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thermal solutions

# Direct steam generation for process heat using Fresnel collectors

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**ICYS-ARE 2015 at German Jordanian University, Madaba, Jordan**

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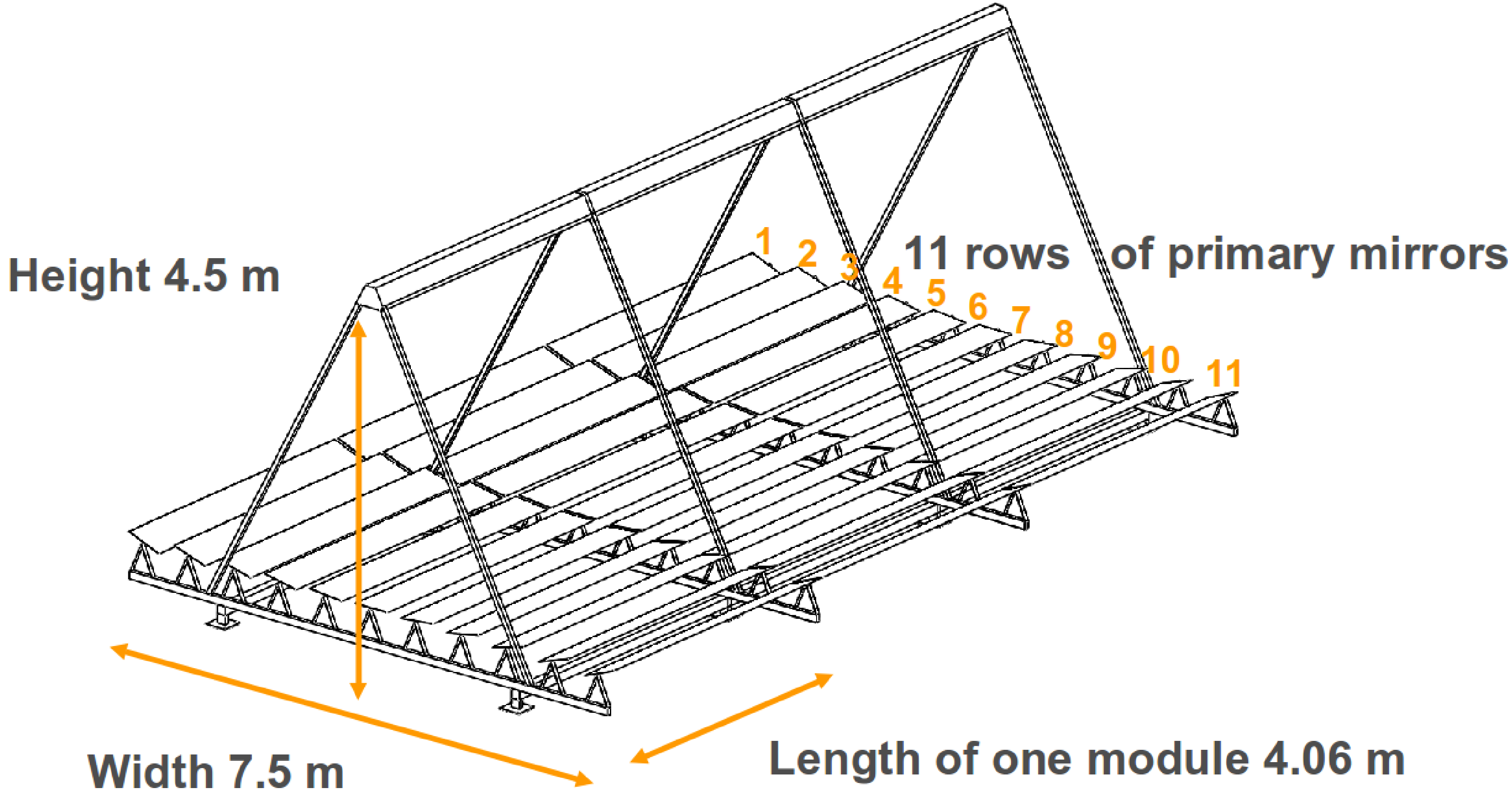
**18.May.2015**

## Outline

- **Introduction**
- Solar Direct Steam Generation (DSG) System
- Control of Solar DSG systems
- Solar DSG Plant in Jordan
- Outlook

## Fresnel Collector for Process Heat



# Fresnel Collector for Process Heat

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- Low wind load
- Good weight-spread
- High ground usage factor
- No north-south alignment necessary compared to non-concentrating collectors

Fresnel Collector for Process Heat

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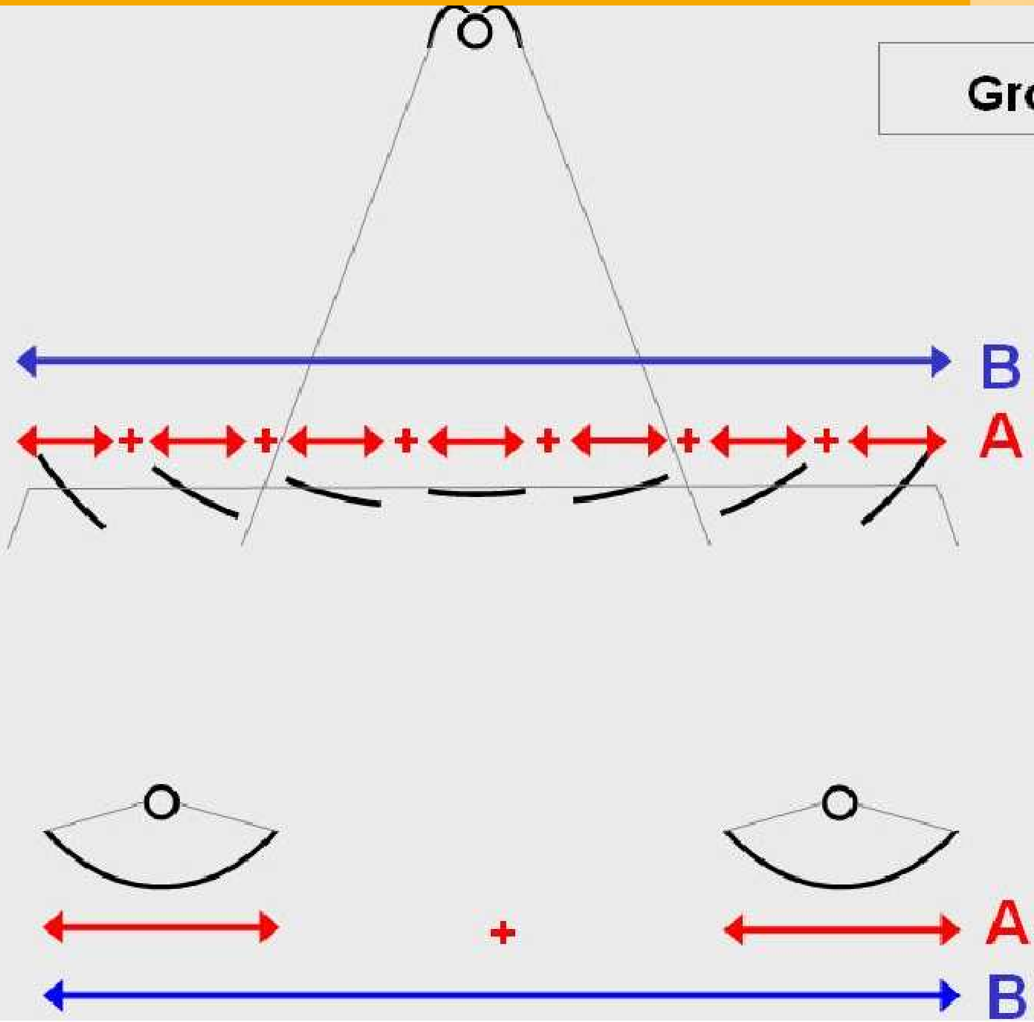


Ground usage factor = A/B

Fresnel: A/B ~ 0.66

High ground usage factor
Low wind load
Good weight-spread

Parabolic Trough: A/B ~ 0.33

# Fresnel Collector for Process Heat

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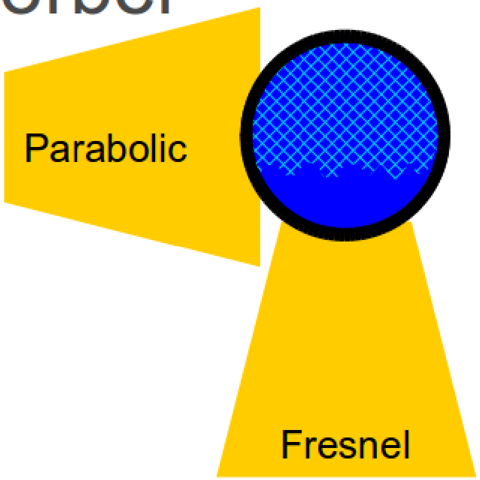
- Stationary receiver, no twisting of flexible connections
- Concentrated sunlight hits absorber tube always from below




⇒ **Best suited for direct steam generation**

## Fresnel Collector for Process Heat

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Single Mirror Line Controls

Mechanically Decoupled

Power Control Using Mirror Combinations

No Stagnation

No Complete defocus

Uniform flux along the absorbers

## Fresnel Collector for Process Heat

- Evacuated Tube Receiver SCHOTT PTR® 70
  - Maximum pressure up to 120 bar (different versions 40, 60, 120 bar)
  - Maximum temperature
    - up to 380 °C with thermal oil
    - up to 330 °C with saturated steam or pressurized water
  - Thermal loss per m² of primary reflector u1 = 0.00043 W/(m²K²)

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# Heat transfer fluids

- Compressed Liquids
  - Pressurized water
  - Thermal oil

- Water Two Phase Mixture for DSG

# Fresnel Collector for Process Heat

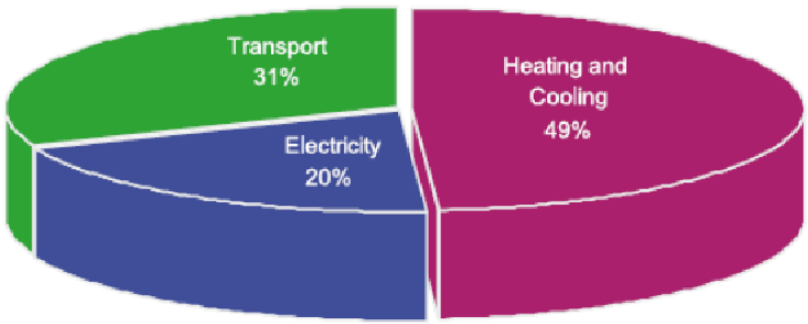


Figure 7: Final Energy demand in the European Union. (Source: EREC, 2006)

- 50% of Europe's end energy demand is for heating and cooling
- 33% of Industrial end use is thermal energy

## Outline

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- **Solar Direct Steam Generation (DSG) System**
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## Solar Direct Steam Generation (DSG) System

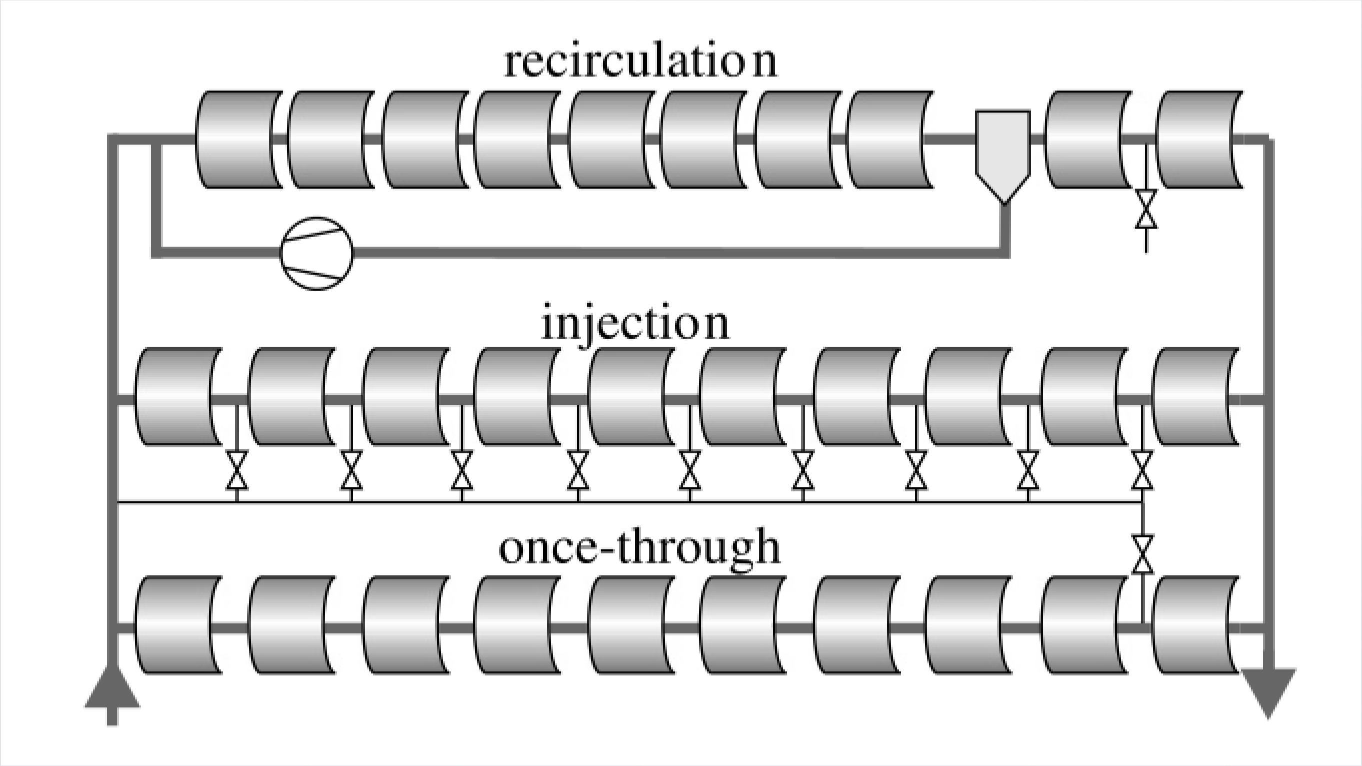
Solar Steam main options:

- Direct Steam Generation in the Solar Field.
- Indirect, using a second HTF and a steam generator.

