Using All Sky Imager to Control the Solar Field of a Parabolic Trough Power Plant – Implementation Steps for Commercial Application

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Introduction / Motivation

Worldwide, 6.5 GW of CSP power plants are installed. Most of them use parabolic trough systems with oil as the heat transfer medium

Why do we want to integrate a new control concept into parabolic trough systems?

- The control strategy used in commercial solar fields has not evolved significantly in previous years
- A system with All Sky Imagers (ASI) allows a better overview of the current irradiation situation for use in the control software
- Simulation studies for automatic control with ASI system have shown good results in different irradiation situations

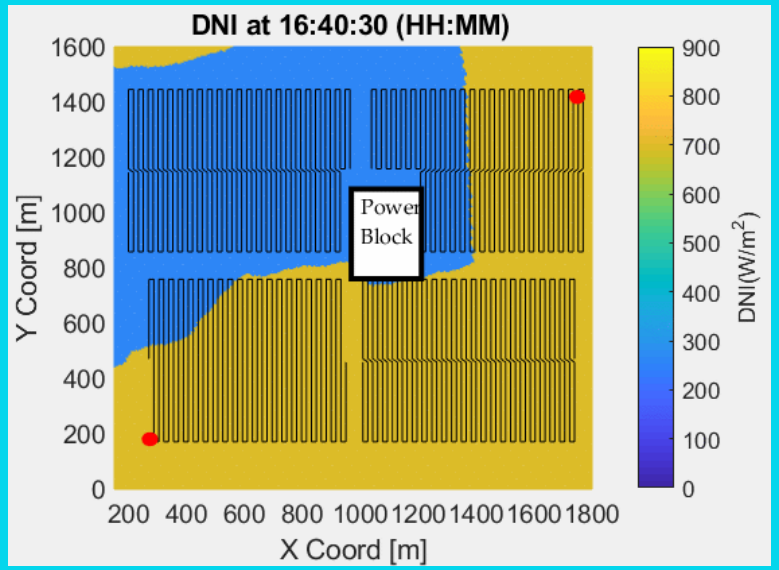
ASI @ La Africana parabolic trough field

All sky imager system

The all sky imager (ASI) system is an irradiance forecasting system which provides reliable information about the varying solar irradiance on an area

Main features of ASI-System:

- Recording of sky images with all sky imager and automatic detection of clouds
- Determination of cloud movement and height
- Calculation of cloud transmittance and shadow map
- Preparation of spatially resolved irradiation maps
- Creation of an irradiation forecasts of up to 20 minutes



For more details see here:

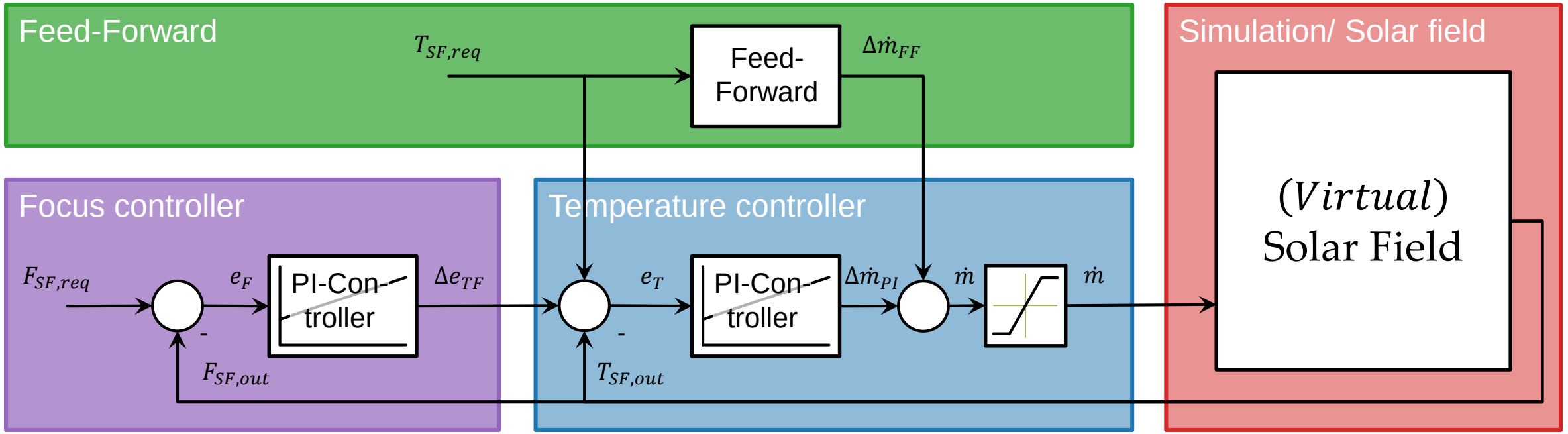
- https://www.cspservices.de/wp-content/uploads/CSPS-Q4cast.pdf

