PIACER
Piattaforma Progettazione Gestione
Comunità Energetiche Rinnovabili

Meeting online

Stato di avanzamento delle attività di ricerca di IN⁴

08/01/2026

Università degli Studi di Ferrara | IN⁴ innovazione ingegneria integrazione industria

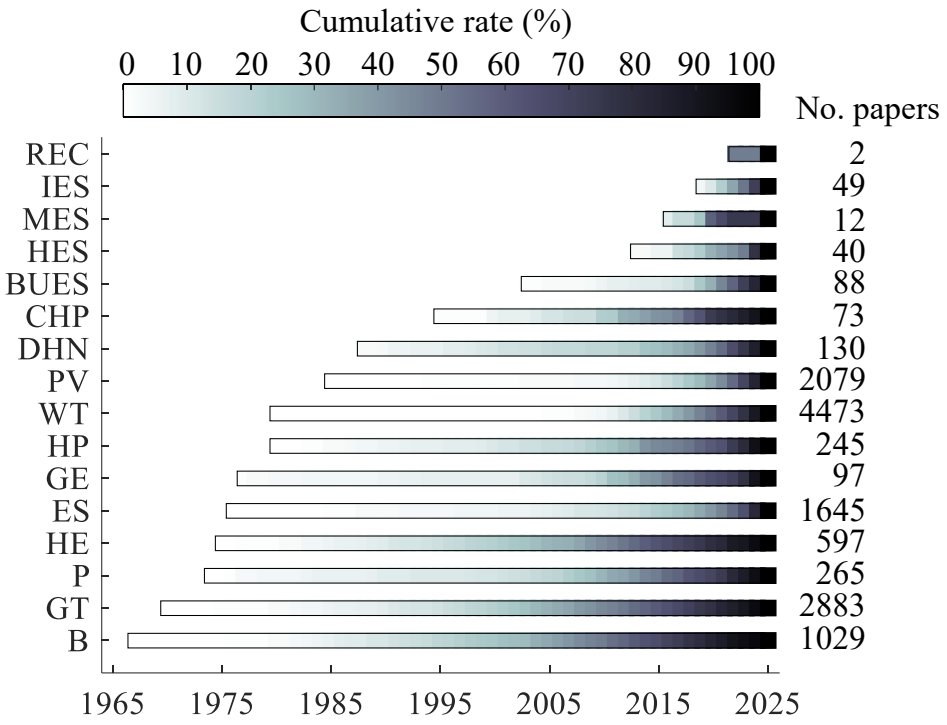
Pier Ruggero Spina

WP 2
ANALISI DELLO STATO DELL'ARTE

State of the art: REC diagnosis

Available papers

- Research source: Science Direct
- Keywords:
  - "fault detection", "diagnostic", "FDD", and "diagnosis"



List of available projects

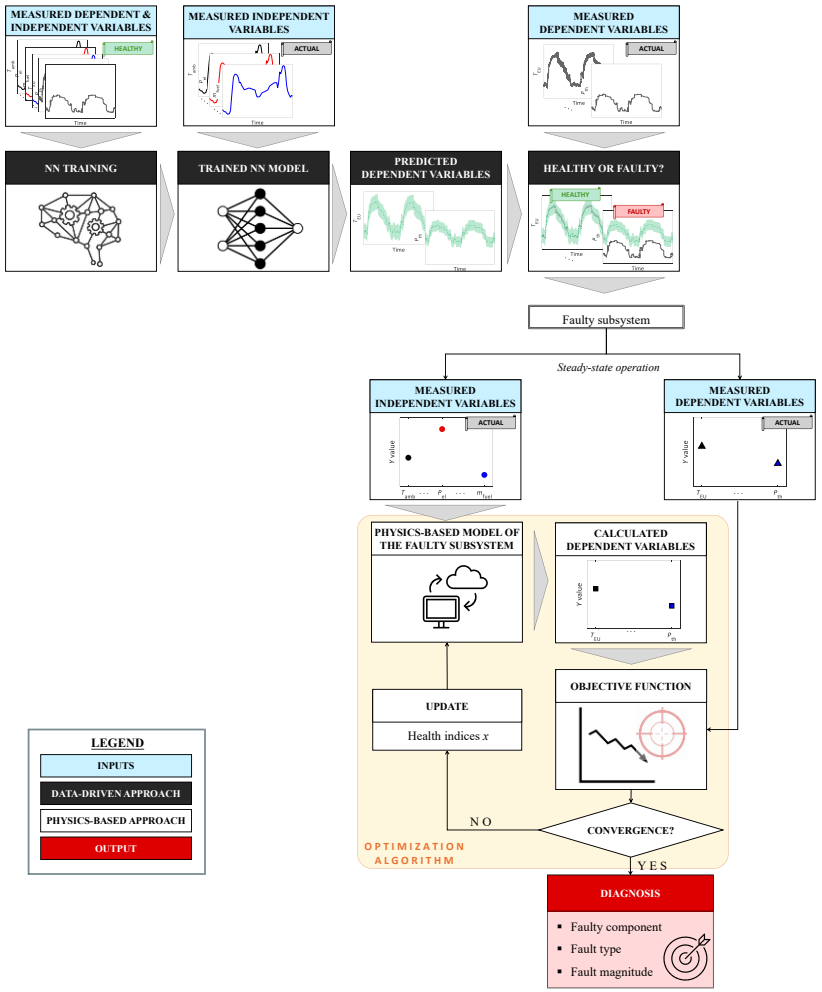
- Research source: Cordis

Project	Duration	Focus
Energynius	2019-2021	Design and management of integrated energy systems
WEDISTRICT	2019-2023	Integration of multiple sources of renewable energy and excess heat at three demonstration sites
ESPON TANDEM	2024-2028	Creation of the largest EU-backed database of energy communities
ASCEND	2023-2027	Implementation of PCED (Positive clean energy district) in multiple cities
D4Heat	2024-2027	Data-driven diagnosis of district heating substations

WP 3

SVILUPPO DI TOOL PER LA DIAGNOSI DI SISTEMI MULTI-ENERGIA & RETI DI TELERISCALDAMENTO

Goal



Data-driven approach

Identification of the faulty sub-system

- Transient and steady-state operation

Physics-based approach

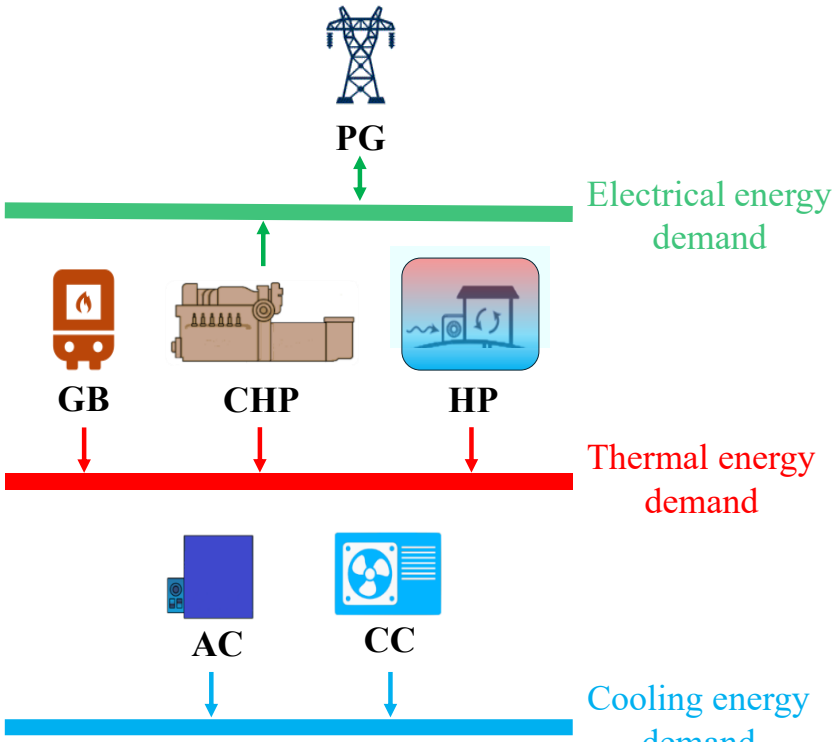
Identification of the fault type and magnitude

- Steady-state operation

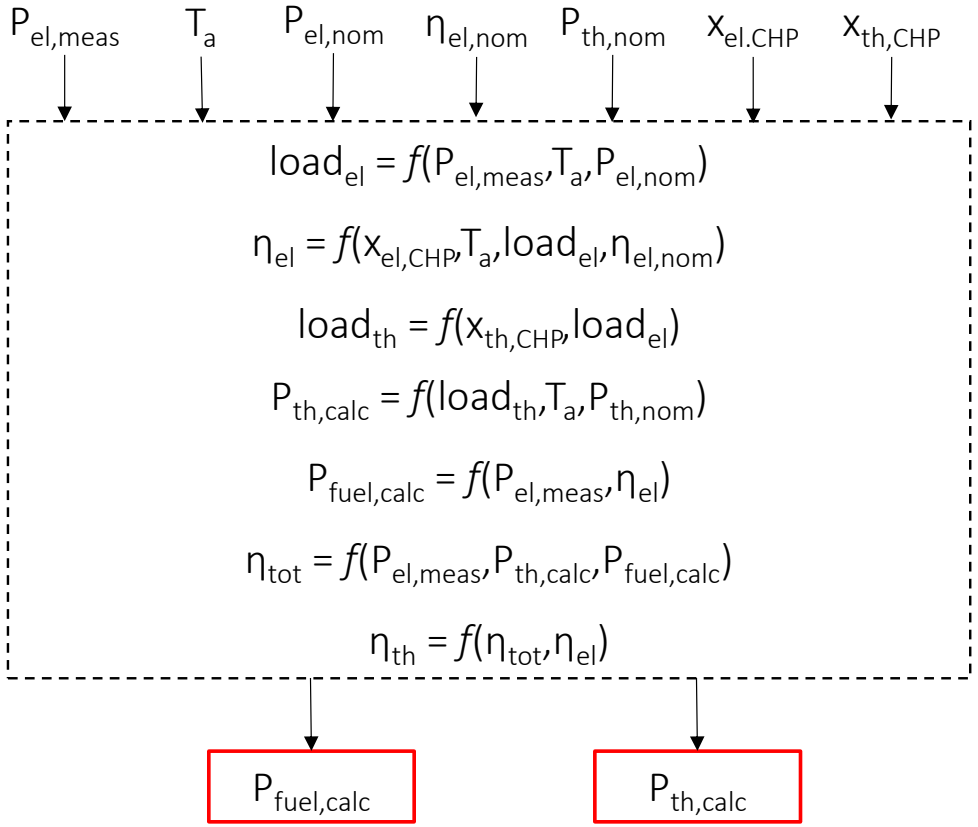
SVILUPPO DI TOOL PER LA DIAGNOSI DI SISTEMI MULTI-ENERGIA

Physics-based approach

Multi-energy system



Combined heat and power system (CHP)



Developed physics-based models: gas boiler, CHP, heat pump, compressor chiller, absorption chiller