## Solar Direct Steam Generation (DSG) System

- Avoiding environmental risks associated with synthetic oil usage
- Single HTF
- No limit on steam temperature
- Simpler overall plant configuration
- Lower investment and operation and maintenance cost

**Solar Direct Steam Generation (DSG) System**




Courtesy of Eck and Hirsch (2007)

## Solar Direct Steam Generation (DSG) System

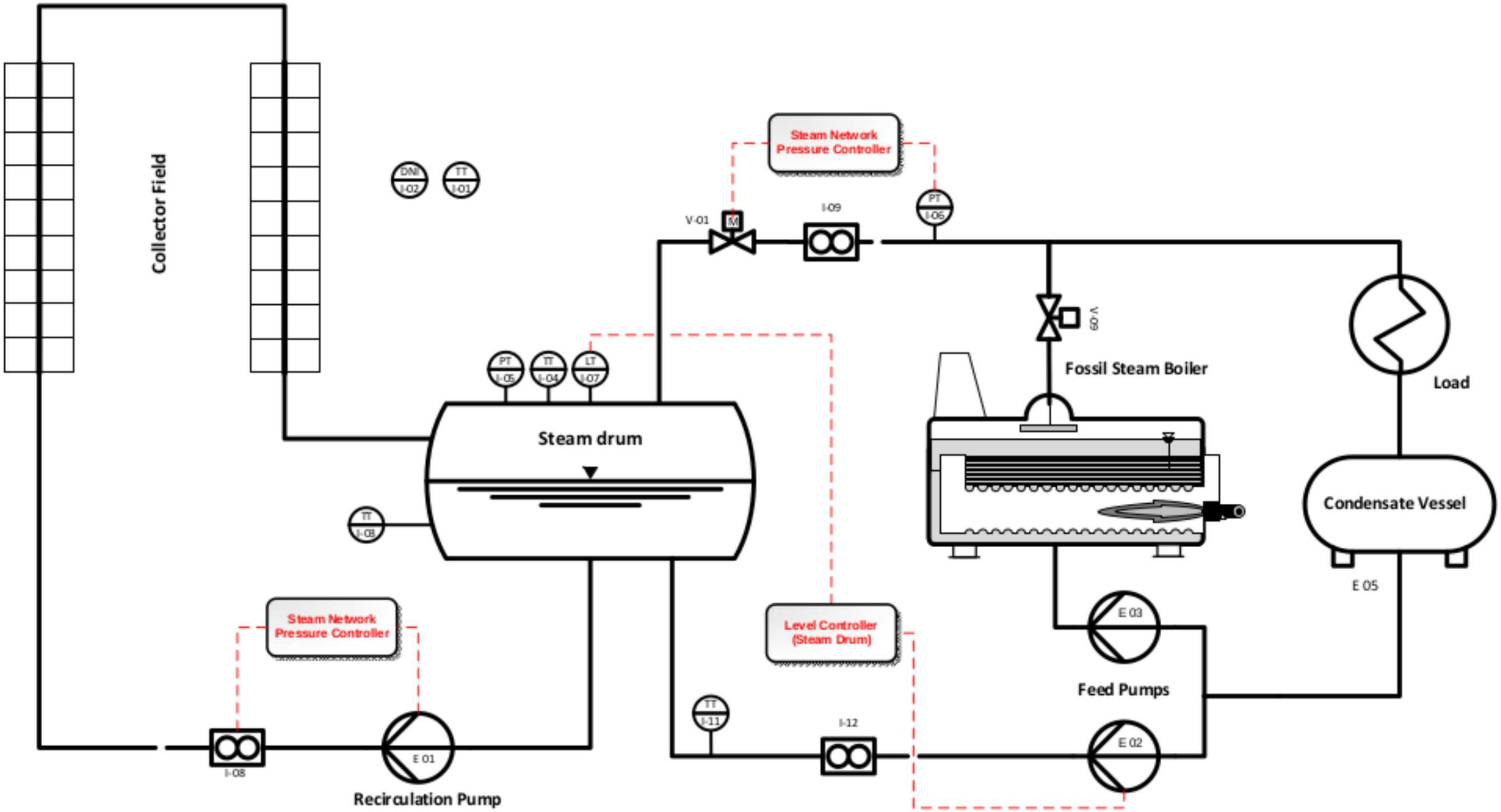
Recirculation Mode:

- More components needed
- Extra pumping power

But

- More reliable
- Safer
- More controllable

# Solar Direct Steam Generation (DSG) System



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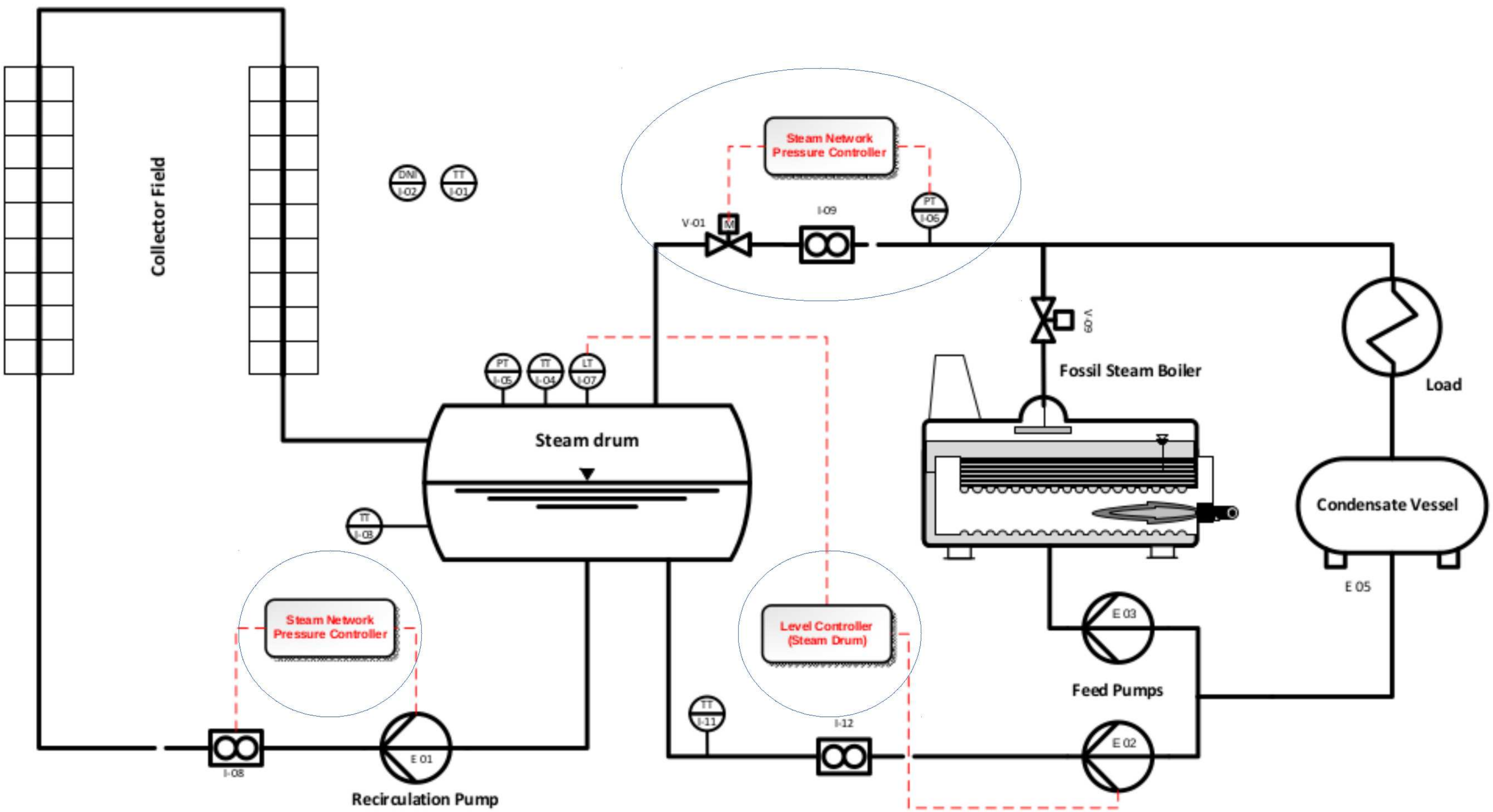
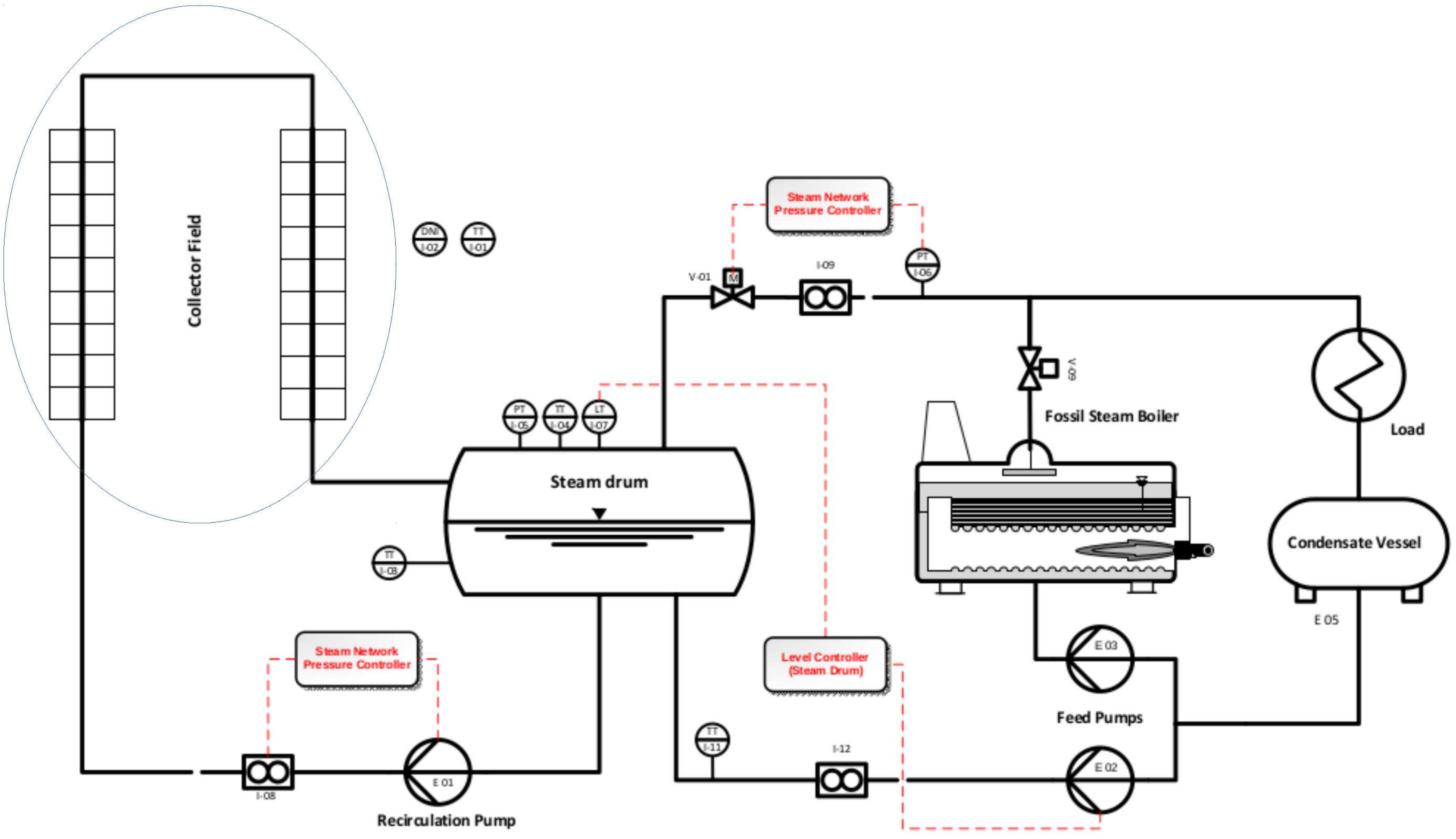
# Main Controllers