Developed control system with the ASI-System
General concept

Feed-Forward:

Computes a required mass flow depending on:

- Current DNI Situation
- System parameters of the solar field



Feed-Back-Focus-Control:

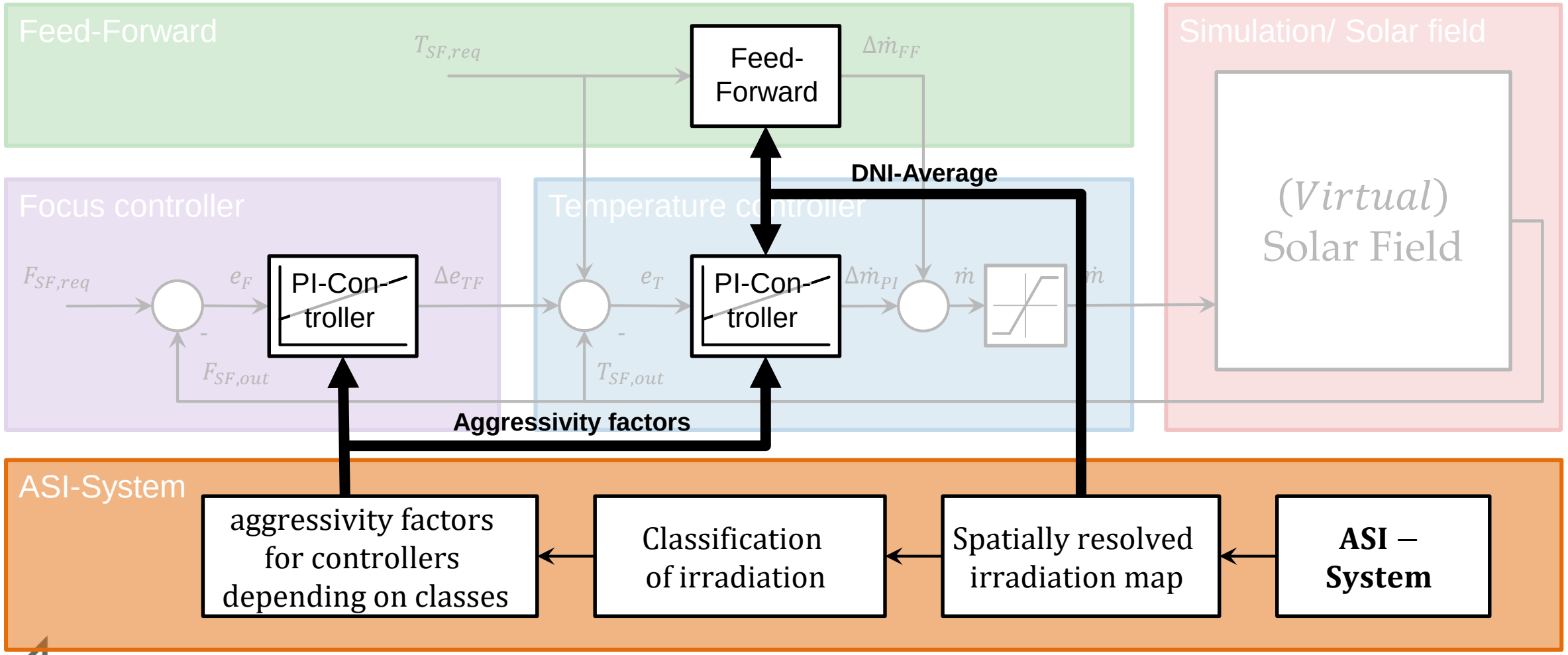
Controls the whole solar field focus of the collectors

Feedback-Temperature-Control:

- Controls the solar field outlet 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 Aachen University.