Campus of University of Parma

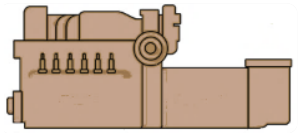
Gas boiler

1 MW_t 2.6 MW_t 3.0 MW_t 3.0 MW_t 3.5 MW_t

Heat pump

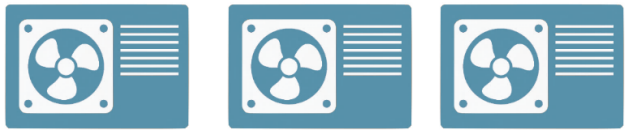
1360 kW_t

CHP (natural gas)



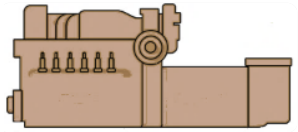
1560 kW_e; 1648 kW_t

Compressor chiller



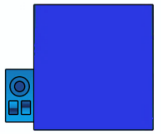
2500 kW_c 2500 kW_c 2500 kW_c

CHP (biomass)



100 kW_e; 215 kW_t

Absorption chiller

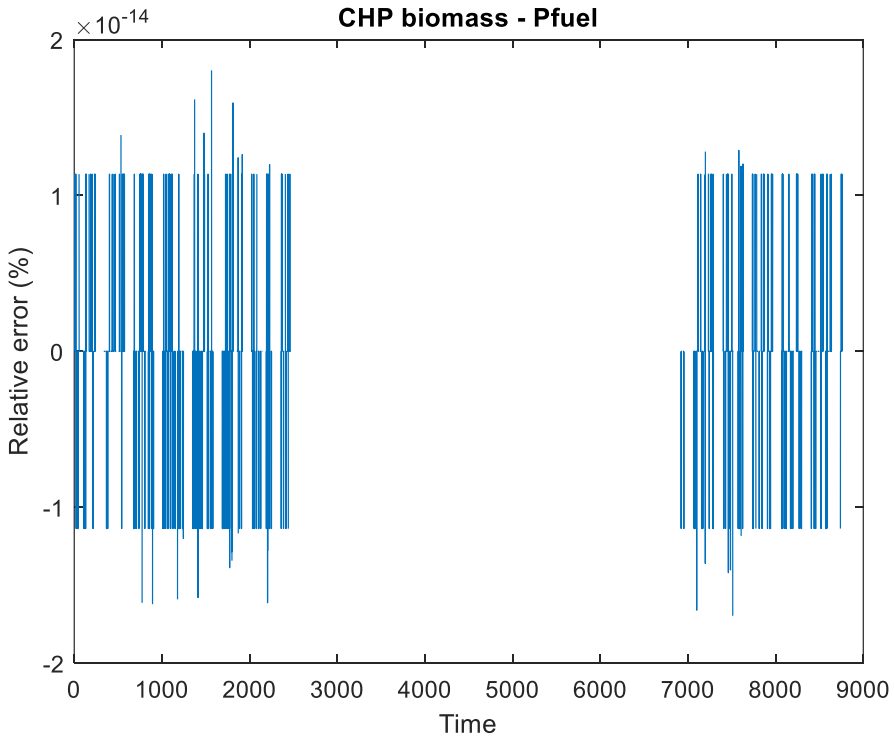


1189 kW_c

Validation of the physics-based model under healthy operation

model

data

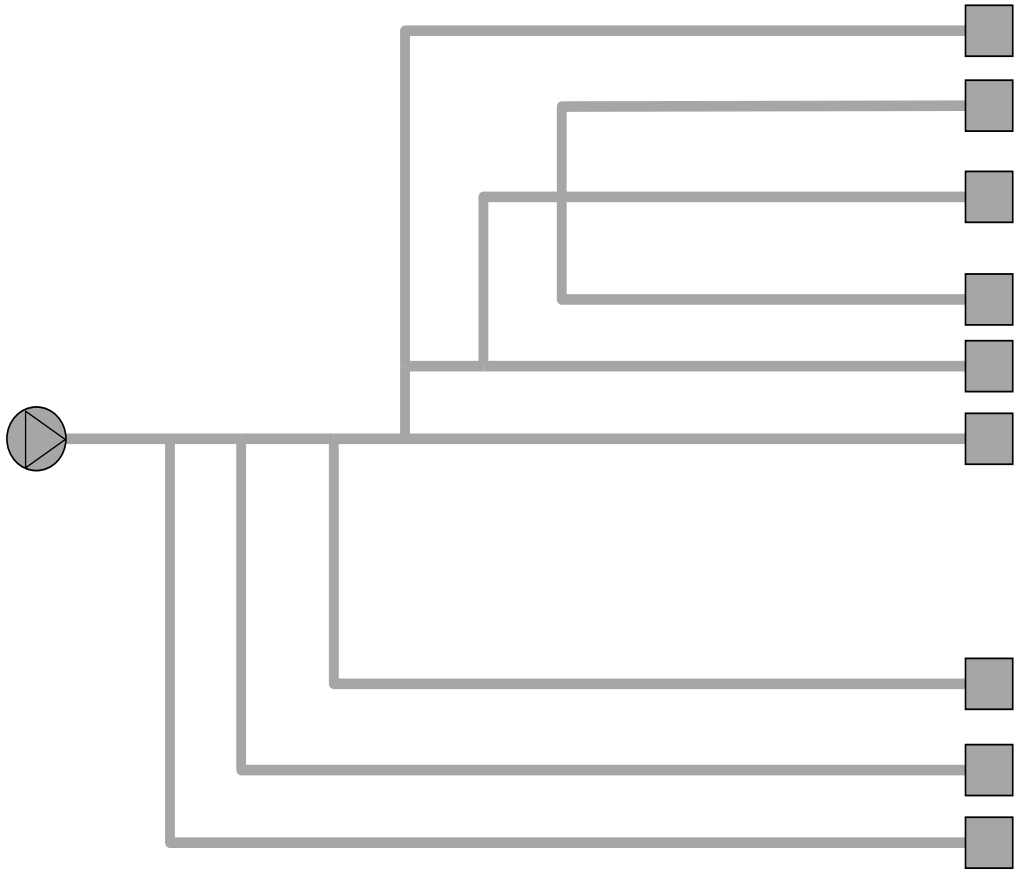


Next step: diagnosis of the multi-energy system

SVILUPPO DI TOOL PER LA DIAGNOSI DI RETI DI TELERISCALDAMENTO

Case study

District heating network of the Campus of University of Parma

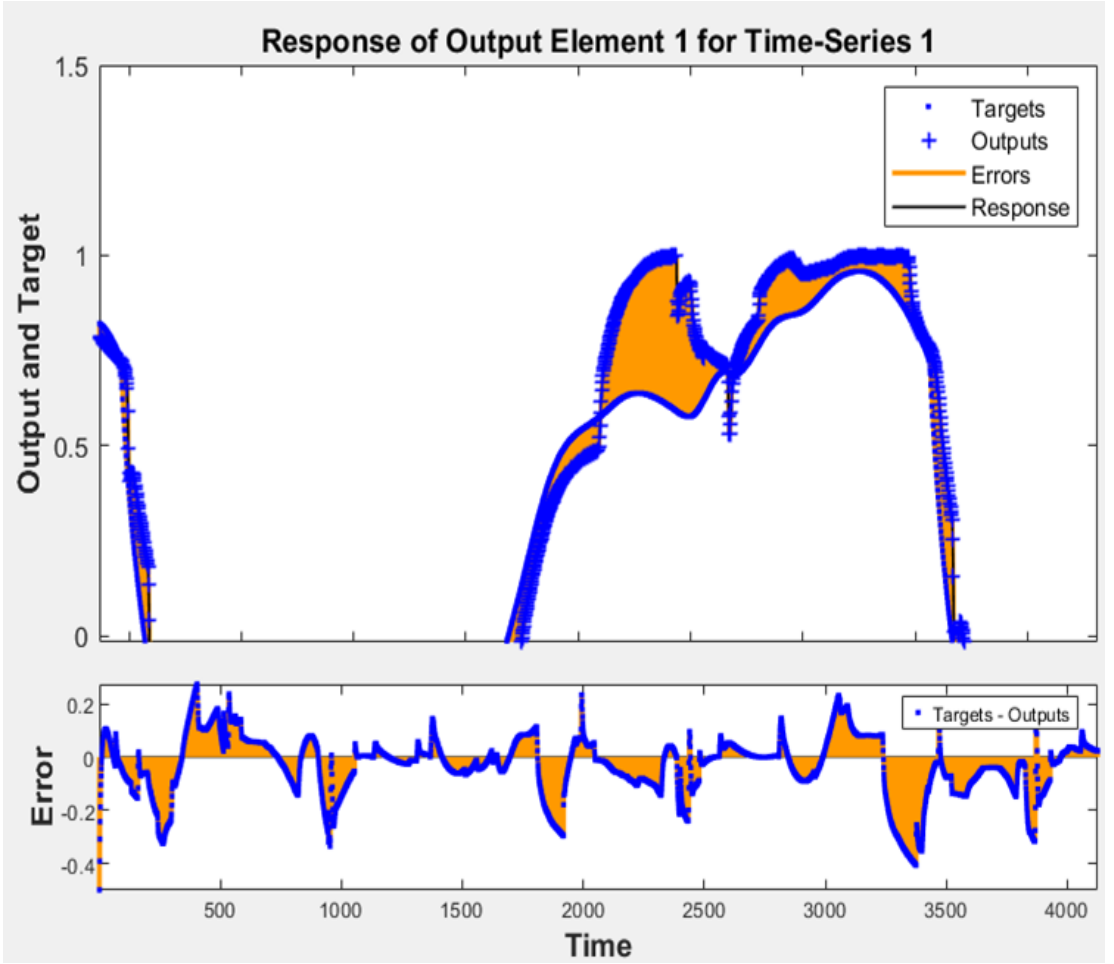


- 9 substations
- 32 pipes (supply + return pipelines)
- 2 pumps

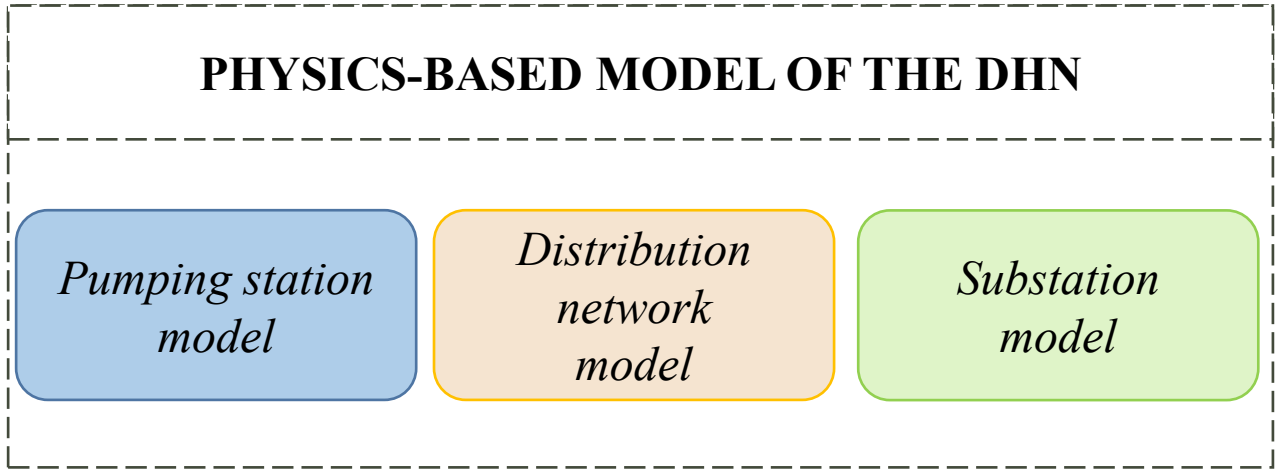
- 18 datasets with faults and without faults