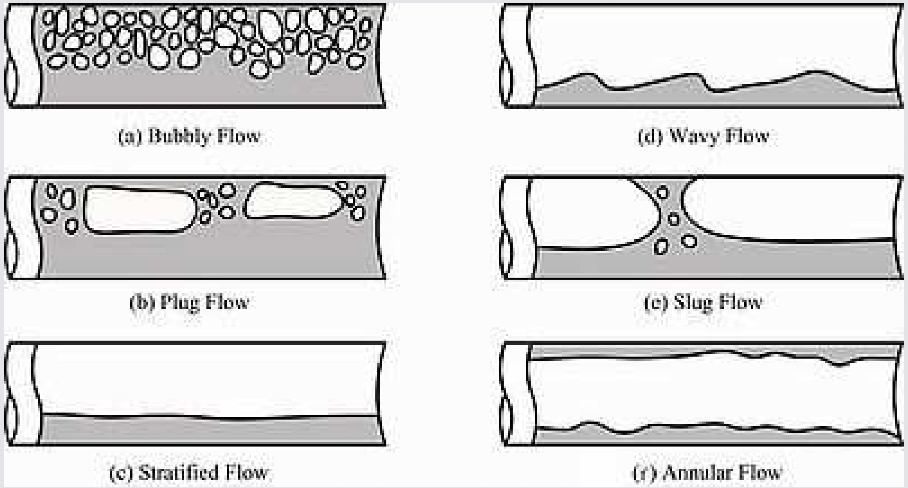
## Solar Field

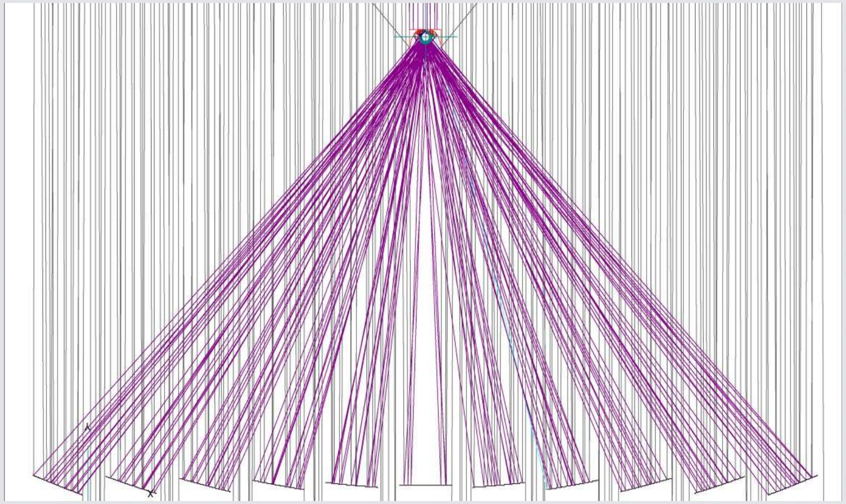


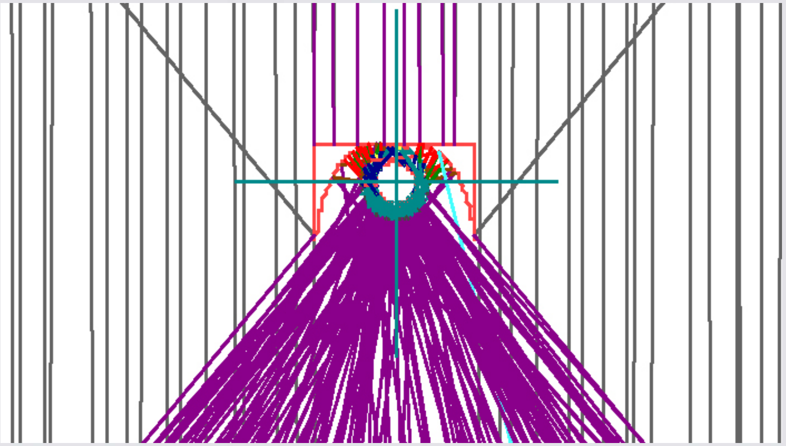
Collector Field
DNI
I-02
TT
I-01
Steam Network
Pressure Controller
V-01
M
I-09
PT
I-06
V-03
Fossil Steam Boiler
Load
PT
I-05
TT
I-04
LT
I-07
Steam drum
TT
I-03
Condensate Vessel
E 05
Steam Network
Pressure Controller
Level Controller
(Steam Drum)
E 03
Feed Pumps
TT
I-11
I-12
E 02
I-08
E 01
Recirculation Pump

## Solar Field

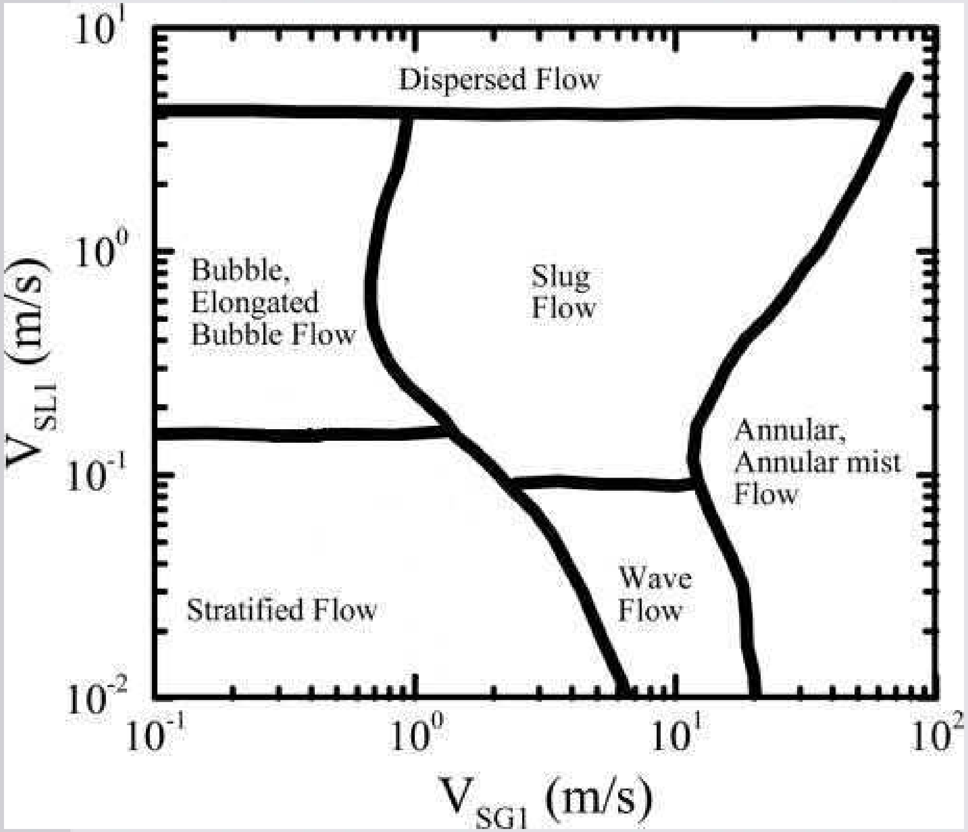
Varying Pressure drops
Instable patterns
Stratified flows

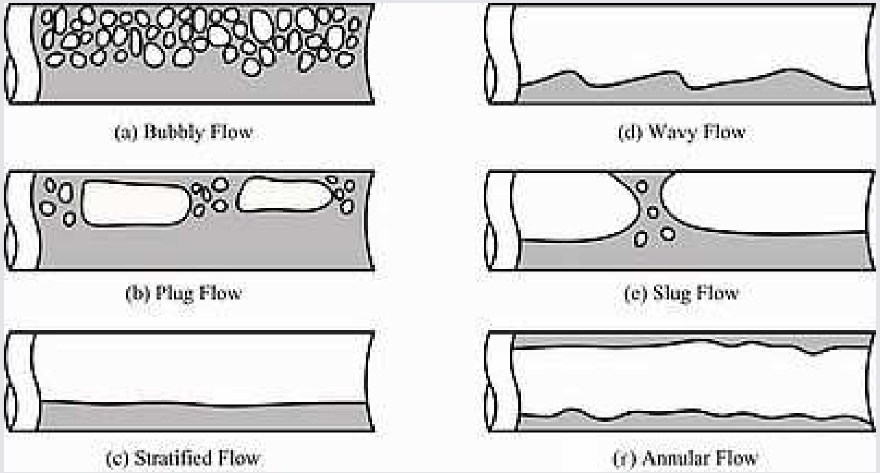




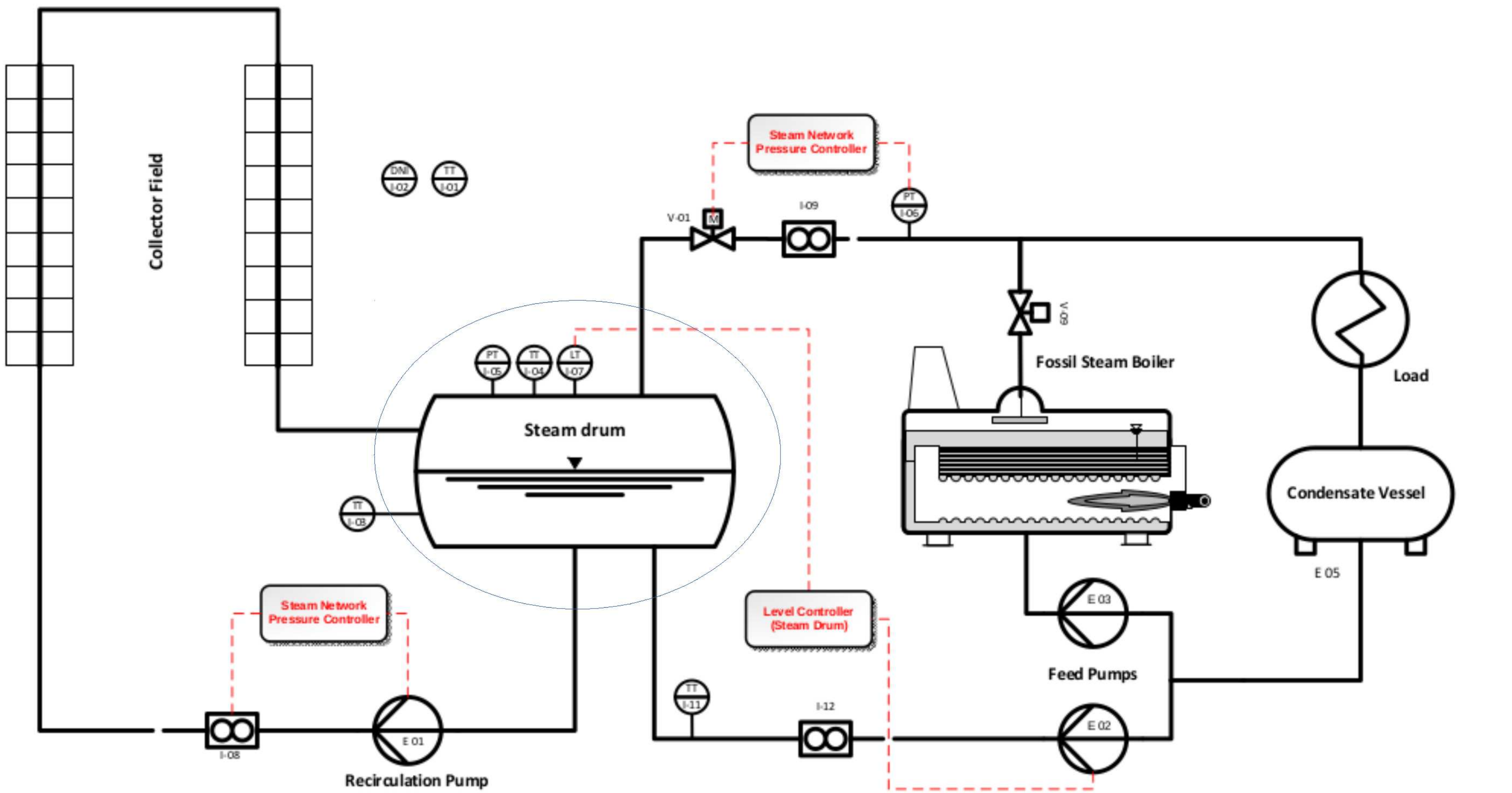
## Solar Field




- Uniqueness?
- dimensionless?
- Applicable range?
- Flow development?