Developed control system with the ASI-System
Use of ASI-System



Set-up of simulation studies with the new control system

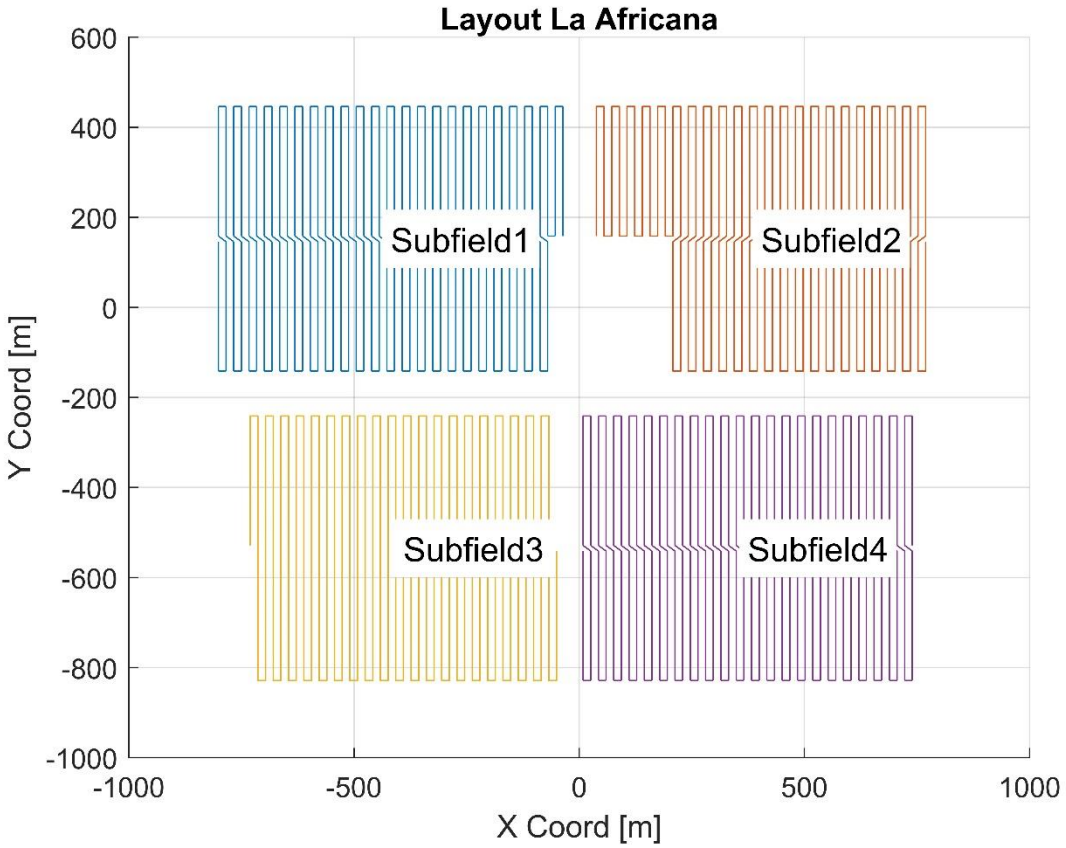
Set-up:

- La Africana power plant
  - 4 subfields
  - 168 loops
  - Oil as heat transfer medium

- Simulation tool **Virtual Solar Field (VSF)**

- Recorded DNI maps of 27 days with different irradiation situations to simulate with VSF

- Evaluation of control concept against a reference controller which has only DNI information of pyrheliometer stations

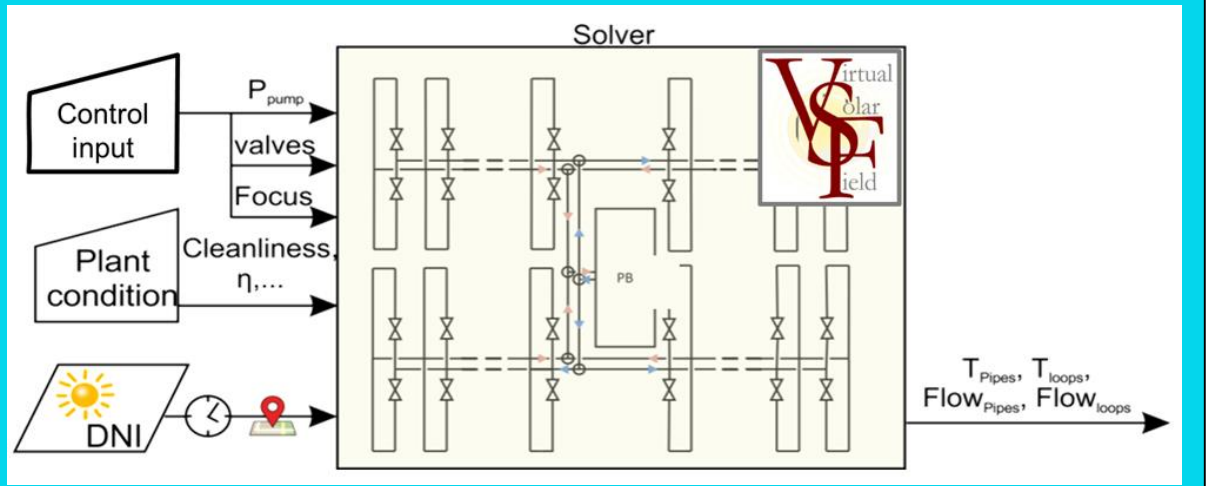


The Virtual Solar Field (VSF)