Data-driven approach (in progress)

For each substation



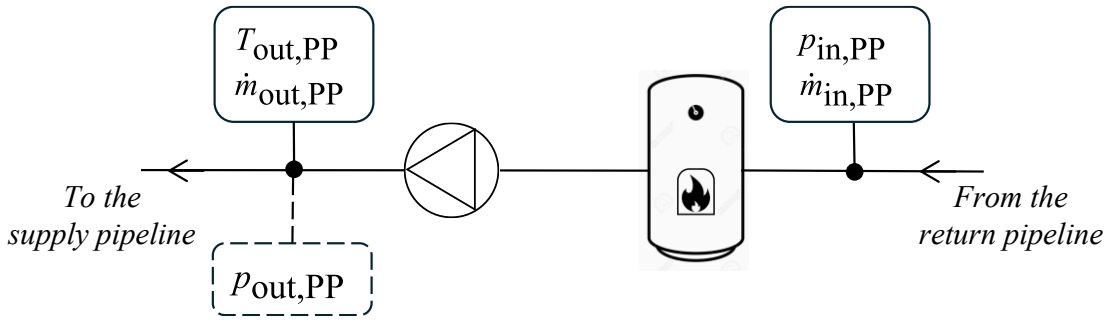
Physics-based approach



Faulty component	Fault type
Pump	▪ Head reduction
Pipe	▪ Leakages ▪ Anomalous heat losses ▪ Anomalous pressure losses
Valve	▪ Incorrect valve opening angle ▪ Leakages
Heat exchanger	▪ Leakages ▪ Anomalous heat losses ▪ Anomalous pressure losses

Physics-based approach

Pumping station model

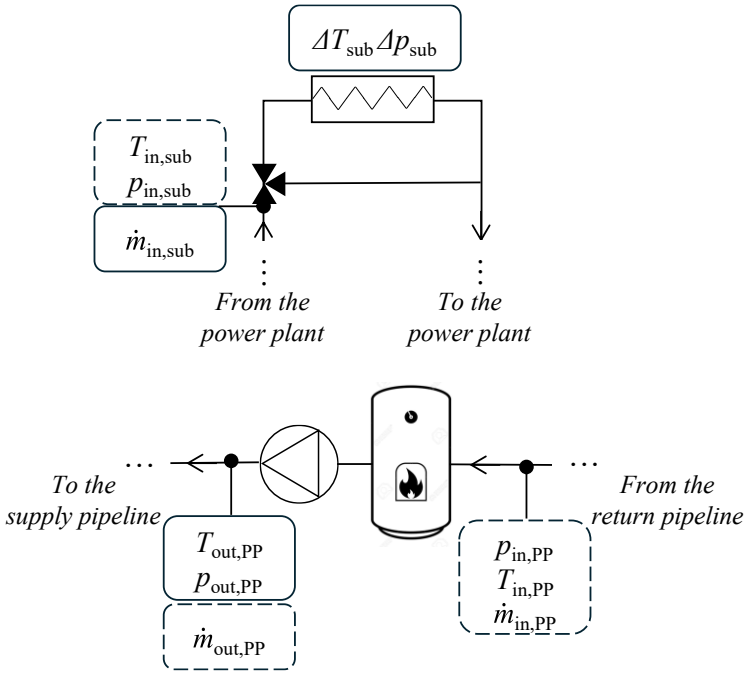


$$OF_{pump} = \left(\frac{p_{out,PP}^{target} - p_{out,PP}}{p_{out,PP}^{target}} \right)^2$$

Minimize the *OF* by using an optimization algorithm based on a gradient-based method

Physics-based approach

Distribution network model

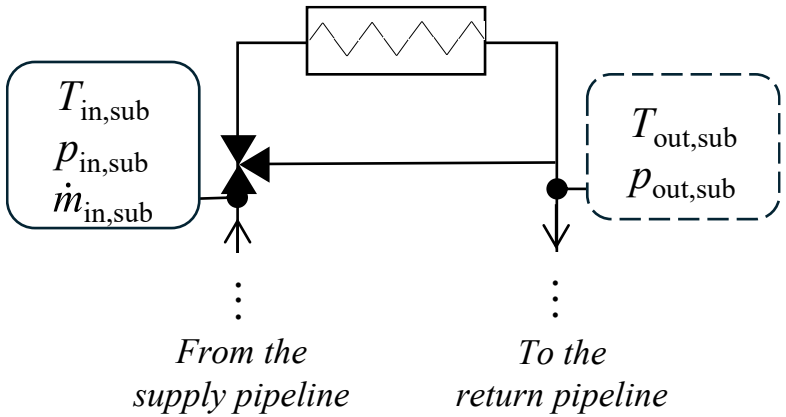


Minimize the *OF* by using an optimization algorithm based on a gradient-based method

$$OF_{distr.net} = \left(\frac{\dot{m}_{out,PP}^{target} - \dot{m}_{out,PP}}{\dot{m}_{out,PP}^{target}}\right)^2 + \left(\frac{\dot{m}_{in,PP}^{target} - \dot{m}_{in,PP}}{\dot{m}_{in,PP}^{target}}\right)^2 + \left(\frac{T_{in,PP}^{target} - T_{in,PP}}{T_{in,PP}^{target}}\right)^2 + \left(\frac{p_{in,PP}^{target} - p_{in,PP}}{p_{in,PP}^{target}}\right)^2 + \sum_{i=1}^{N_{sub}} \left(\frac{p_{in,sub,i}^{target} - p_{in,sub,i}}{p_{in,sub,i}^{target}}\right)^2 + \left(\frac{T_{in,sub,i}^{target} - T_{in,sub,i}}{T_{in,sub,i}^{target}}\right)^2$$

Physics-based approach

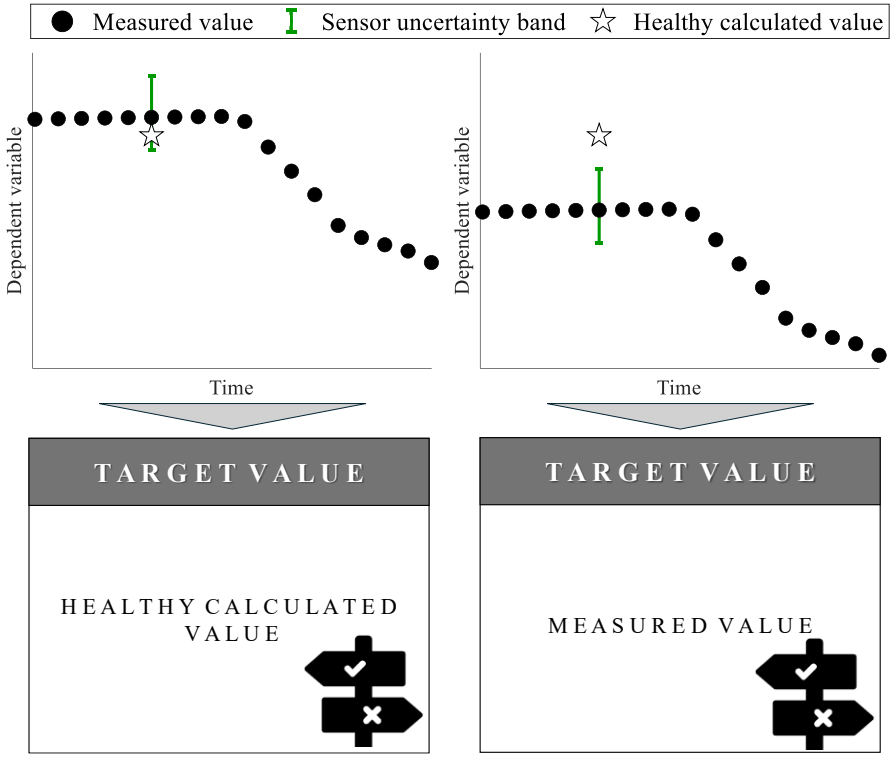
Substation model



$$OF_{sub} = \sum_{i=1}^{N_{sub}} \left(\frac{p_{out,sub,i}^{target} - p_{out,sub,i}}{p_{out,sub,i}^{target}} \right)^2 + \left(\frac{T_{out,sub,i}^{target} - T_{out,sub,i}}{T_{out,sub,i}^{target}} \right)^2$$

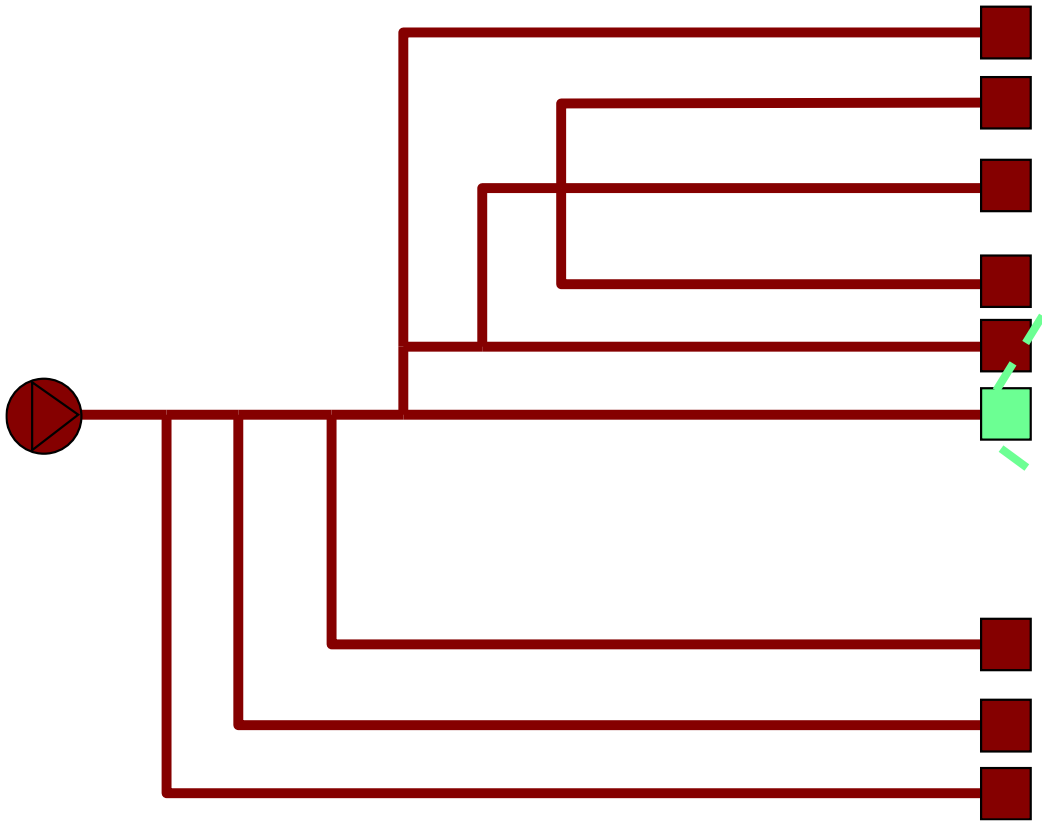
Minimize the *OF* by using an optimization algorithm based on a gradient-based method