# Steam Drum



Collector Field
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Pressure Controller
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PT
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V-09
Fossil Steam Boiler
Load
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I-05
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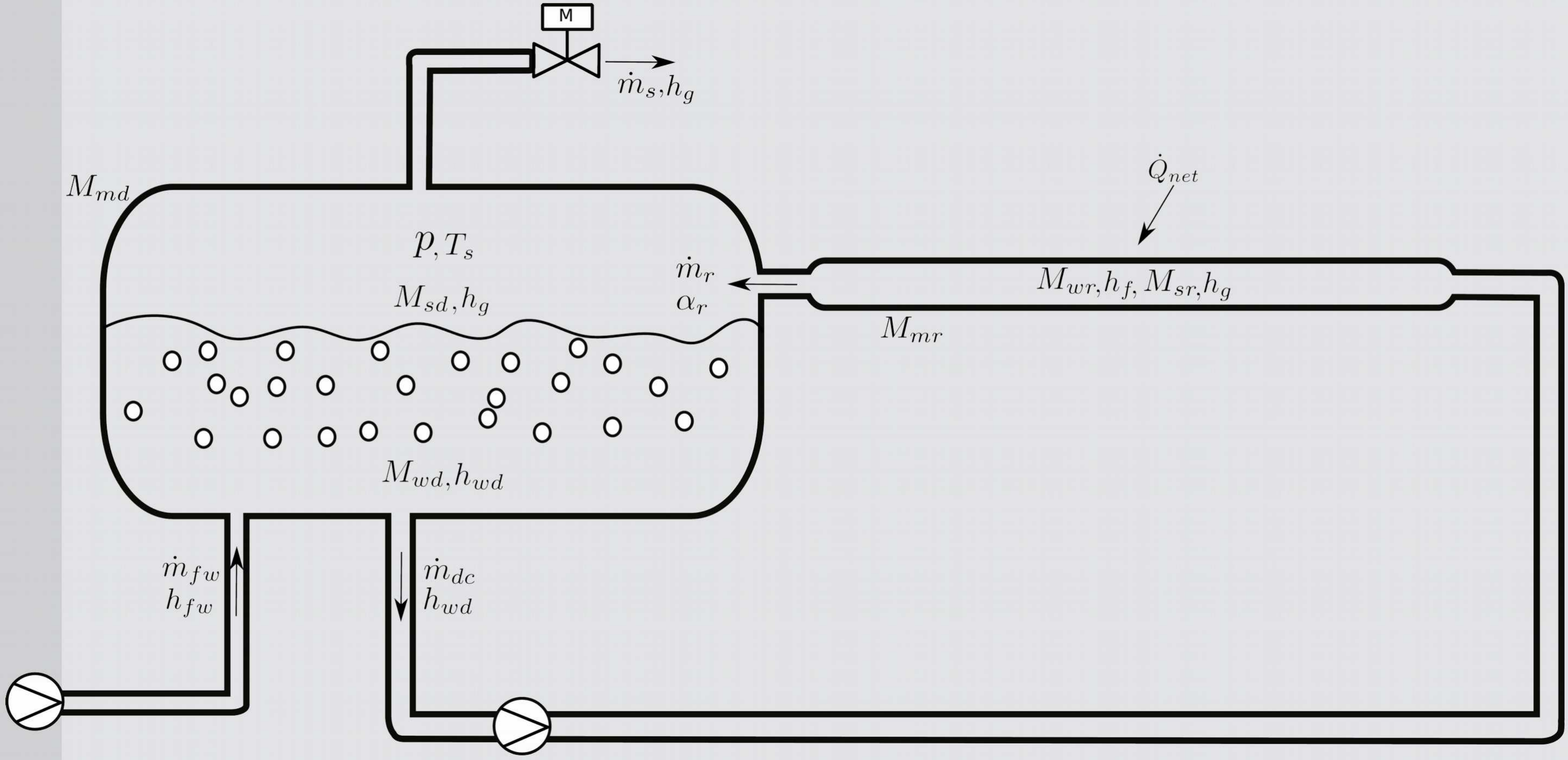
I-04
LT
I-07
Steam drum
TT
I-03
Condensate Vessel
E 05
E 03
Feed Pumps
Steam Network
Pressure Controller
Level Controller
(Steam Drum)
TT
I-11
I-12
E 02
I-08
E 01
Recirculation Pump

## Steam Drum

The Steam Drum

1. Phase Separator
2. Pressure maintenance system
3. Buffer Storage (15-30 min)
4. Water reservoir

## Steam Drum



M
$\dot{m}_s, h_g$
$M_{md}$
$\dot{Q}_{net}$
$p, T_s$
$\dot{m}_r$
$\alpha_r$
$M_{wr}, h_f, M_{sr}, h_g$
$M_{sd}, h_g$
$M_{mr}$
$M_{wd}, h_{wd}$
$\dot{m}_{fw}$
$h_{fw}$
$\dot{m}_{dc}$
$h_{wd}$


Then What?!
Amman-2015-05-13 11:47

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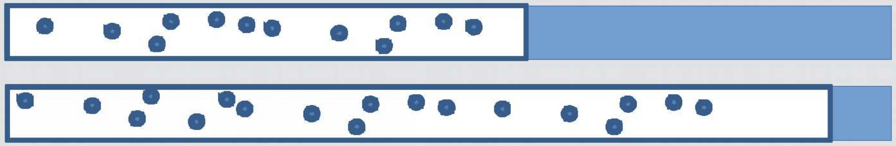
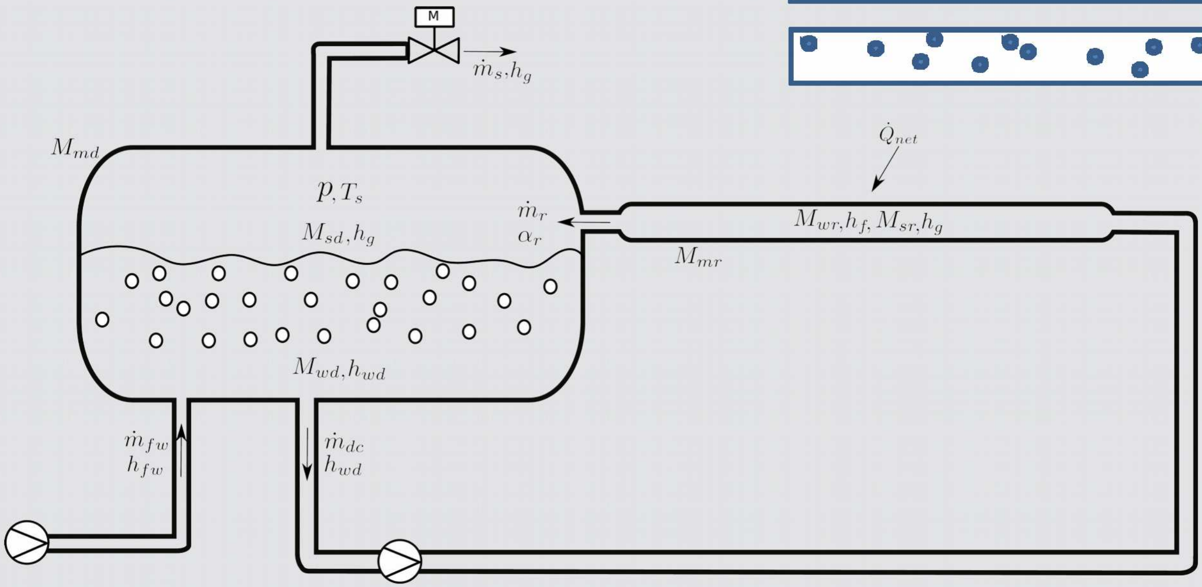
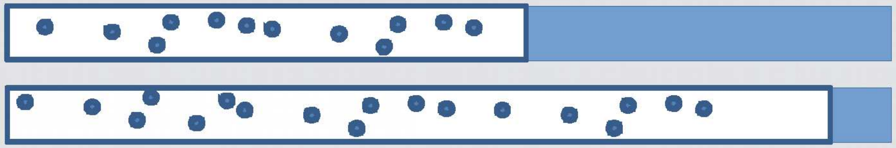
- As the cloud passes, pressure drops in the steam drum as steam generation is interrupted and load is still supplied.
- This will cause steam flashing in the steam drum and the level would rise a little bit

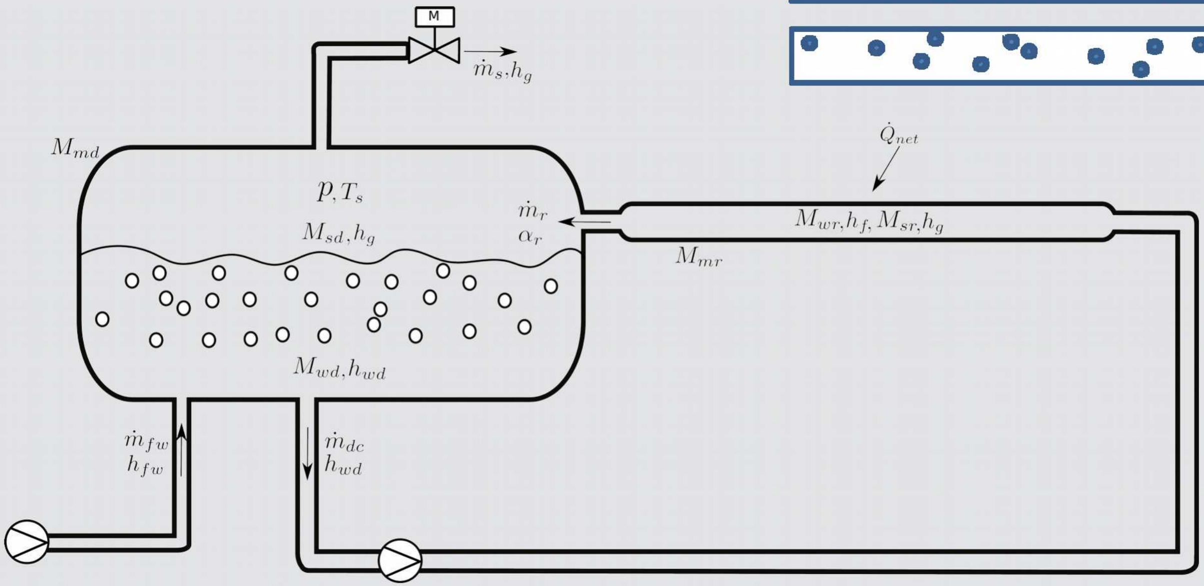


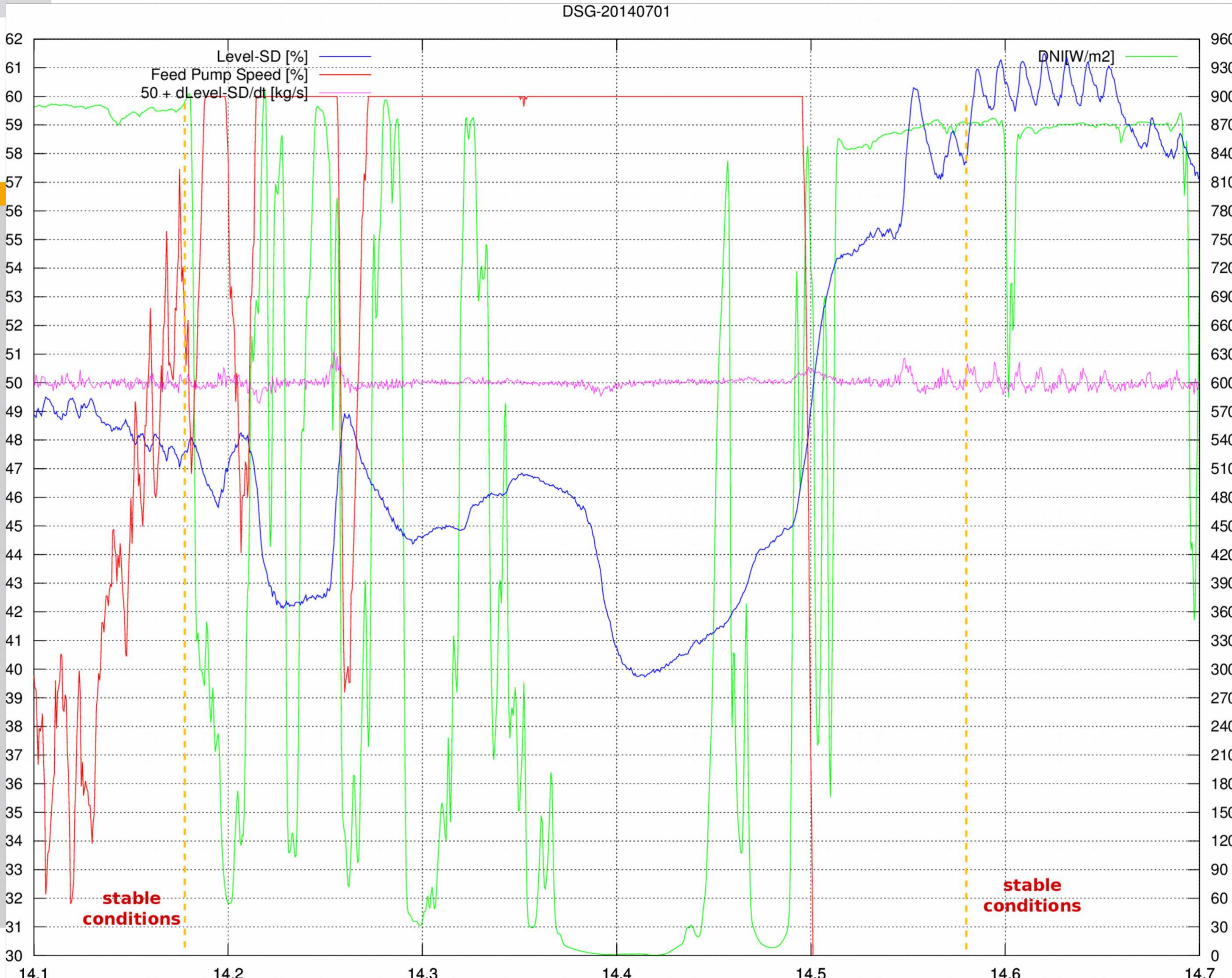


# Control of Solar DSG systems

- However since the water is then used from the steam drum  to fill the absorber tube the level drops
- This causes feed pump to start
- When the cloud goes away the level will increase since the water in the absorber will be pushed back to the steam drum and hence the level will increase above the required level