Virtual Solar Field (VSF) is a dynamic simulation program which models a complete parabolic trough solar field with high level of detail and adequate computation time

Main features of VSF:

- Mass flow distribution depending on the pressure loss in each piping element
- Spatially variable irradiance can be modelled
- Flexible field layout whilst operation and maintenance activities can be considered
- Any solar field and collector controllers can be integrated to the model



For more details see here:

- https://www.dlr.de/sf/en/desktopdefault.aspx/tabid-9315/22254_read-73797/
- Noureldin, K. **„Modelling and control of transients in parabolic trough power plants with single-phase heat transfer fluids“**, PhD Thesis (2018)

Results obtained with the control system in simulation studies

Results: In the publications mentioned below, the control system was developed and analyzed at optimal conditions as well as in a **robustness analysis** under "real" conditions in simulation studies. In general, with this developed system, **an improvement of 1.4% in yield increase, 0.43 % in focusing and 48 % reduction of emergency defocusing can be achieved.**

Nouri, B. et al. 2020. **"Optimization of parabolic trough power plant operations in variable irradiance conditions using all sky imagers."** Solar Energy 198: 434-453.

- *Investigations of the control concept for uncertainties in the ASI system*

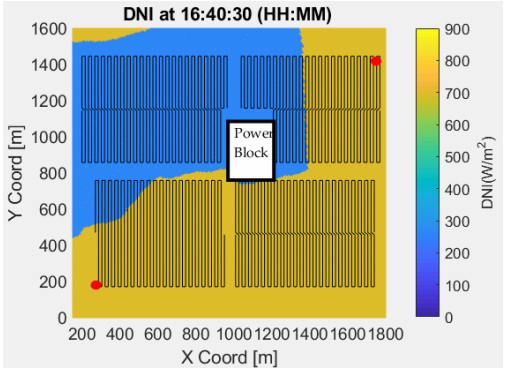
Kotzab, T. et al. 2020. **“Using DNI Forecasts provided by All Sky Imager to improve Control of Parabolic Trough Solar Fields.”** SolarPACES 2020. Online Conference.

- *Investigation of the control concept using the irradiation forecasts*

Kotzab, T. et al. 2021. **“Parabolic trough field control utilizing all sky imager irradiance data – A comprehensive robustness analysis.“** Solar Energy. Submitted.

- *Investigations of the control concept for robustness in different situations*

Integration possibilities of ASI- and Control System

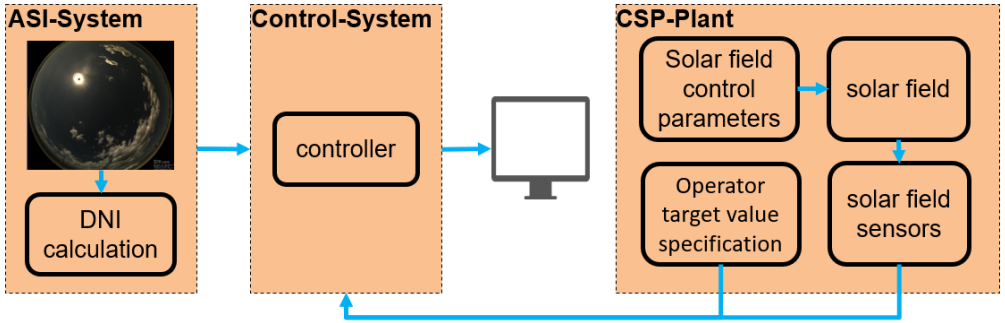


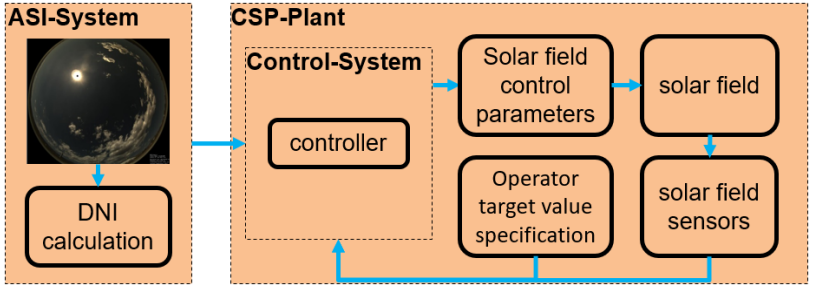
How can we use and integrate the ASI- and control system in a commercial power plant?