Physics-based approach

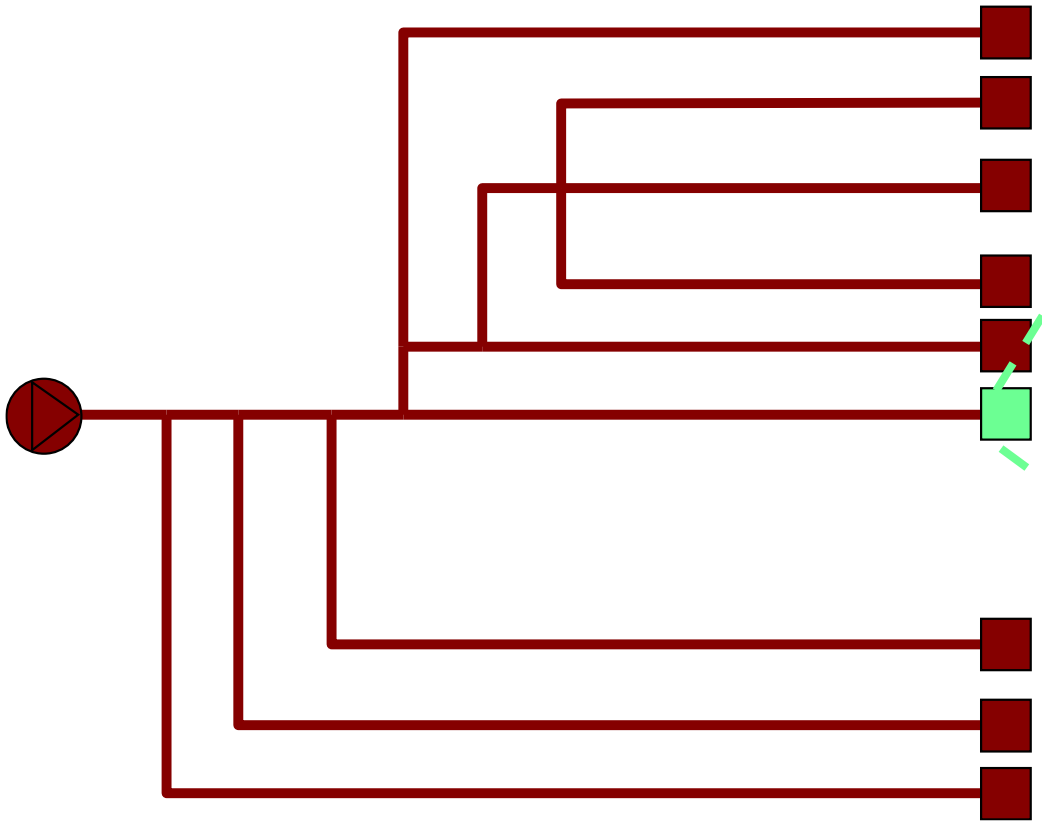


Sensor	Uncertainty band
Flow meter	± 0.3 % of reading value
Thermocouple	± 0.5 °C
Pressure gauge	± 0.25 % of the full-scale