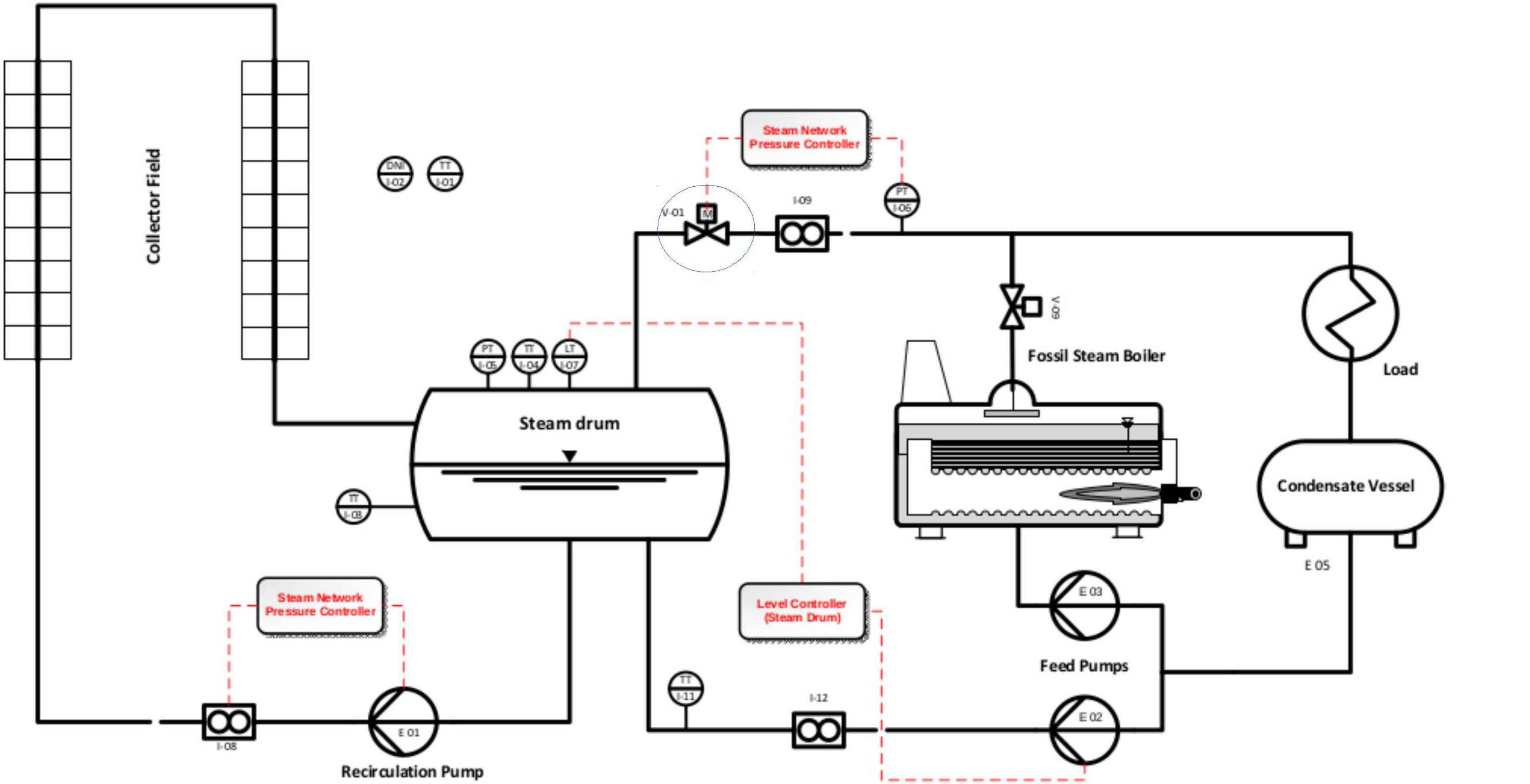






DSG-20140701
Level-SD [%]
Feed Pump Speed [%]
50 + dLevel-SD/dt [kg/s]
DNI[W/m2]
stable conditions
stable conditions

# Steam Valve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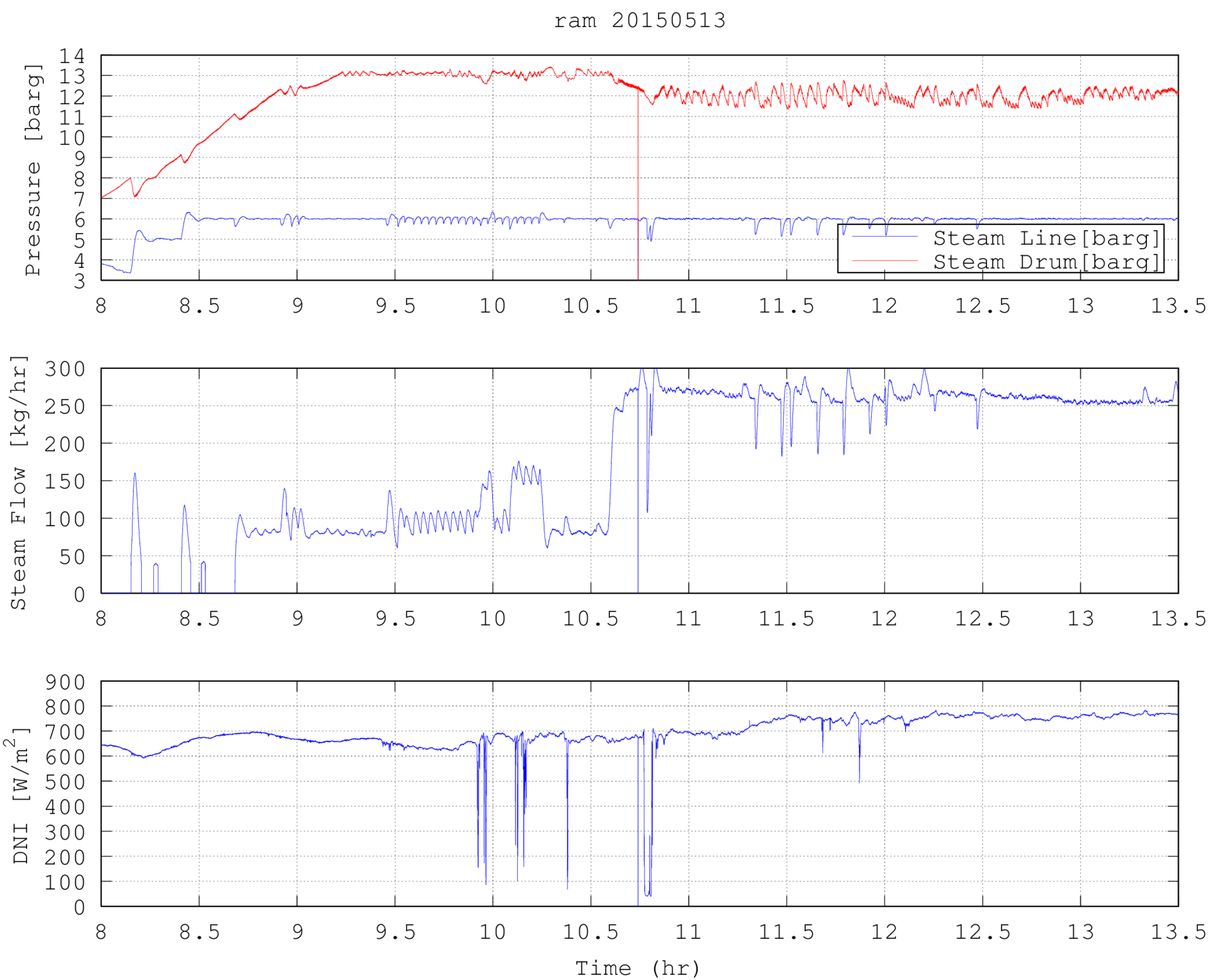
Level Controller
(Steam Drum)
Feed Pumps
TT
I-11
I-12
E 02
I-08
E 01
Recirculation Pump

# Steam Valve

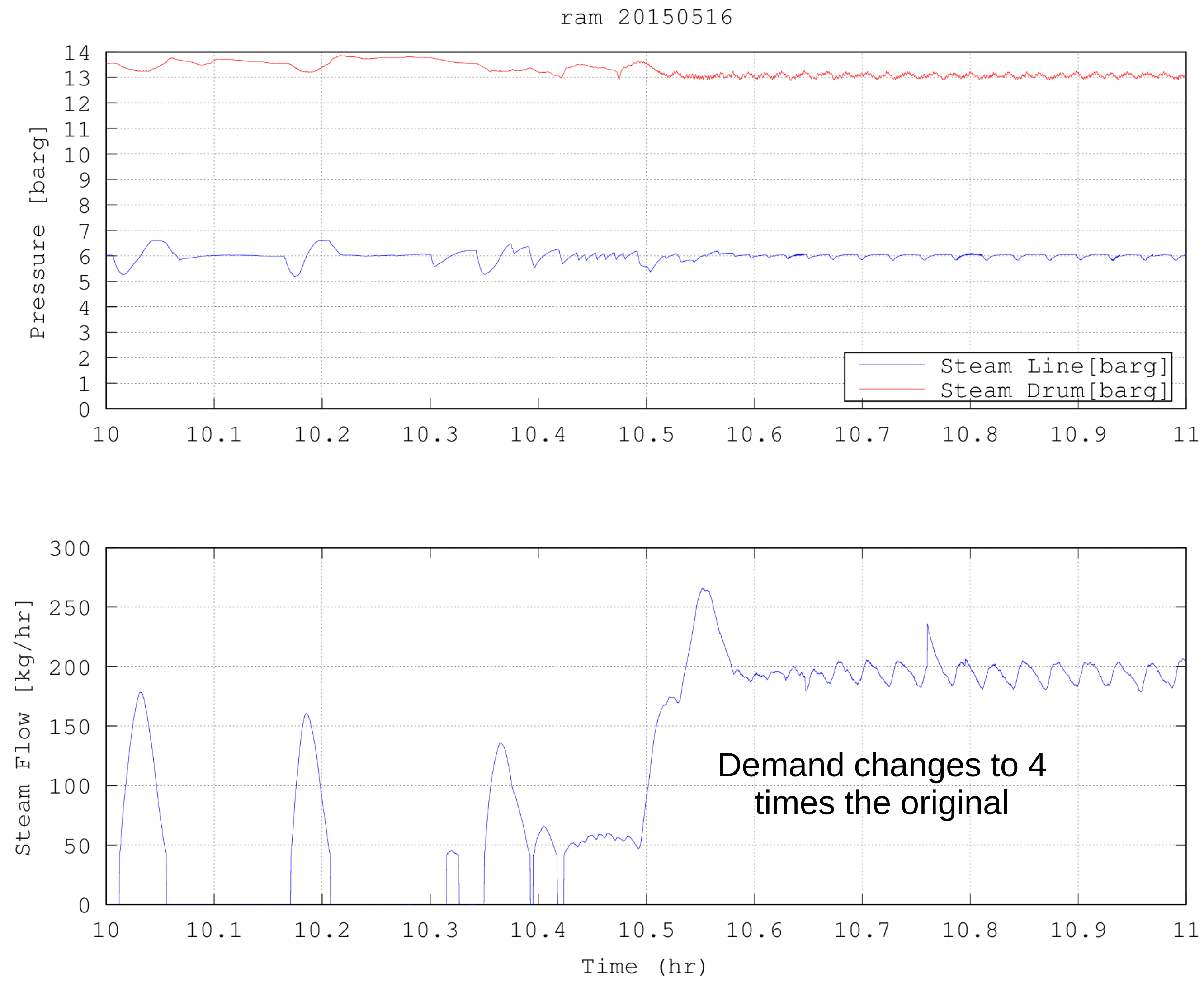
The Steam Valve

1. Draws saturated steam from the top of the Steam Drum
2. Controls the pressure on the customer side.
3. Has to react to variations on demand, solar irradiation, steam drum pressure and setpoint changes.