1. Information of operator: Use ASI system for a better overview of the DNI over the solar field

2. Support operator: Use ASI + control system as assistance to support the mass flow adjustment in the solar field

3. Automation: Full integration of the systems for automatic control of the solar field





Use and integration of the all sky imager systems in the power plant

Implementation:

- 2+ all sky imagers in the solar field, at least one co-located with DNI weather station
- Evaluation computer at control room (generates system output + visual interface)
- Integration of DNI weather station(s) real-time data
- Implementation time approx. 12 weeks

Main features of the implemented ASI-system:

- Continuous calculation of DNI maps on the solar field
- Display of DNI maps in GUI + output in flexible data interface
- Irradiation forecast of the next 15-20 minutes
- High temporal + spatial resolution possible

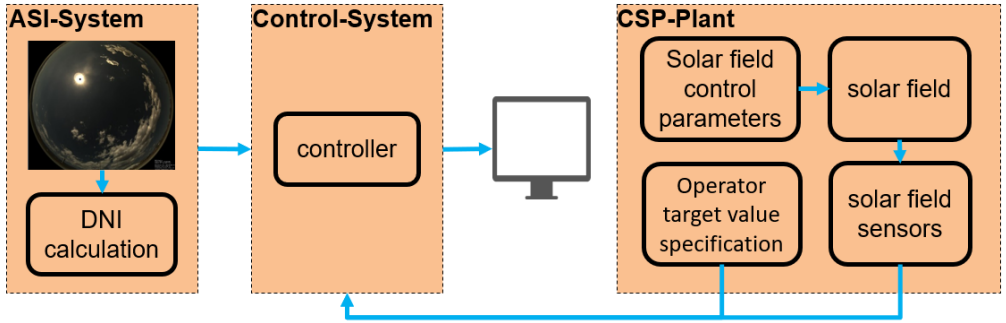
Effort for the operator:

- Placing ASI in the solar field
- Set-up of the evaluation computer in the control room
- Support in the implementation of an interface for DNI weather station data

Use of concept as a operation assistance system

Implementation:

- Infrastructure of ASI system used for assistance system
- Control system implemented on evaluation computer
  - Output of mass flow on screen
- Interface to Distributed Control Systems (DCS) necessary
  - Read access to DCS data (set points, sensor data)



Main features of the implemented assistance system:

- Continuous calculation of mass flow for the solar field
- Display of the mass flow for the solar field on a separate screen
- Operator can adopt the recommendation in the real solar field

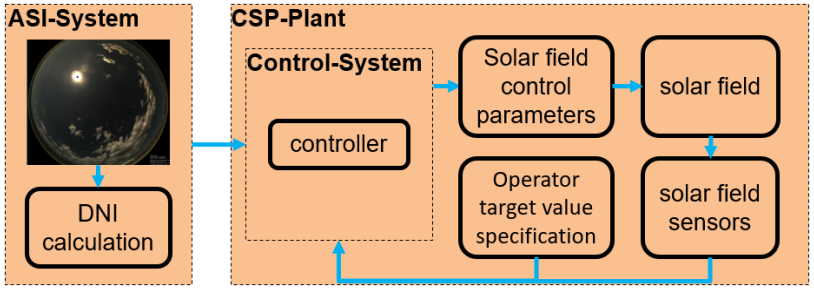
Effort for the operator:

- Set-up of the screen in the control room
- Support in implementation of the interface to the DCS data

Use of concept as a fully integrated control system

Implementation:

- Full integration in the solar field control of the power plant
  - The ASI control system consists of simple functions and PI controllers
  - Functions for calculating feedforward and parameters of the PI controllers must be implemented
- Interface to ASI system must be established for classification and DNI values
- Automatic adjustment of mass flow in the solar field



Main features of the full implemented control-system:

- Continuous calculation of mass flow for the solar field in the power plant operation system
- Automatic adjustment of the mass flow for the solar field depending on the setpoint

Effort for the operator:

- Implementation of control functions in DCS
- Implementation of interface between ASI system and DCS

Summary and conclusion

- A control system was developed that uses spatially resolved DNI maps to calculate irradiance-adjusted control parameters for the solar field
  - The control system was tested in comprehensive simulation studies with Virtual Solar Field
  - The results of the simulation studies show improvements in the area of focusing, reduction of emergency defocusing and the increase of the yield

- The integration in a commercial power plant can be done in several steps
  - Use only the ASI system for a better overview of the irradiation situation in the solar field
  - Use of an operating assistant system for mass flow recommendations on the basis of the current sensor values and irradiation
  - Full integration into the control system of the power plant for automatic control of the solar field