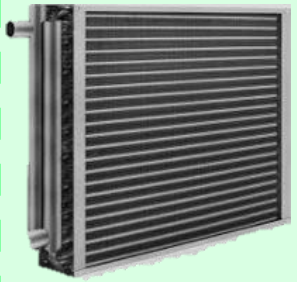
Diagnosis of dataset #1



Diagnosis of dataset #1



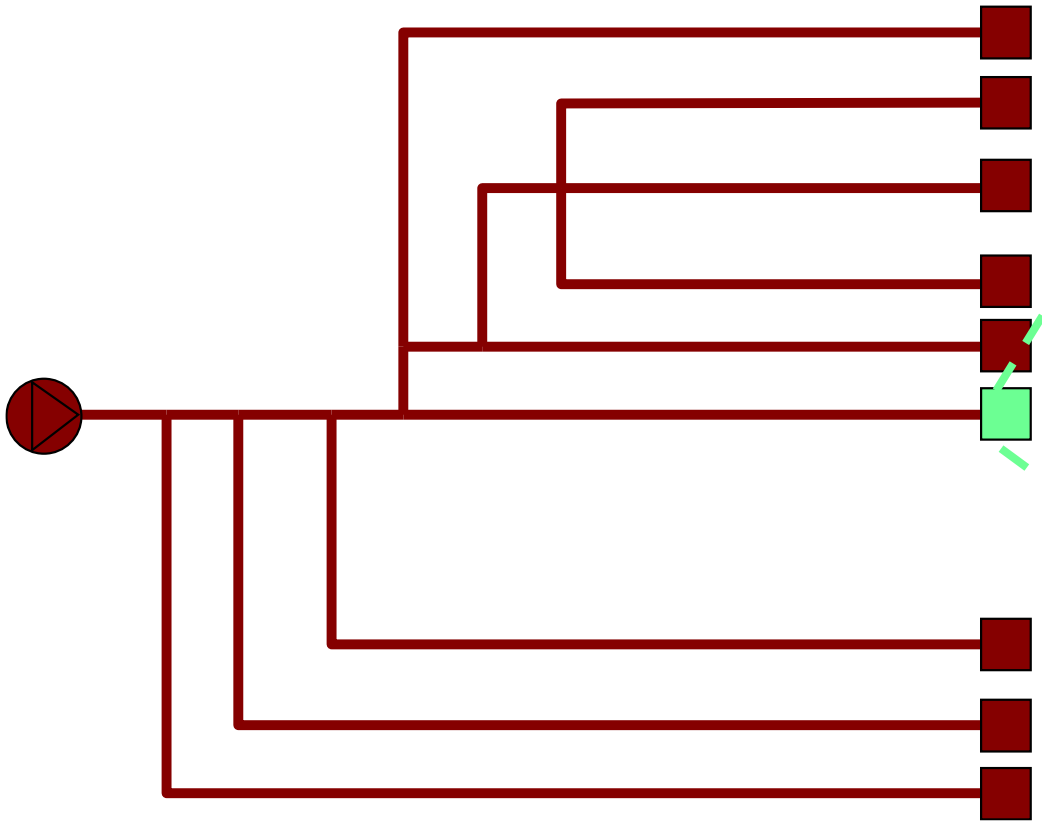
SUBSTATION #4

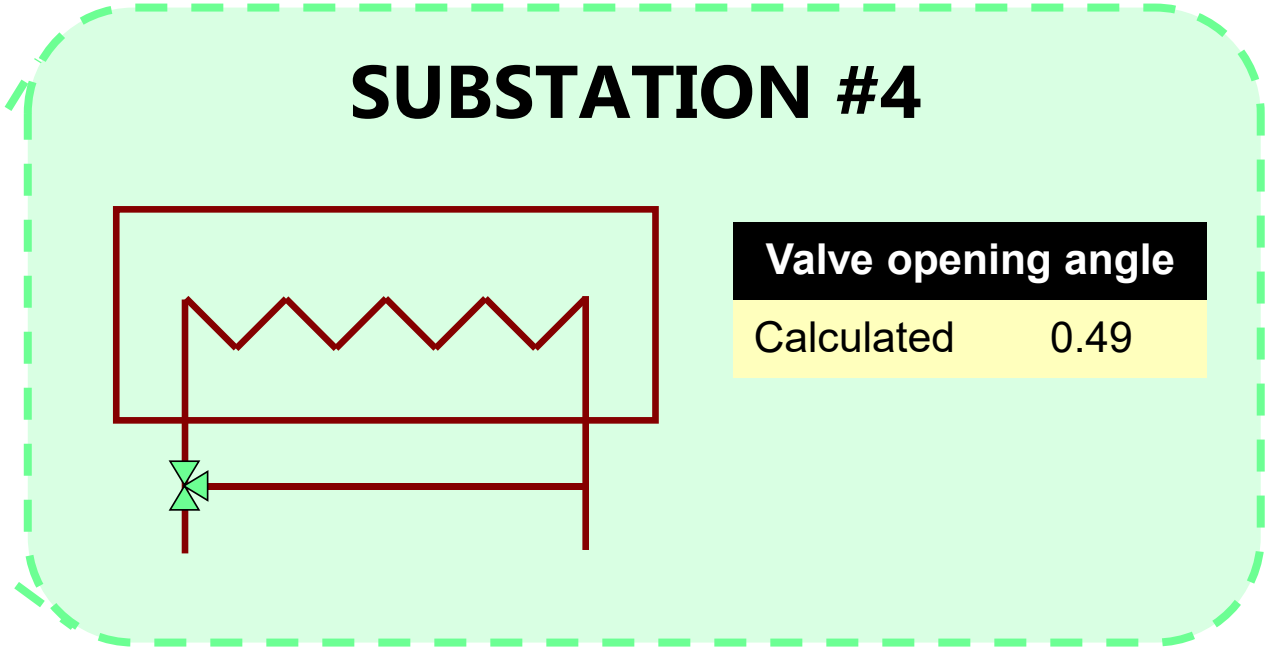


$x_{leak} = 1.00$
$x_{th.loss} = 1.00$
$x_{p.loss} = 1.00$

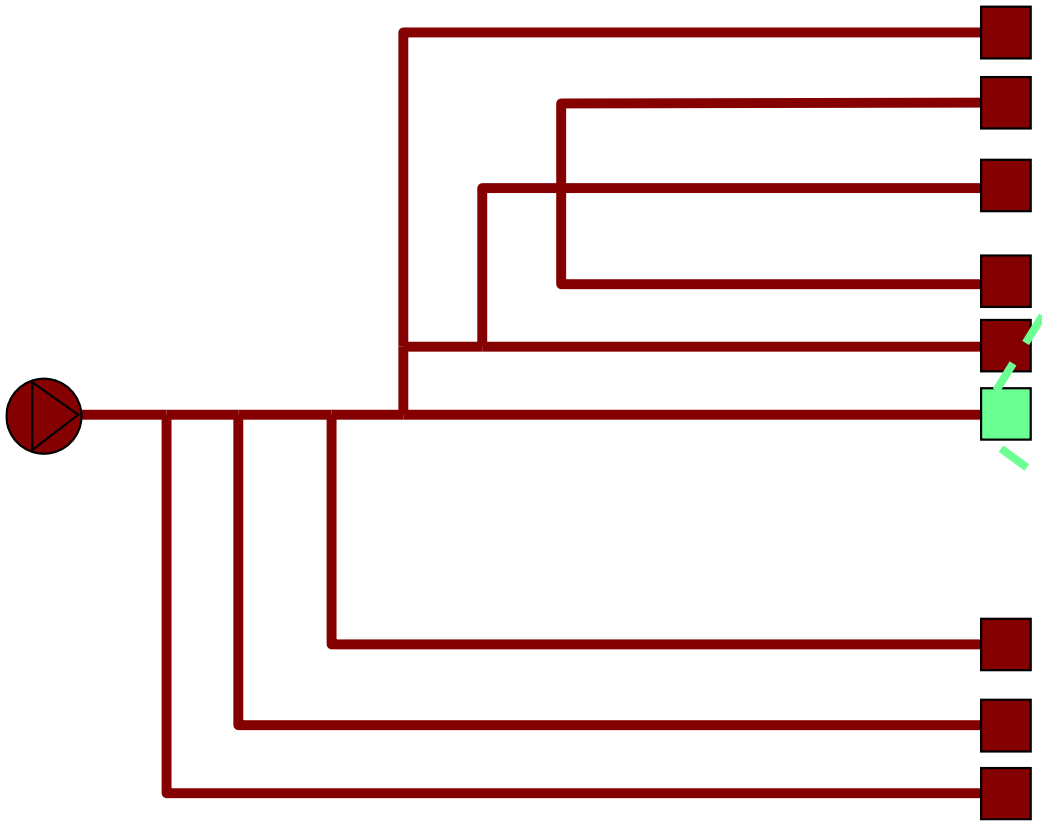
$x_{valve} = 0.49$

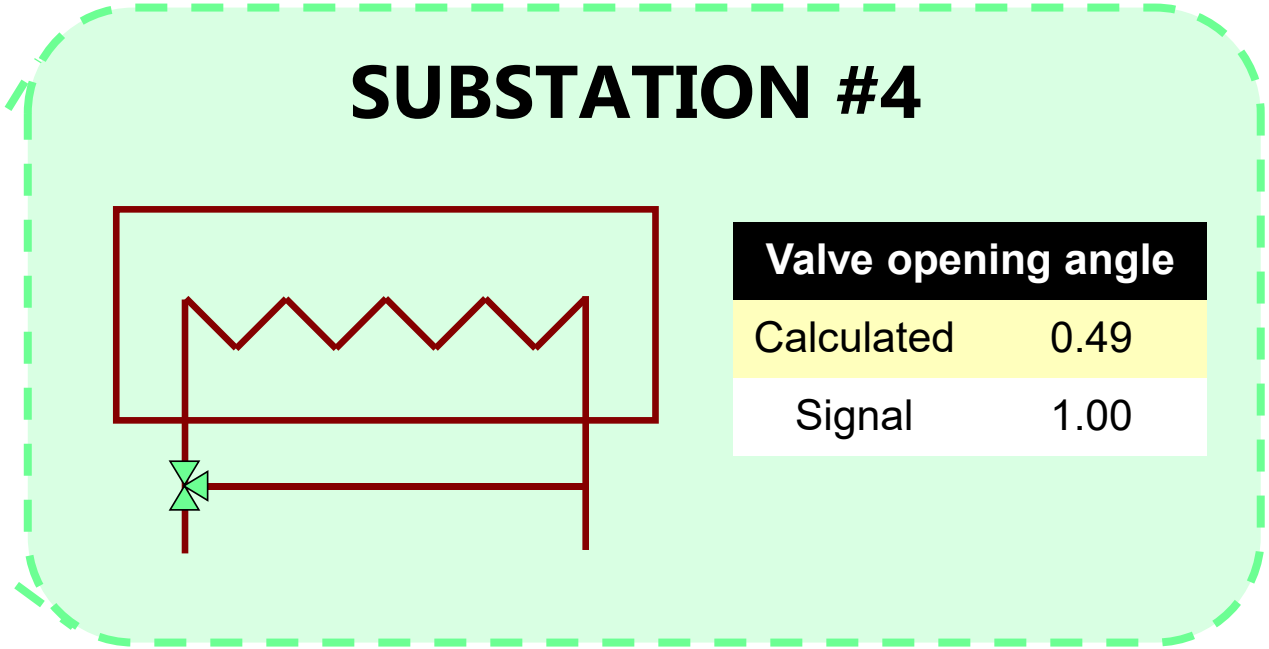
Diagnosis of dataset #1





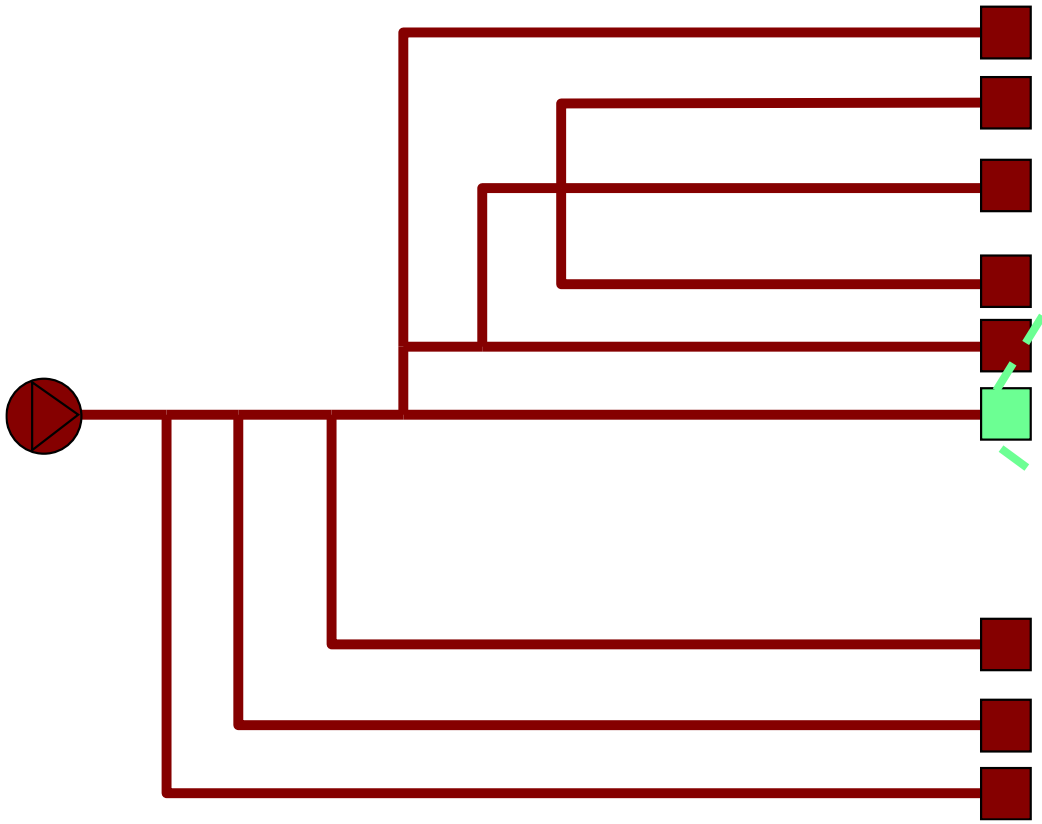
Diagnosis of dataset #1



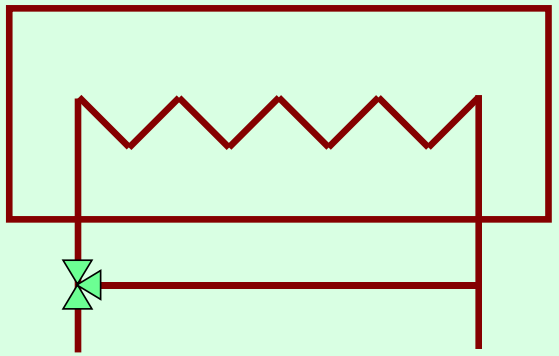


Valve opening angle	
Calculated	0.49
Signal	1.00

Diagnosis of dataset #1



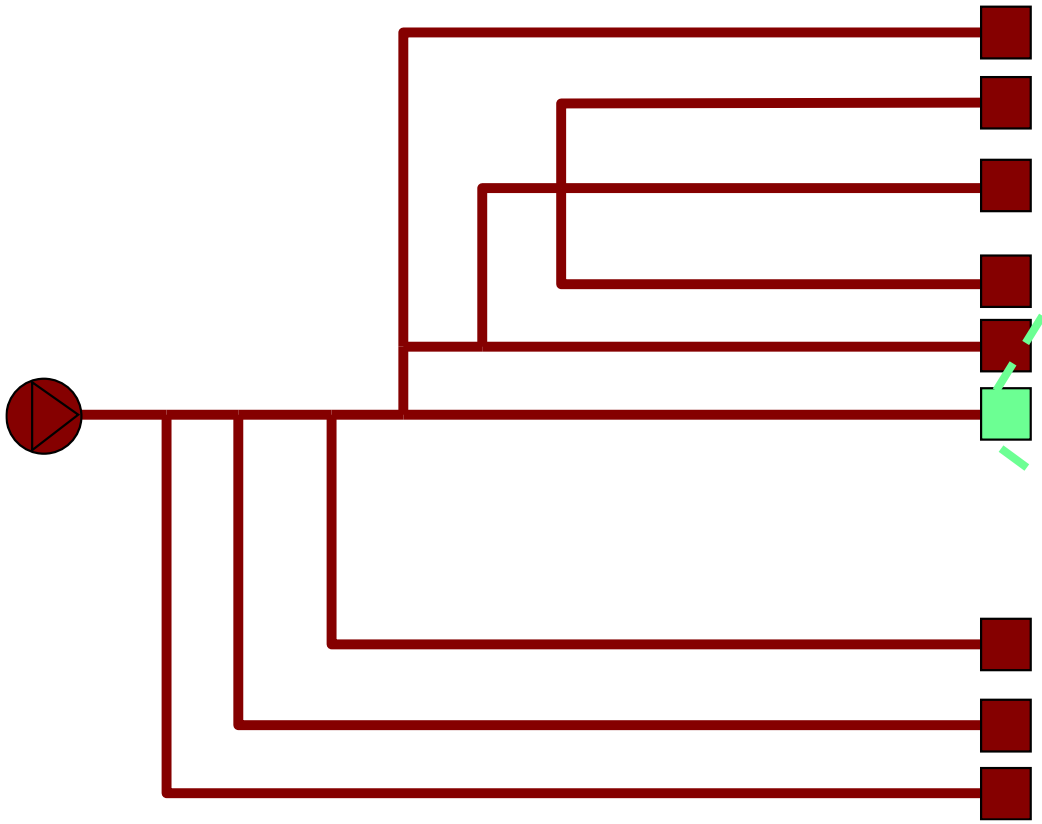
SUBSTATION #4



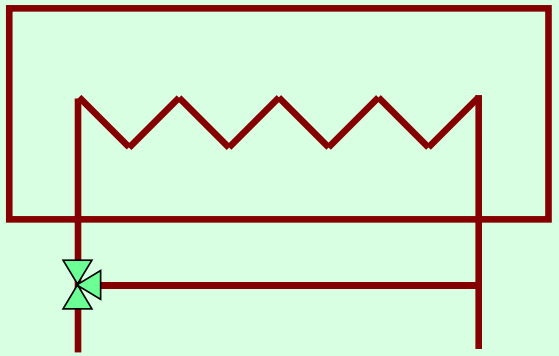
Valve opening angle	
Calculated	0.49
Signal	1.00