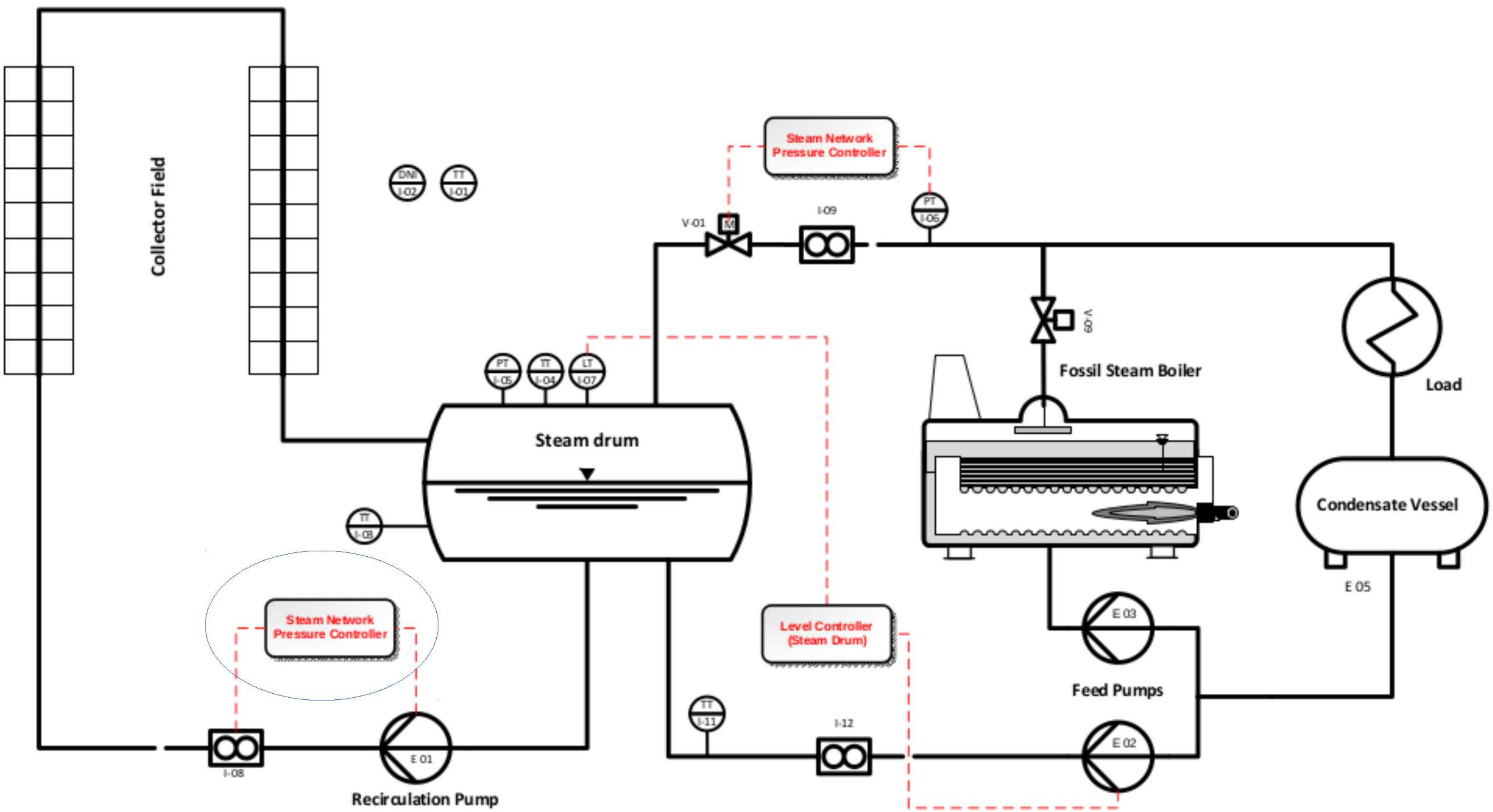


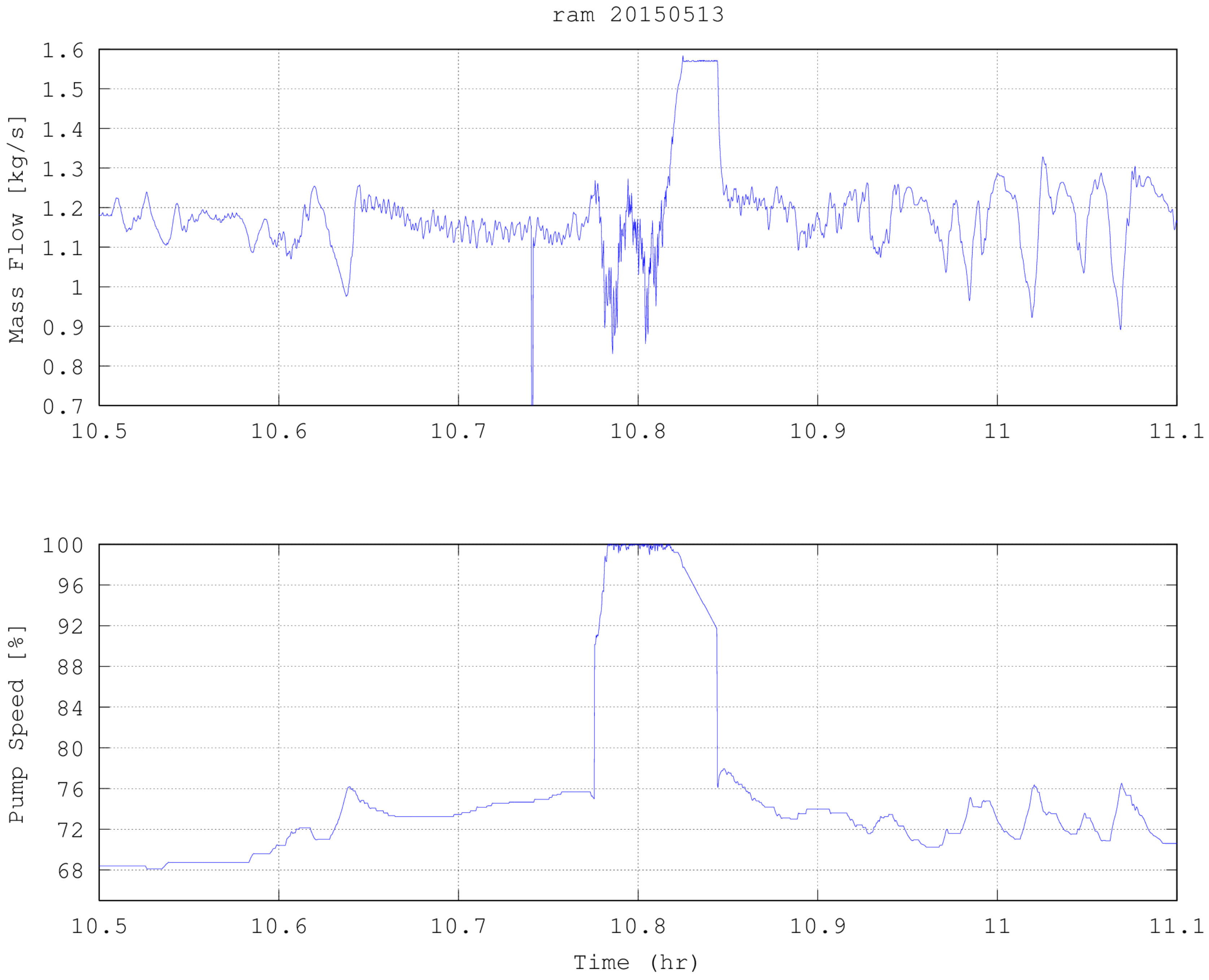
ram 20150513
Pressure [barg]
Steam Line[barg]
Steam Drum[barg]
Steam Flow [kg/hr]
DNI [W/m2]
Time (hr)

## Quick Response



# Control of Solar DSG systems





ram 20150513
Mass Flow [kg/s]
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
10.5
10.6
10.7
10.8
10.9
11
11.1
Pump Speed [%]
100
96
92
88
84
80
76
72
68
Time (hr)

## Outline

- Introduction
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- **Solar DSG Plant in Jordan**
- Outlook

# Solar DSG plant in Jordan

1. The Plant is installed at al RAM pharmaceutical company and was commissioned in March 2015.
2. The system provides saturated steam augmenting the diesel steam boiler

# Solar DSG plant in Jordan

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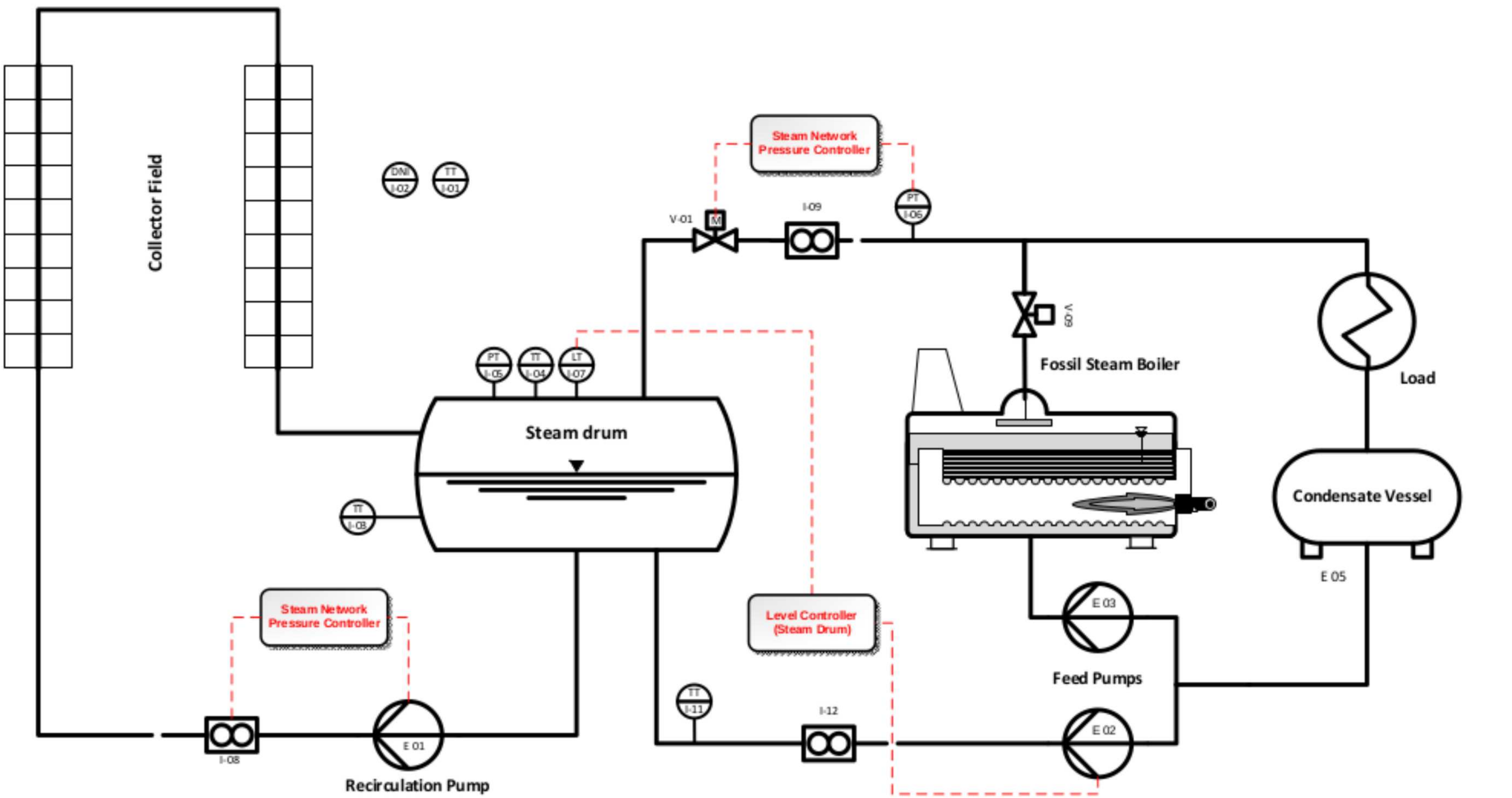


