Cyber-Physical agent-based applications

TUTORIAL SESSION – CYBER-PHYSICAL MULTI-AGENT SYSTEM

Dr. Phuong Nguyen, p.nguyen.hong@tue.nl

Digital Power & Energy Systems (digi-PES) laboratory

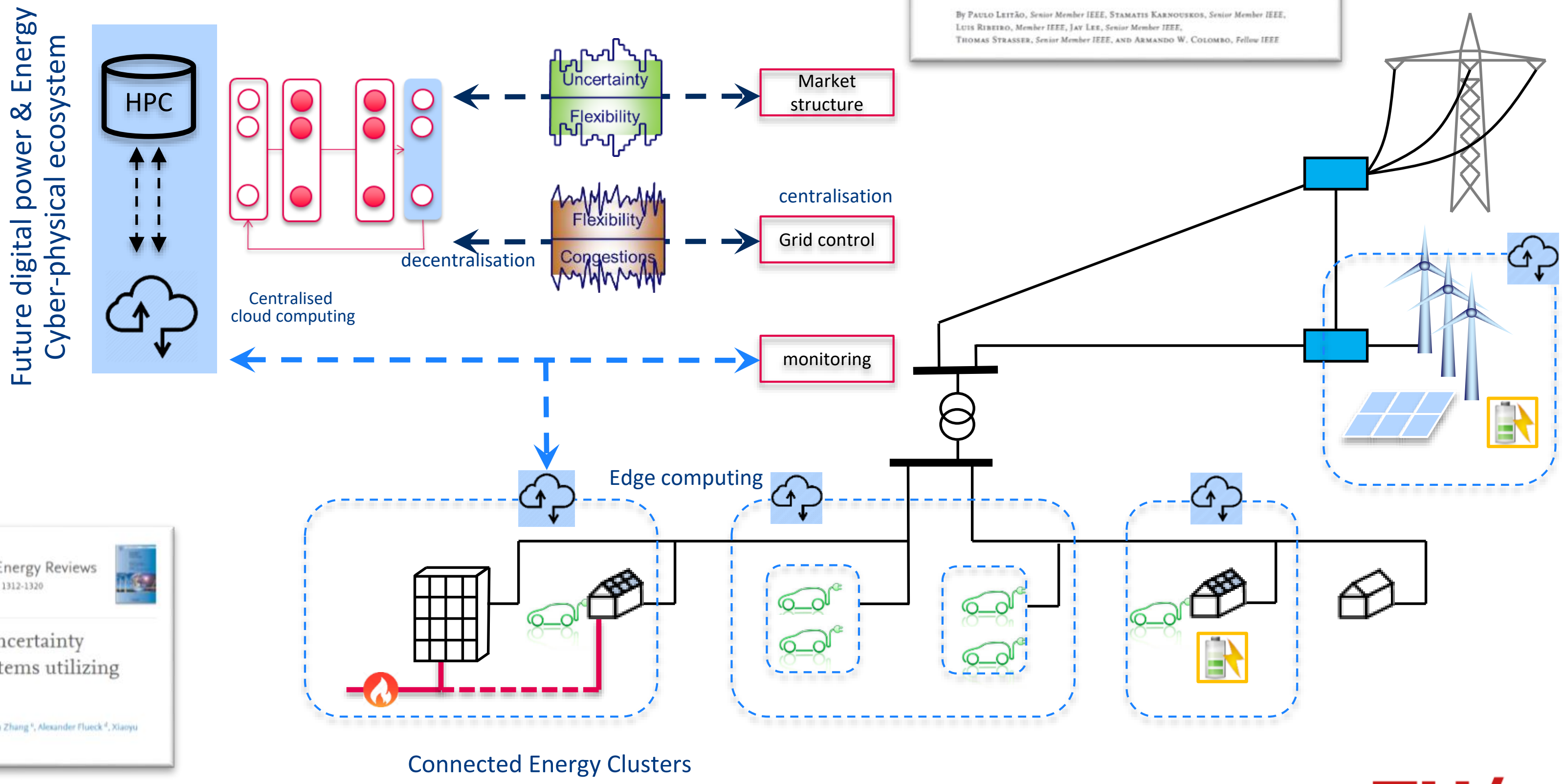
AAMAS2021
ONLINE, MAY 3–7

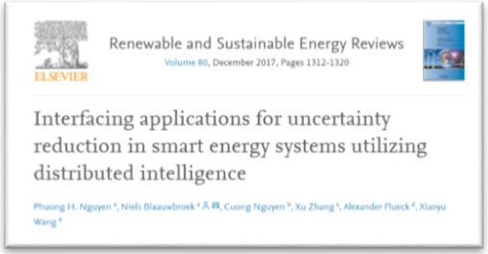
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Content

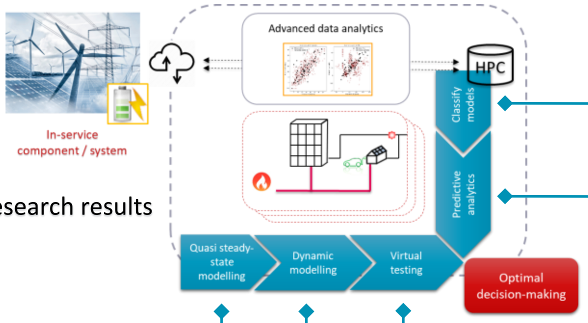
1. Introduction
2. Agent-based modelling
3. Local supply-demand matching
4. Congestion management
5. Overlaying voltage control
6. PV forecasting