FAULT ALERT

Diagnosis of dataset #1

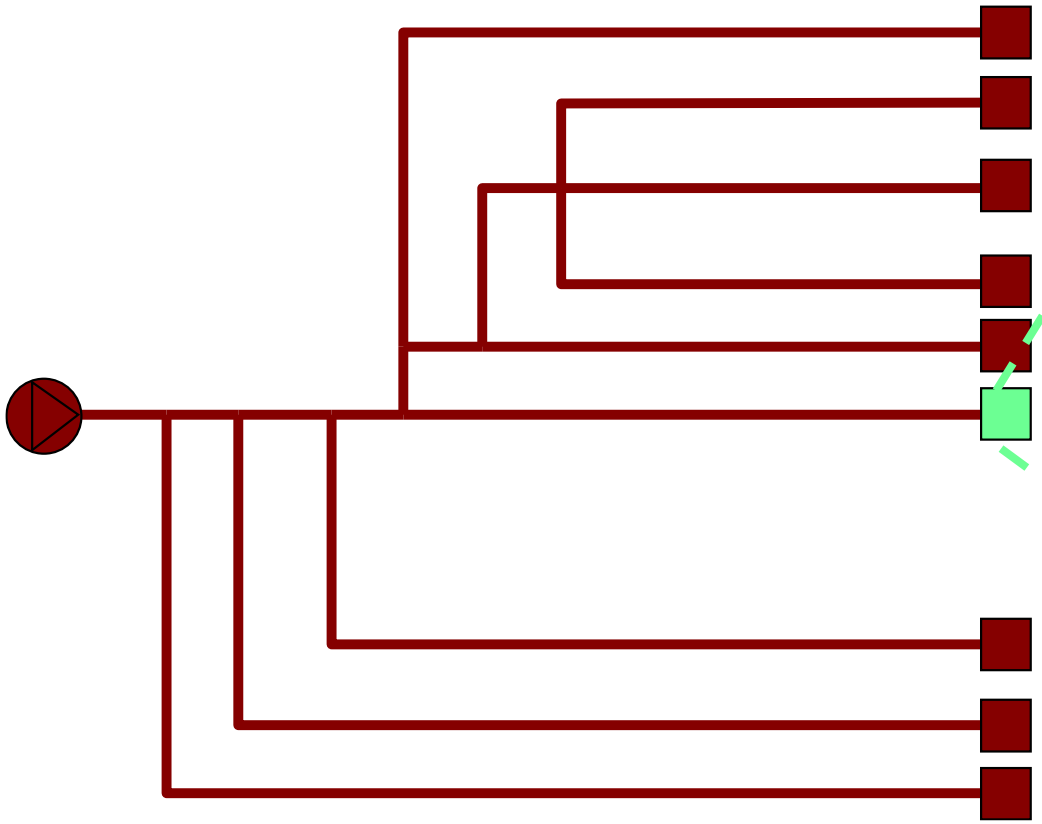


SUBSTATION #4

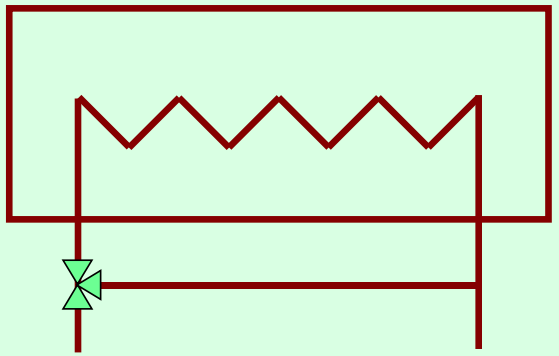


Valve opening angle	
Calculated	0.49
Signal	1.00
Actual	0.50

Diagnosis of dataset #1



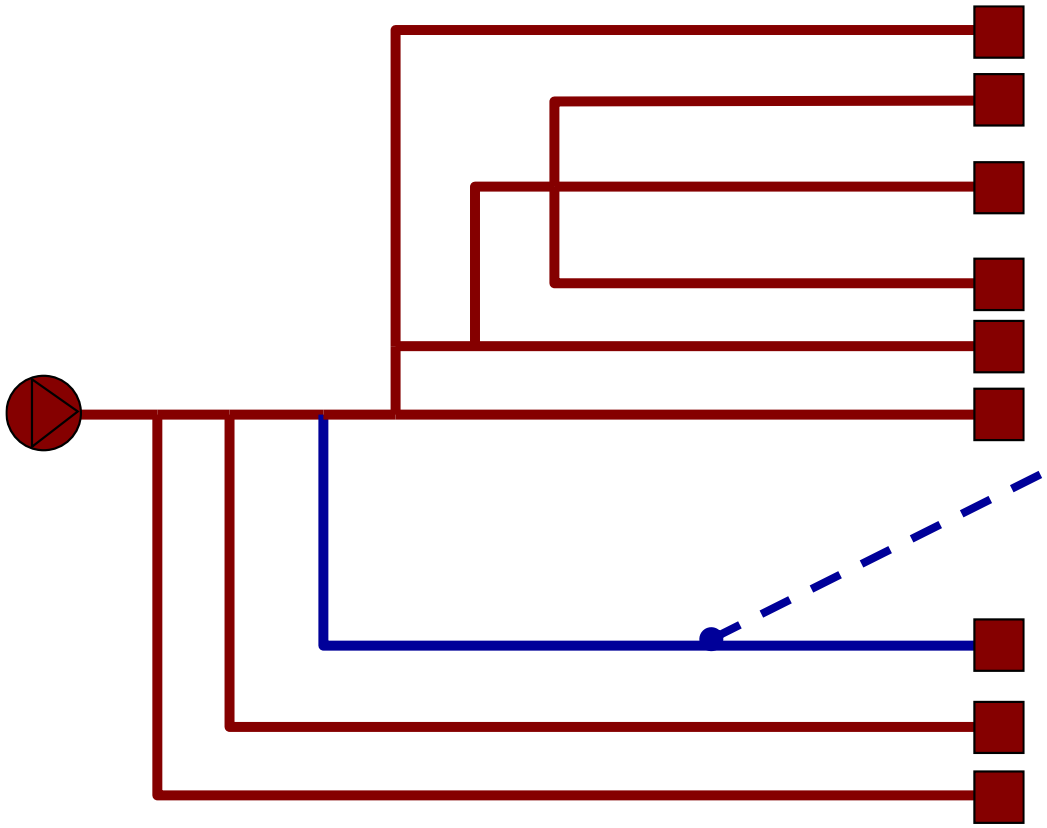
SUBSTATION #4



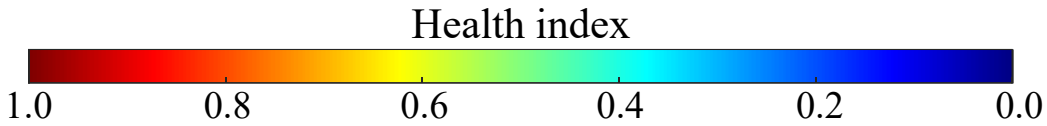
Valve opening angle	
Calculated	0.49
Signal	1.00
Actual	0.50