## Solar DSG plant in Jordan

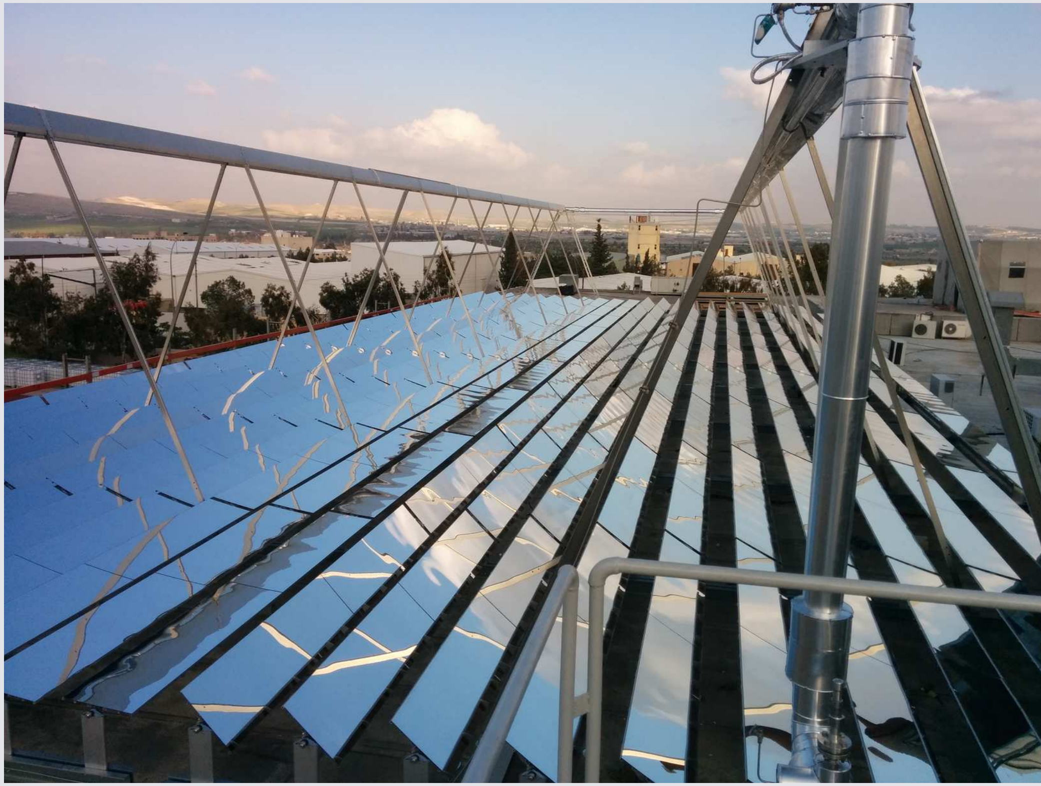
1. 18 Modules of Industrial Solar's Fresnel Collector arranged in two parallel strings each 36.5m long.

Total reflective area of $396m^2$

2. Peak Plant Power 222kW

3. Maximum steam pressure $15.5bar_g$

4. Required delivery steam pressure $6.0bar_g$



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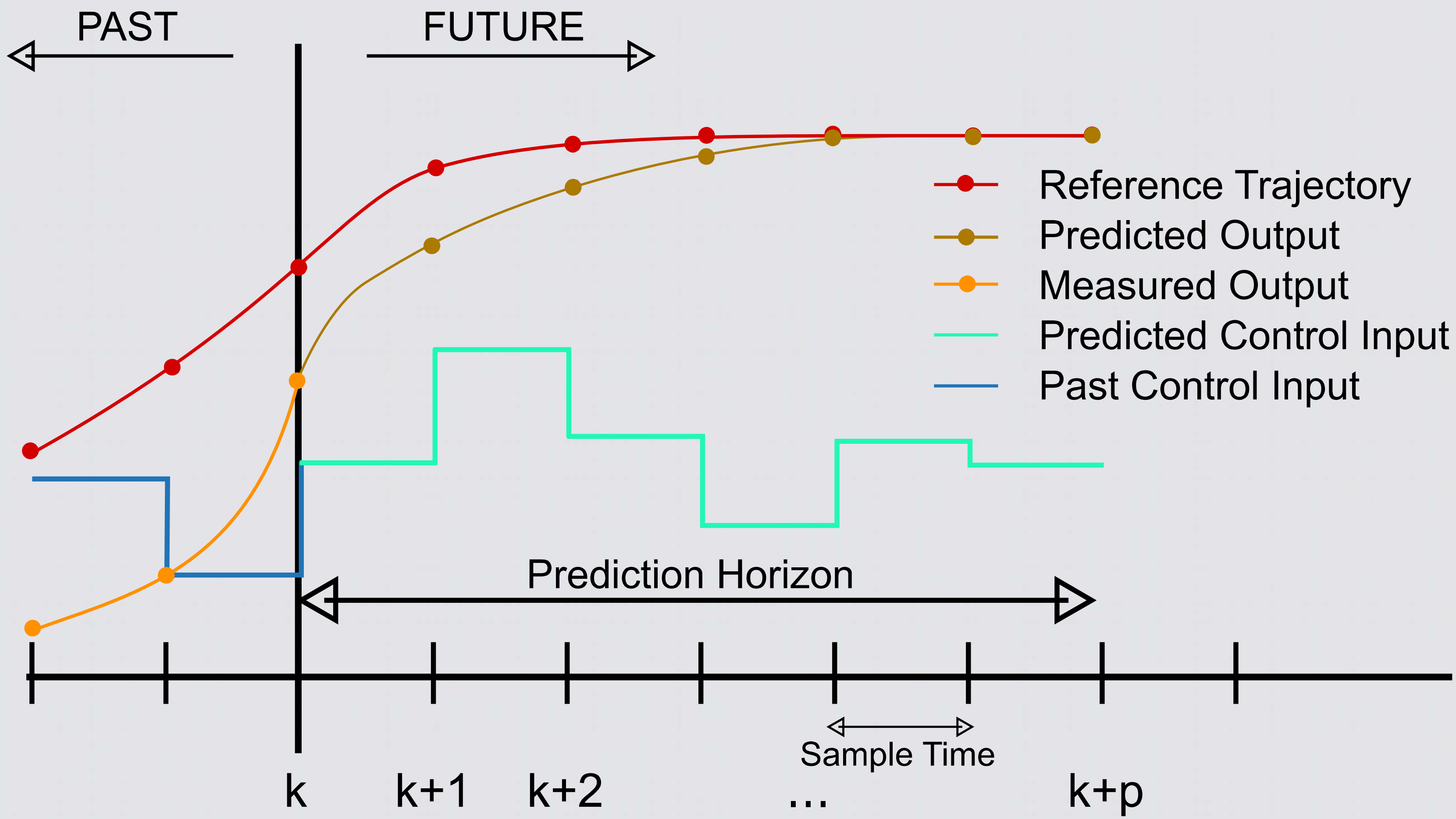
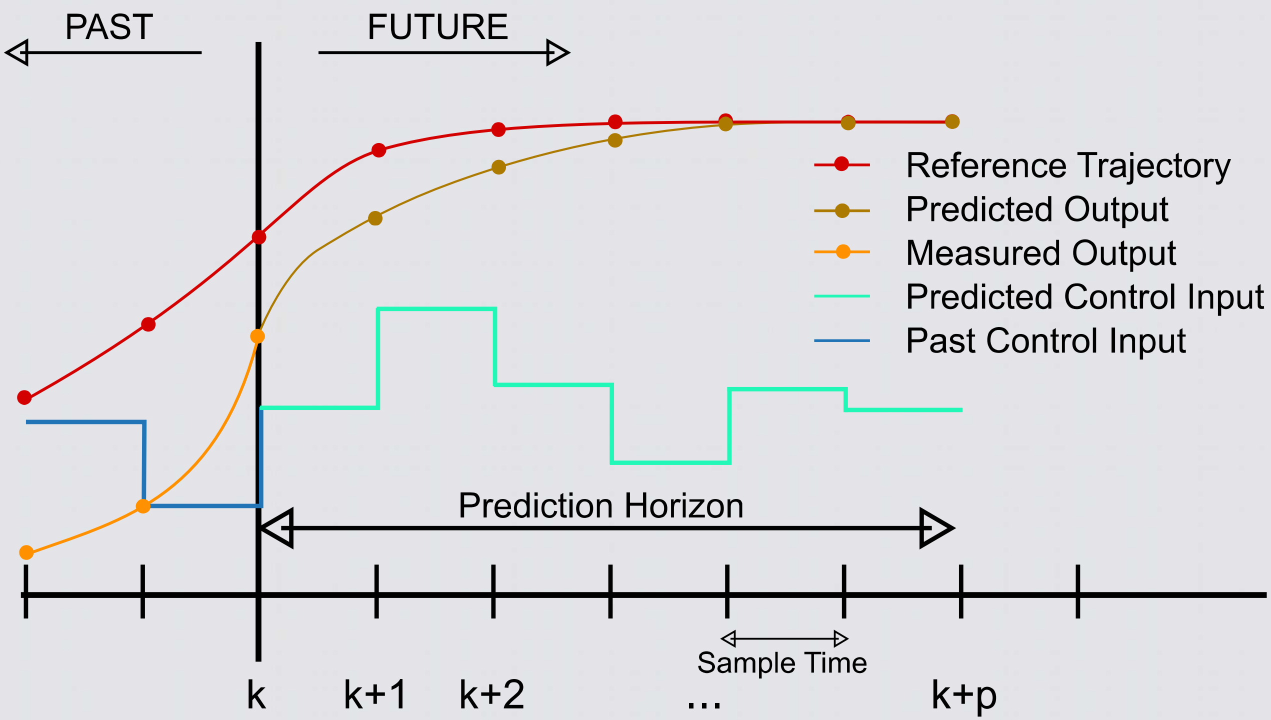
## Model Predictive Control - Pros




http://en.wikipedia.org/wiki/Model_predictive_control

## Model Predictive Control - Pros

1. Multi-variable Universal Control Law
2. Measure disturbances included
3. Long term goals vs. short term corrections
4. Naturally accounts for constraints