7. Conclusion

Terminology & Context

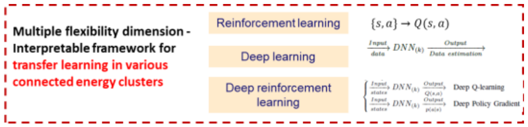




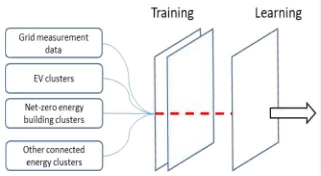
TU/e

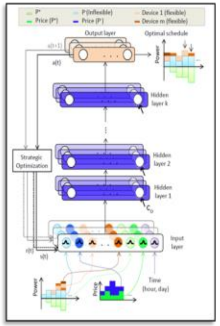


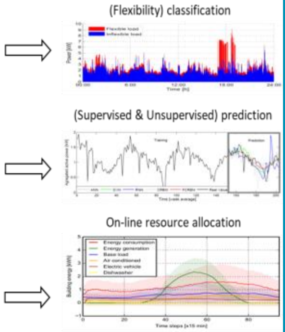
DigiPES Lab
Highlighted research results



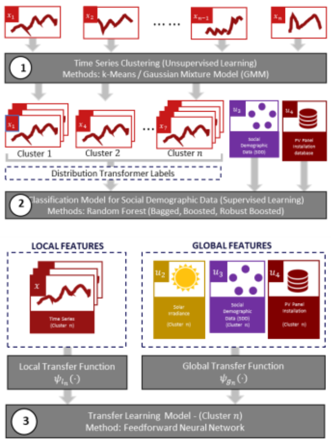
Mocanu, E., Mocanu, D. C., Nguyen, P. H., Liotta, A., Webber, M. E., Gibescu, M., & Slootweg, J. G. (2019). On-line building energy optimization using deep reinforcement learning. *IEEE Transactions on Smart Grid*, *10*(4), 3798-3708.

