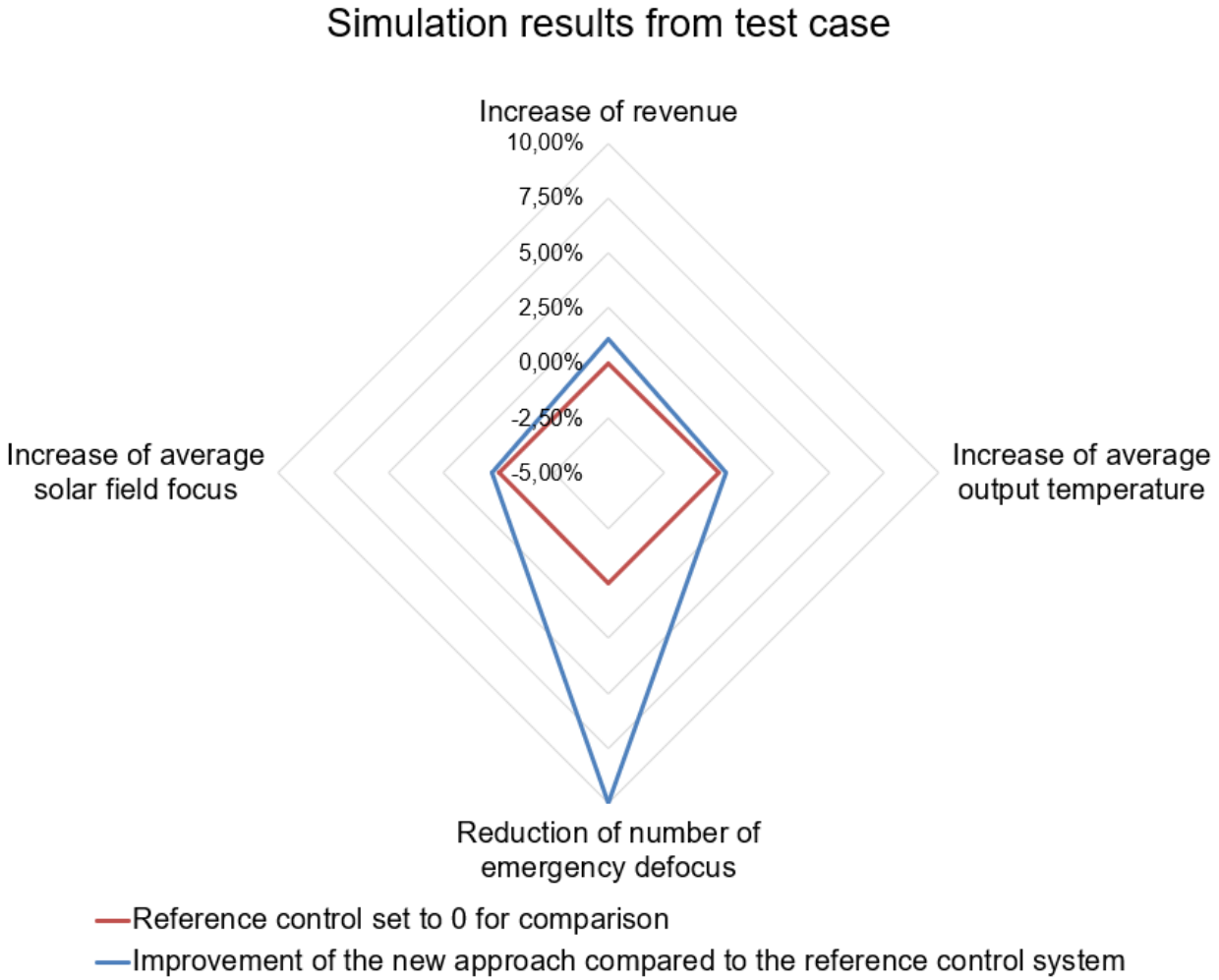


Use VSF as Digital Twin in the Feedforward: Test case

- La Africana power plant
- 168 loops in 4 subfields
- DNI maps from ASI in PSA, Almeria
  - Used for VSF and control
- Simulation of 27 days
  - Allow simulation of different DNI situations
  - Also used in other studies

Picture from: https://www.google.de/maps/@37.754782,-5.0569854,2042m/data=!3m1!1e3

Use VSF as Digital Twin in the Feedforward: Comparison to Reference Controller



A comparison of the new approach to the simulation results with the reference control:

- Increase of revenue by 1.1%
- Increase of average output temperature by 0.4%
- Increase of average solar field focus by 0.3%
- Reduction of emergency defocusing by 10%

Summary and conclusions

- Benefit of using DNI maps of current situation has been proven in former studies.
- This study analyses a new control approach for the mass flow control of parabolic trough fields:
  - Current & predicted DNI maps are used to estimate the required mass flow
  - Digital twin model simulates expected behavior for different mass flow trajectories
  - Best trajectory is selected
- DLR's Virtual Solar Field (VSF) model simulates the field behavior for 27 test days
- Conclusions:
  - Additional forecasts of more than one minute does not significantly increase the yield (compared to the use of current DNI maps)
  - Additional forecasts helps to reduce defocusing events due to local over-temperatures especially in situation with cloud patterns over the field.
  - Approach further improves the control and can be used since forecasts anyway available when using an all sky imager system in the field.