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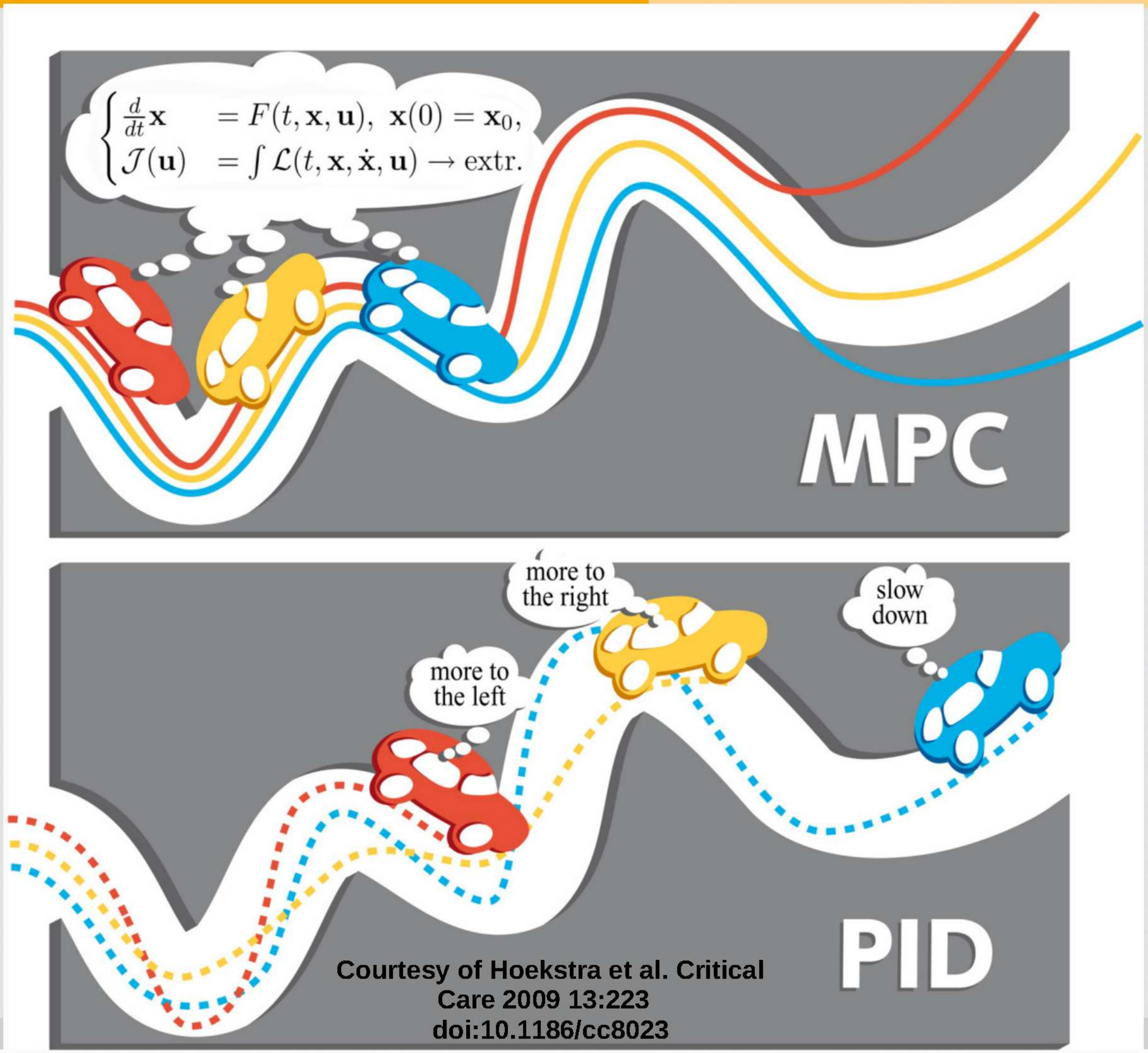
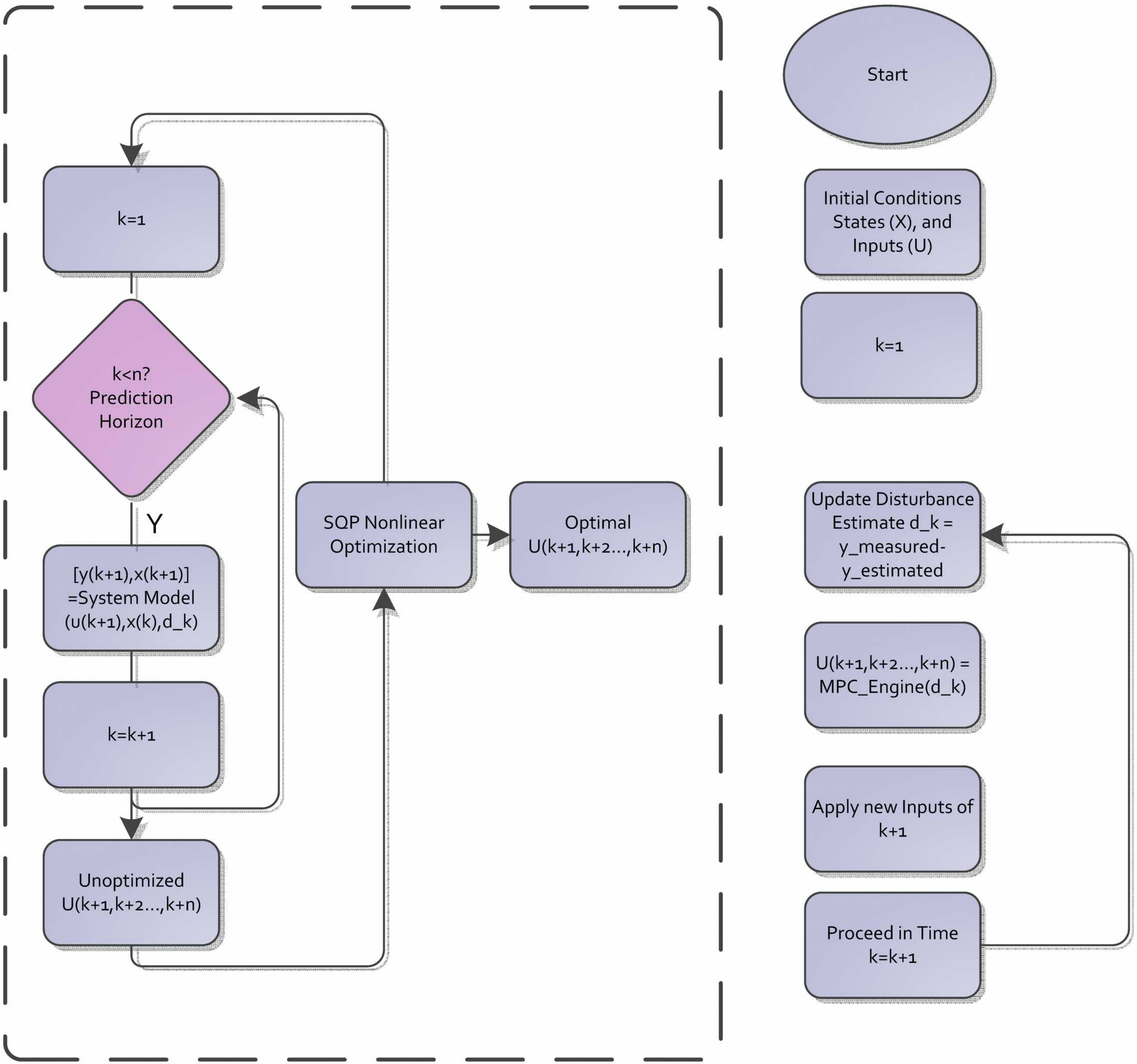
## Model Predictive Control - Pros



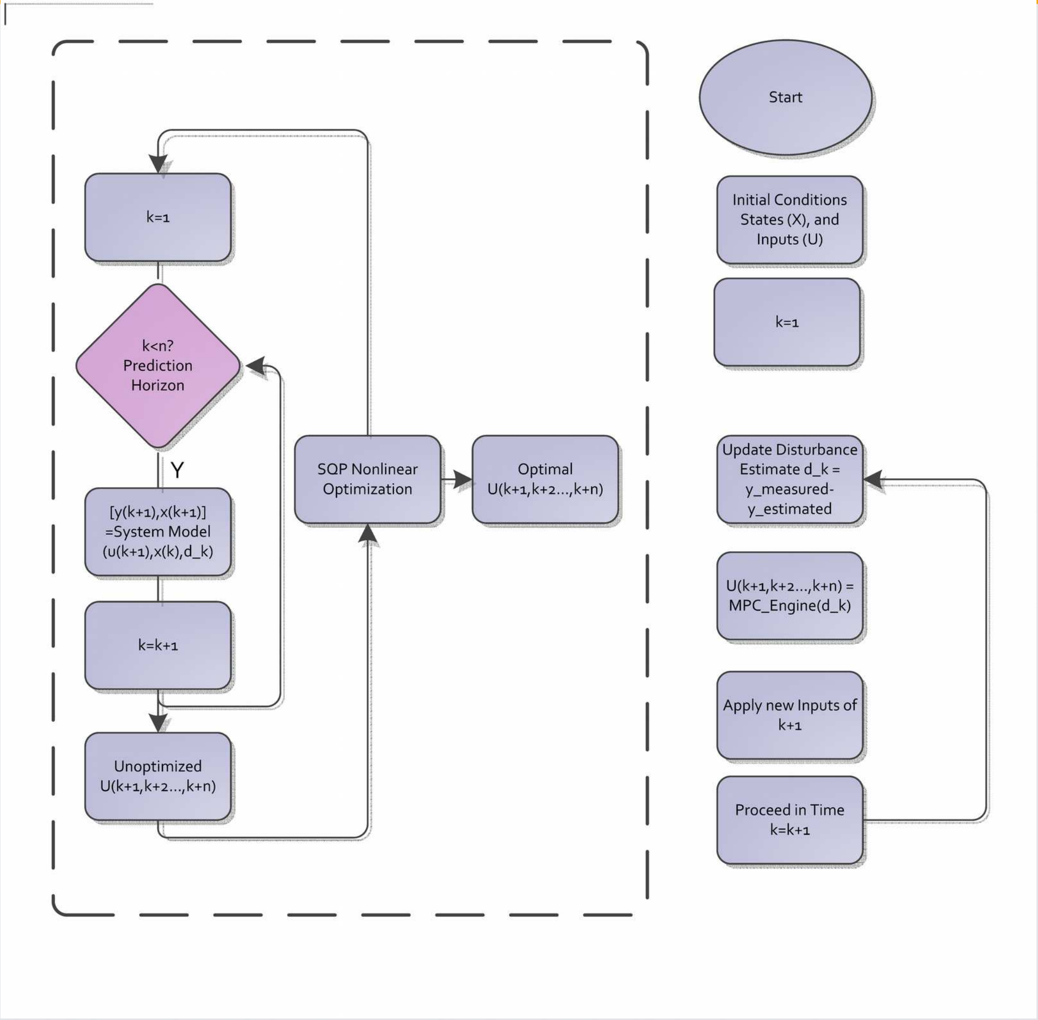

Courtesy of Hoekstra et al. Critical Care 2009 13:223 doi:10.1186/cc8023



Start
Initial Conditions States (X), and Inputs (U)
k=1
Update Disturbance Estimate d_k = y_measured-y_estimated
U(k+1,k+2...,k+n) = MPC_Engine(d_k)
Apply new Inputs of k+1
Proceed in Time k=k+1
k=1
k<n? Prediction Horizon
Y
[y(k+1),x(k+1)] =System Model (u(k+1),x(k),d_k)
k=k+1
Unoptimized U(k+1,k+2...,k+n)
SQP Nonlinear Optimization
Optimal U(k+1,k+2...,k+n)

# Model Predictive Control -Cons

1. Dynamic model needed
2. Optimization problem solution each time step (Computationally intensive)
3. Generally, more complex to develop



# SolSteam

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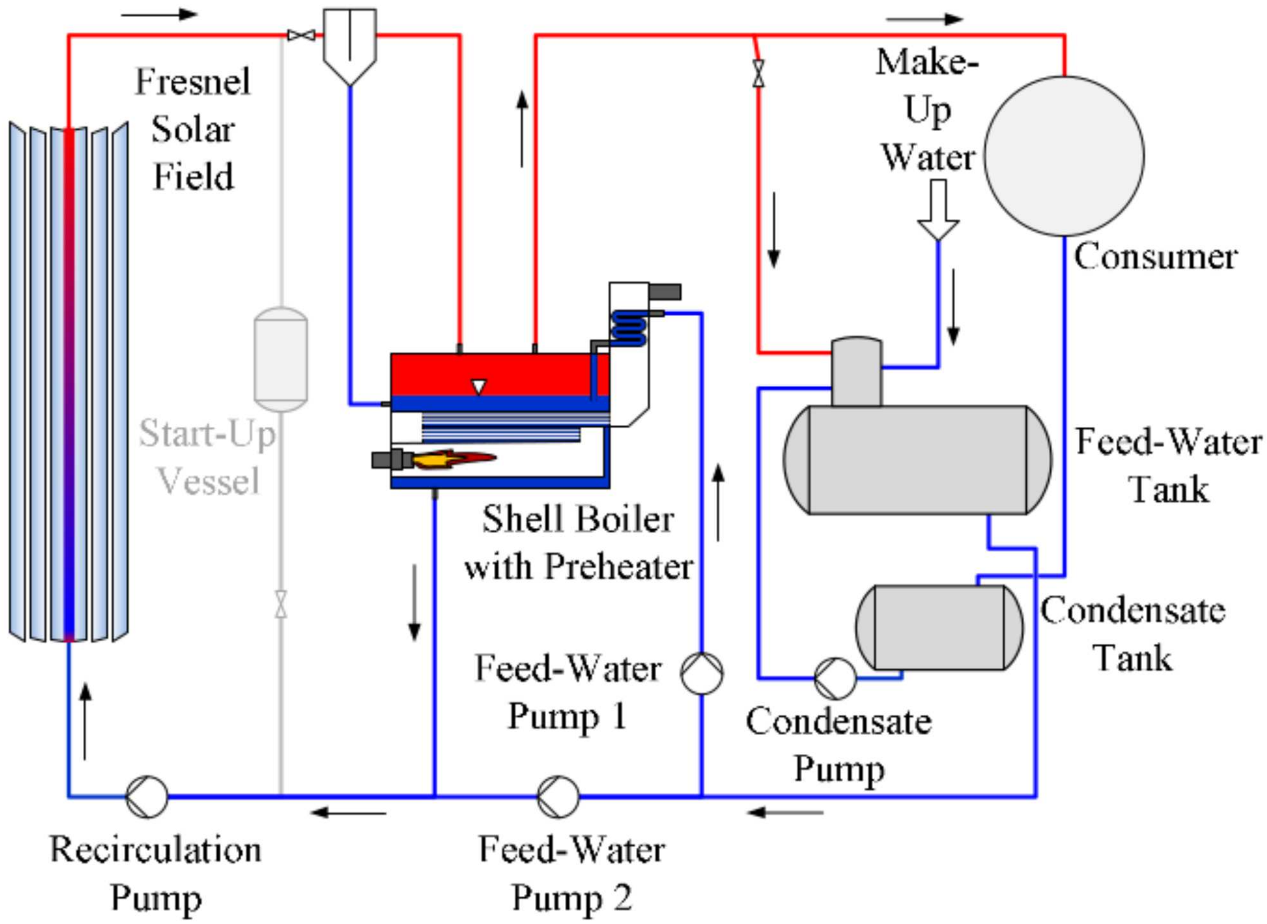


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DLR

Bundesministerium für Wirtschaft und Energie

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## To sum up !

# Thank You

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