FAULT DETECTED & IDENTIFIED

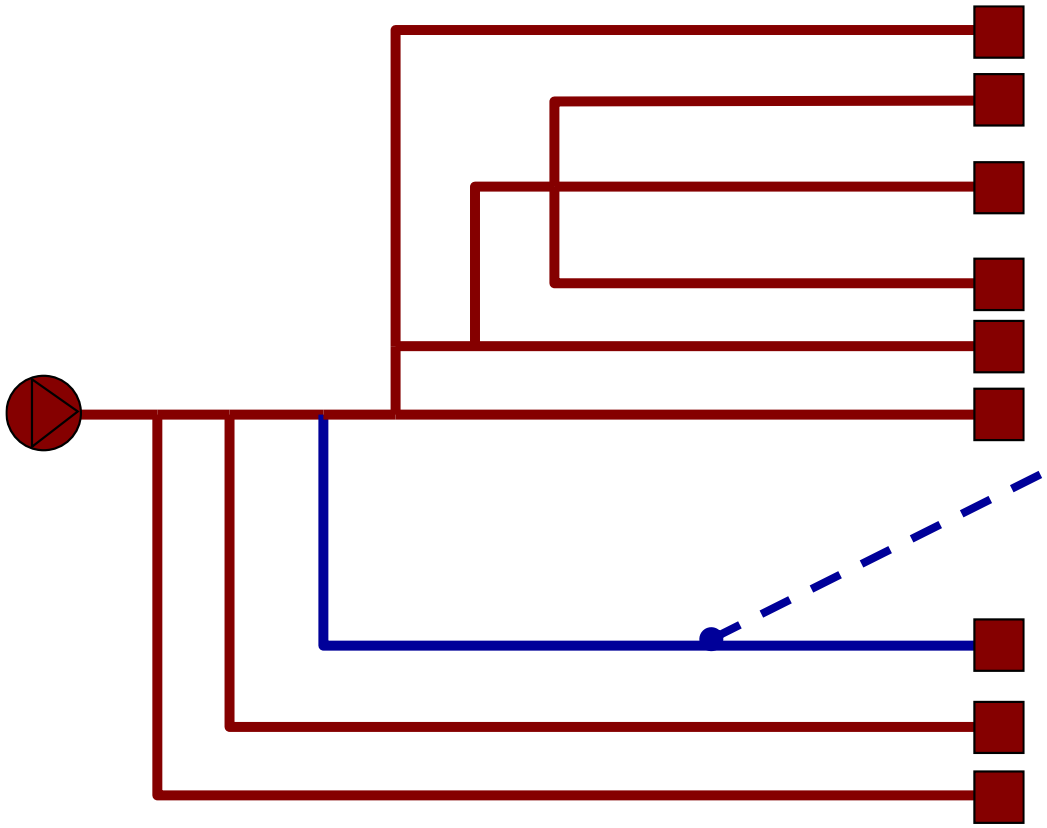
Diagnosis of dataset #2



PIPE #6

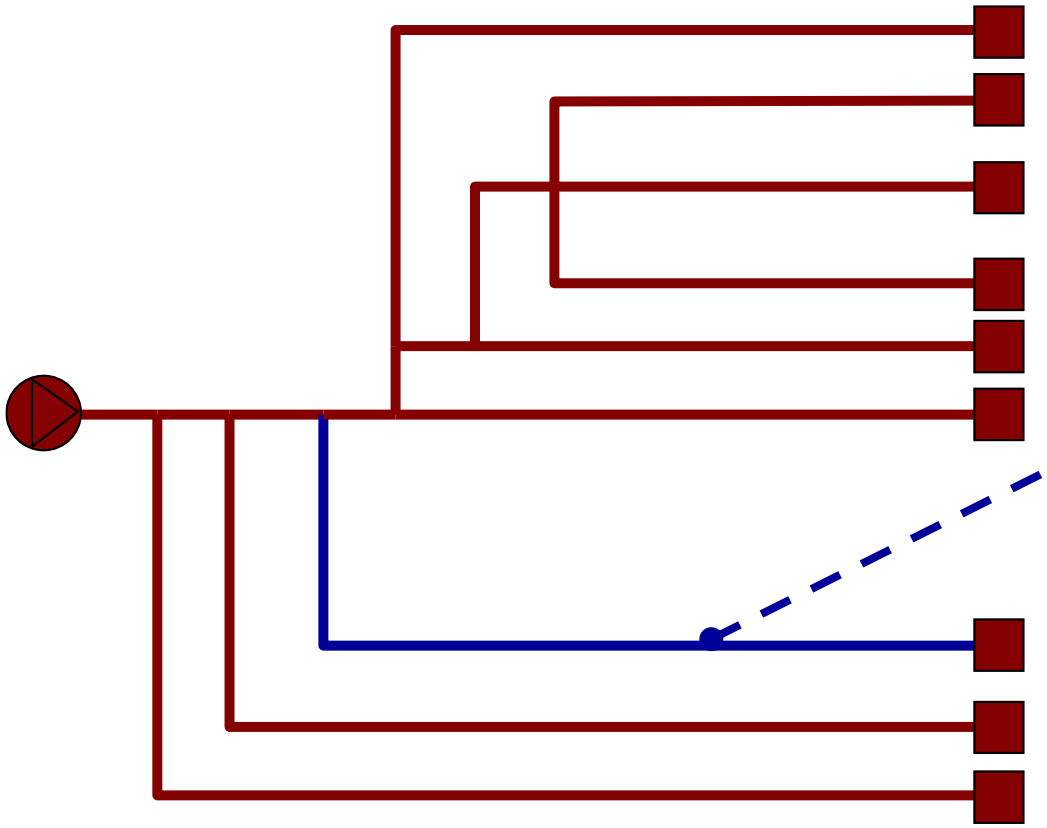


Diagnosis of dataset #2



PIPE #6

Diagnosis of dataset #2



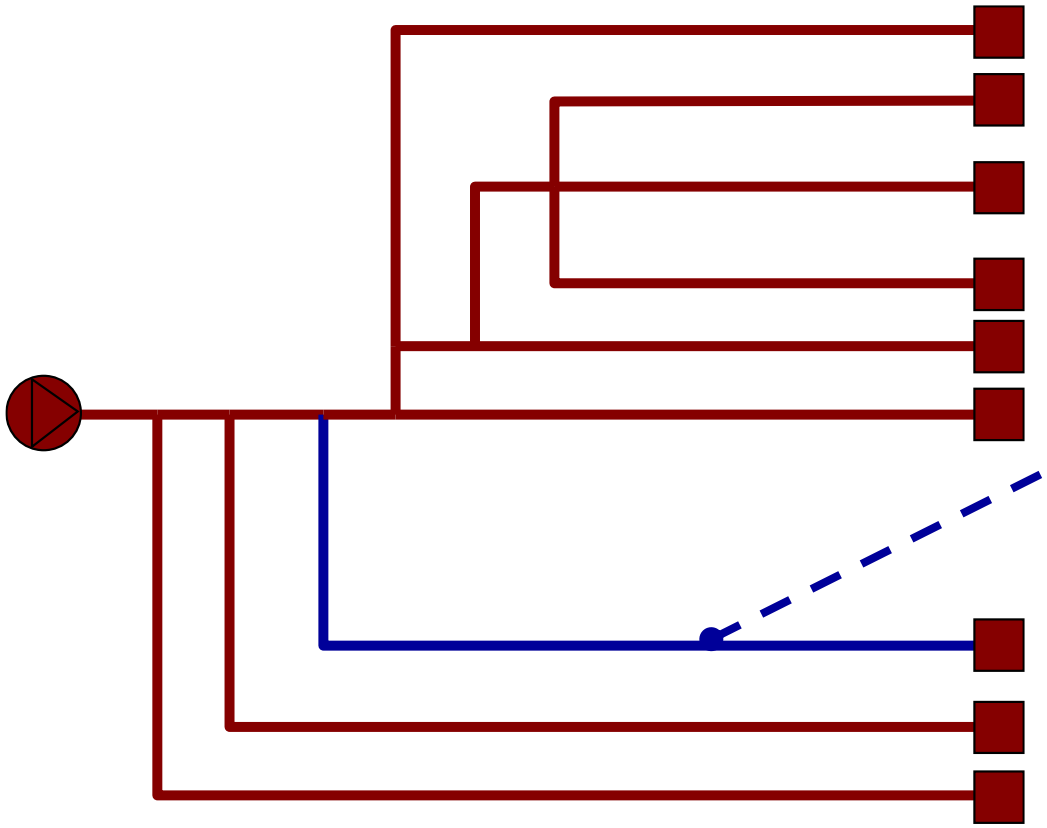
PIPE #6

x_{leak} = 1.00

$x_{th.loss}$ = 0.02

$x_{p.loss}$ = 1.00

Diagnosis of dataset #2



PIPE #6

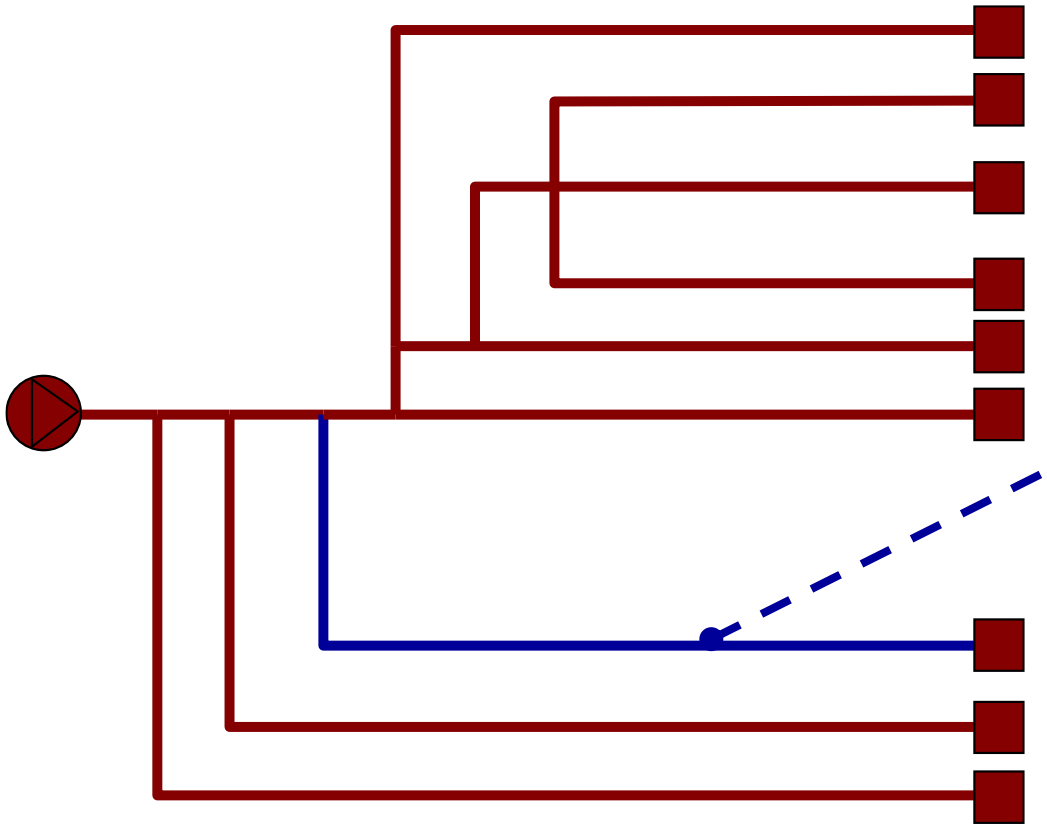
x_{leak} = 1.00

$x_{th.loss}$ = 0.02

$x_{p.loss}$ = 1.00

FAULT ALERT

Diagnosis of dataset #2

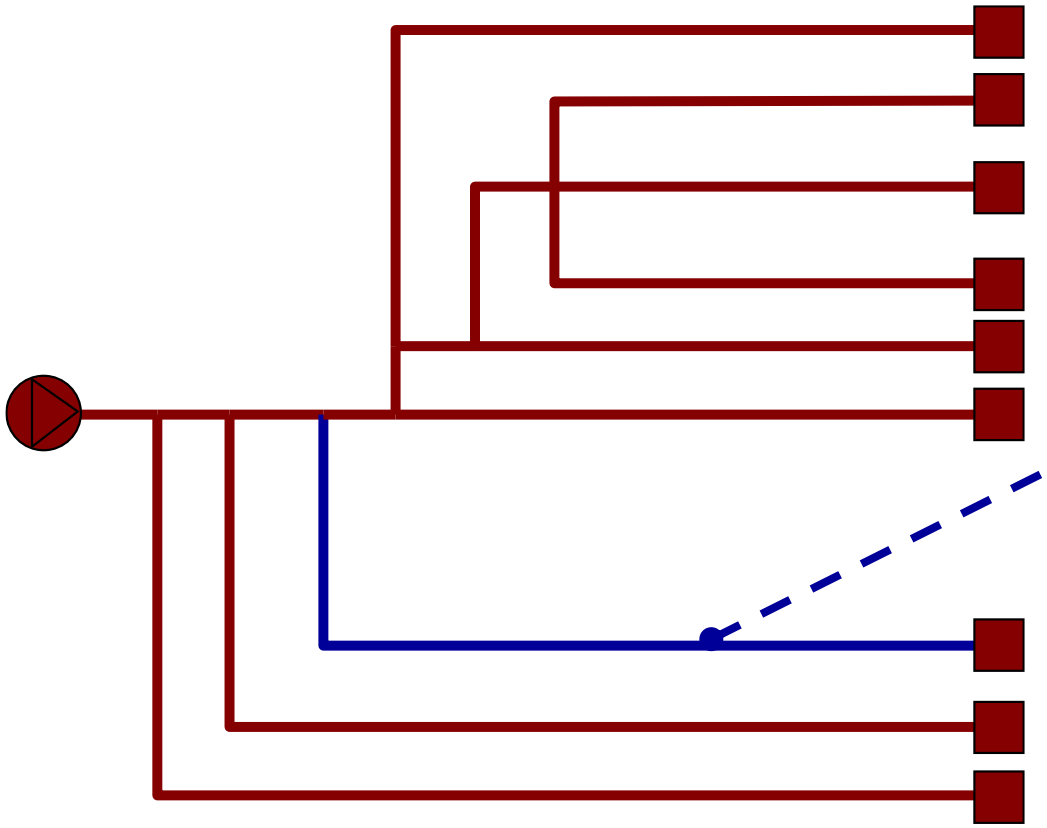


PIPE #6

$x_{th.loss}$ = 0.02

λ_{ins} [W·m^{-1}·K^{-1}]	
Calculated	1.9

Diagnosis of dataset #2

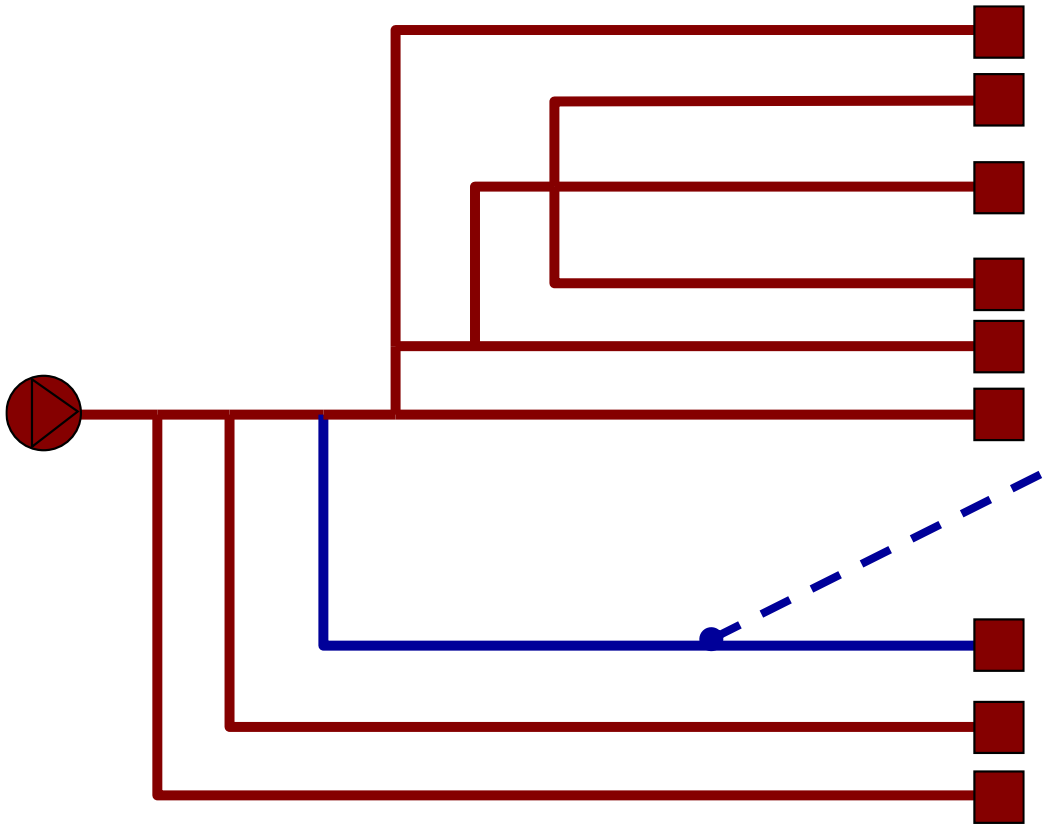


PIPE #6

$x_{th.loss}$ = 0.02

λ_{ins} [W·m^{-1}·K^{-1}]	
Calculated	1.9
Healthy	0.04

Diagnosis of dataset #2