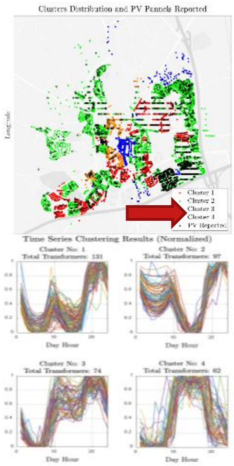






Data-driven (Transformer Load) Modelling





Salazar Duque, E. M. M., Dukovska, I., Nguyen, P. H., & Bernards, R. (2020). Data Driven Framework for Load Profile Generation in Medium Voltage Networks via Transfer Learning. In *2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)* (pp. 909-913).

Sequential Droop Control (SDC) – Consensus based algorithm to mitigate voltage rise

Mai, T., Haque, A. N. M. M. N., Vergara Barrios, P., Nguyen, P. H., & Pemen, A. J. M. G. (2020). Adaptive coordination of sequential control for PV inverters to mitigate voltage rise droop in PV-Rich LV distribution networks. *Electric Power Systems Research*, [106931].

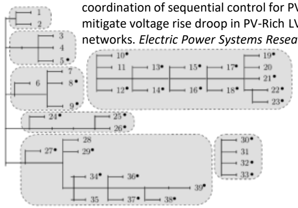
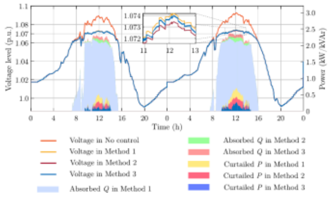
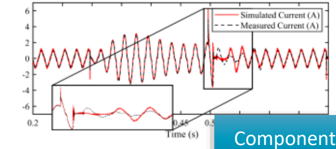
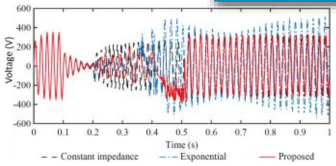


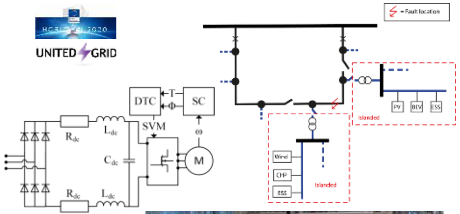
Fig. 4. Decomposition of the test network for ε = 0.21 and determination of control areas as shaded regions. The solid circles represent PV units along with their index.



Dynamic modelling and stability analysis for fault-initiated islanding







Component-based model

[i] Roos, M, Nguyen, P, Morren, J & Slootweg, H 2020, 'Modeling and experimental validation of power electronic loads and DERs for microgrid islanding simulations', *IEEE Transactions on Power Systems*, vol. 35, no. 3, 8902151, pp. 2279-2288. https://doi.org/10.1109/TPWRS.2019.2953757
[ii] M. H. Roos, P. H. Nguyen, J. Morren and J. G. Slootweg, "Direct-quadrature Sequence Models for Energy-function based Transient Stability Analysis of Unbalanced Inverter-based Microgrids," in *IEEE Transactions on Smart Grid*, doi: 10.1109/TSG.2021.3069188.

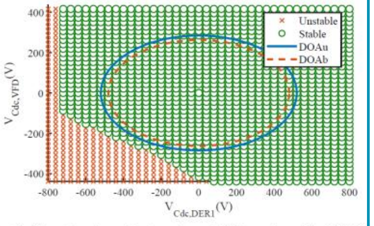


Fig. 21: Time domain analysis results and DOA estimated by EBTSA in scenario 3.