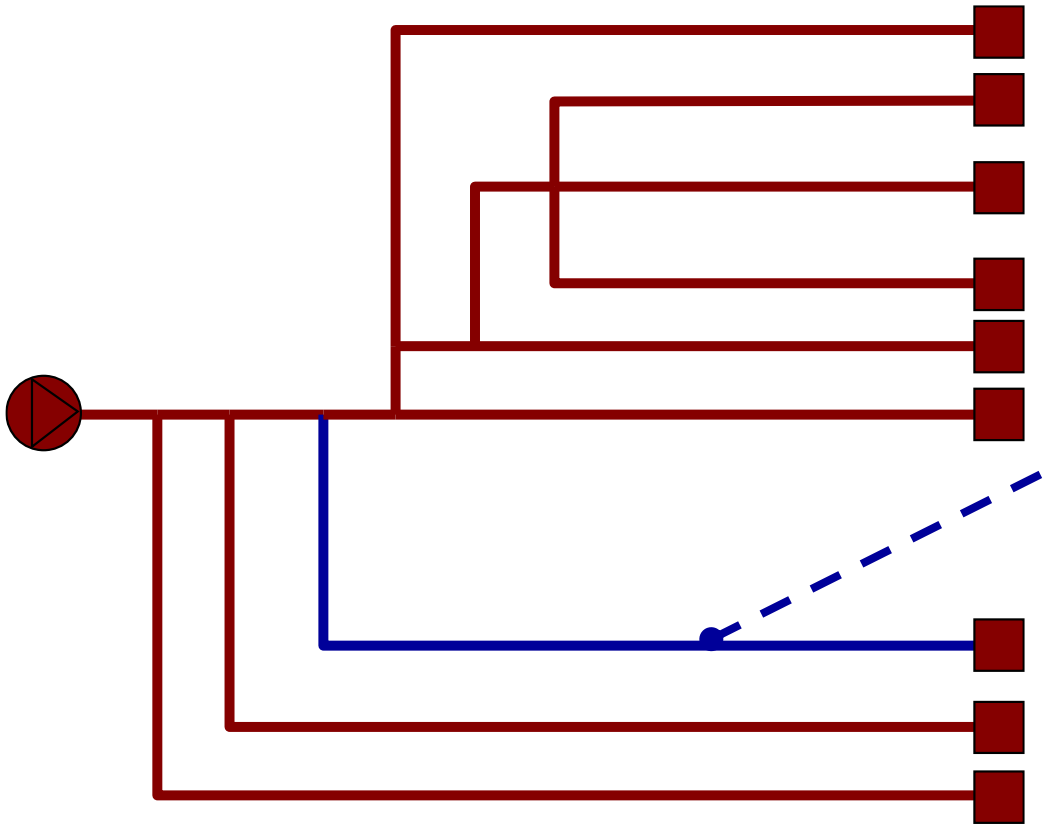


PIPE #6

$x_{th.loss}$ = 0.02

λ_{ins} [W·m^{-1}·K^{-1}]	
Calculated	1.9
Healthy	0.04
Actual	2.0

Diagnosis of dataset #2



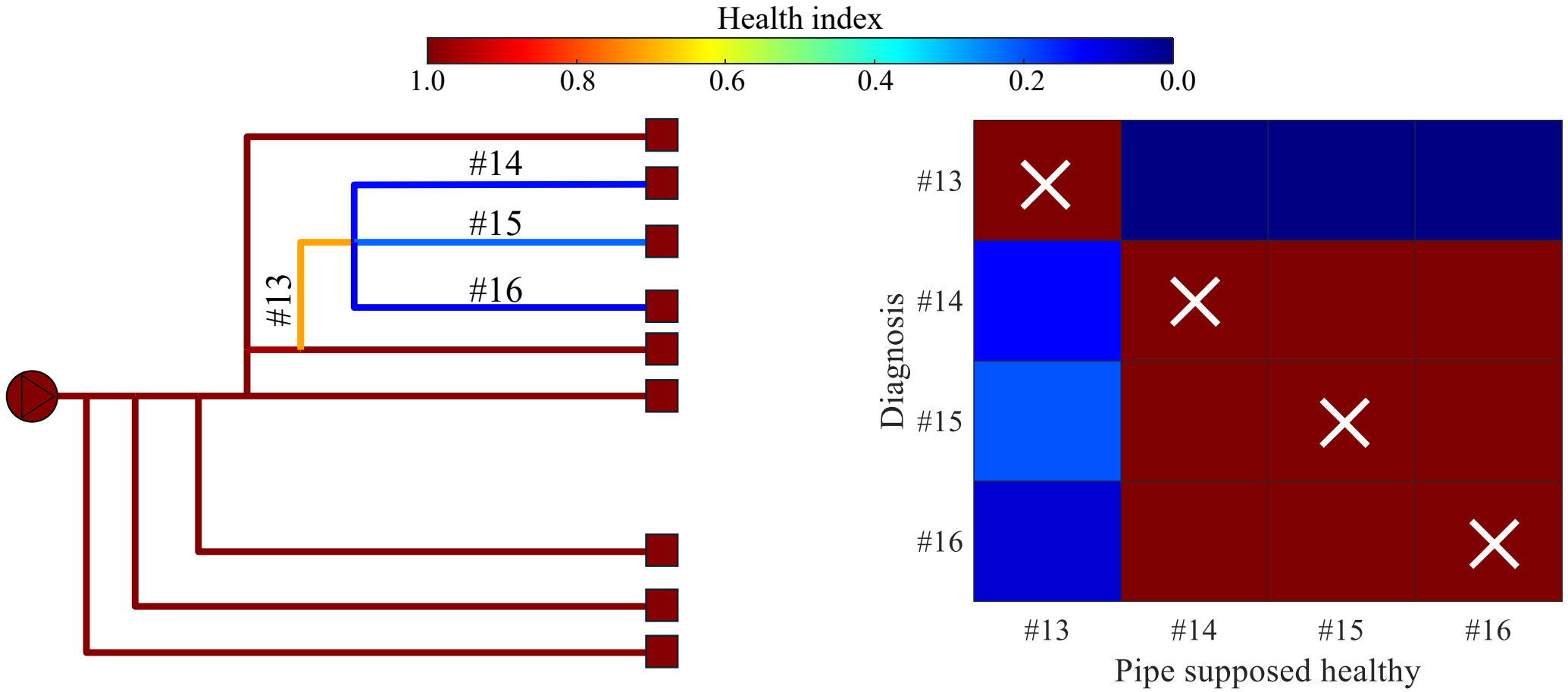
PIPE #6

$x_{th.loss}$ = 0.02

λ_{ins} [W·m^{-1}·K^{-1}]	
Calculated	1.9
Healthy	0.04
Actual	2.0

FAULT DETECTED & IDENTIFIED

Diagnosis of dataset #3



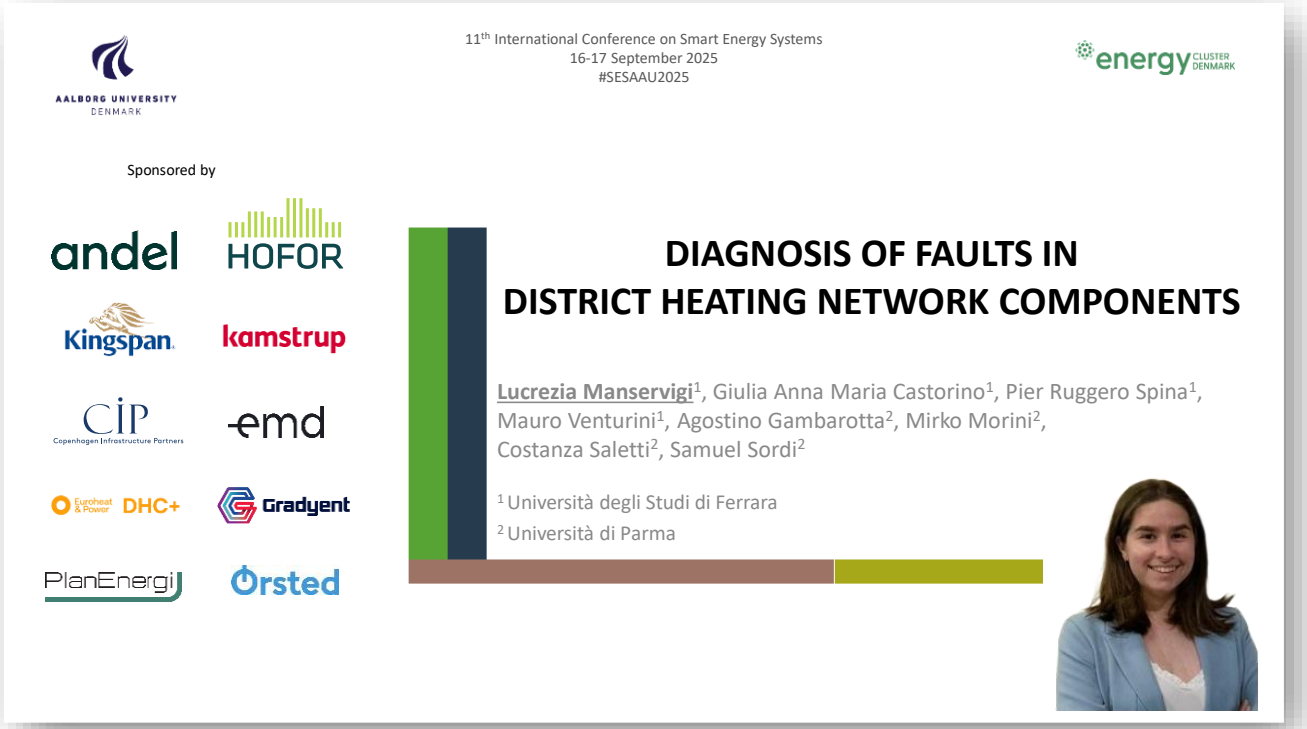
IN^4 goals

- ☑ *Literature review*
- ☑ *Data-driven approach*
- ☑ *Physics-based approach*
  - ✓ *Validation of the DHN*
  - ✓ *Diagnosis of the DHN*
  - ✓ *Validation of the MES*
  - ○ *Diagnosis of the MES*

✓	done
✓	in progress

DISSEMINAZIONE

Conferences & papers



Invitation to submit the paper to special issue of Energy

Submission of the manuscript in a few days