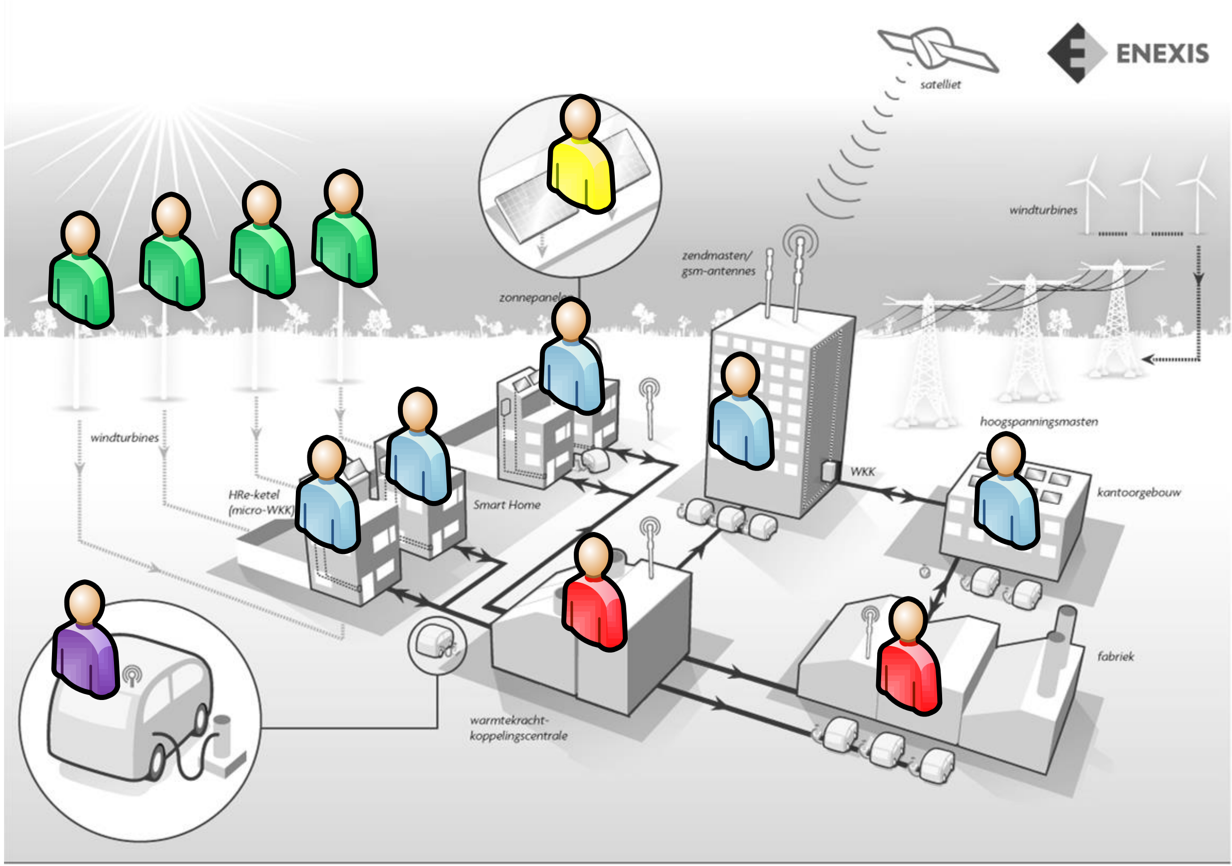
Content

1. Introduction
2. Agent-based modelling
3. Local supply-demand matching
4. Congestion management
5. PV forecasting
6. Conclusion

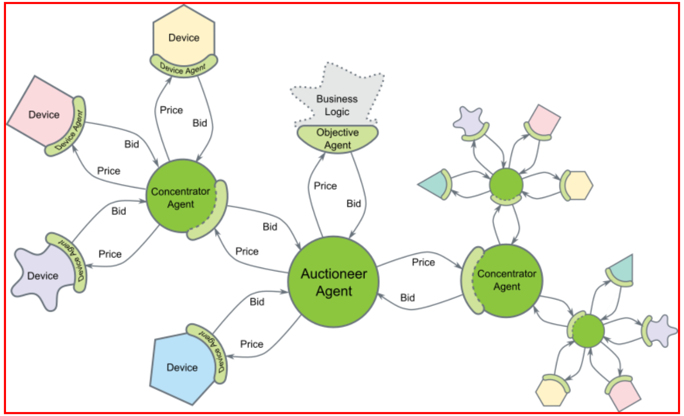
Background

Agent-based modelling

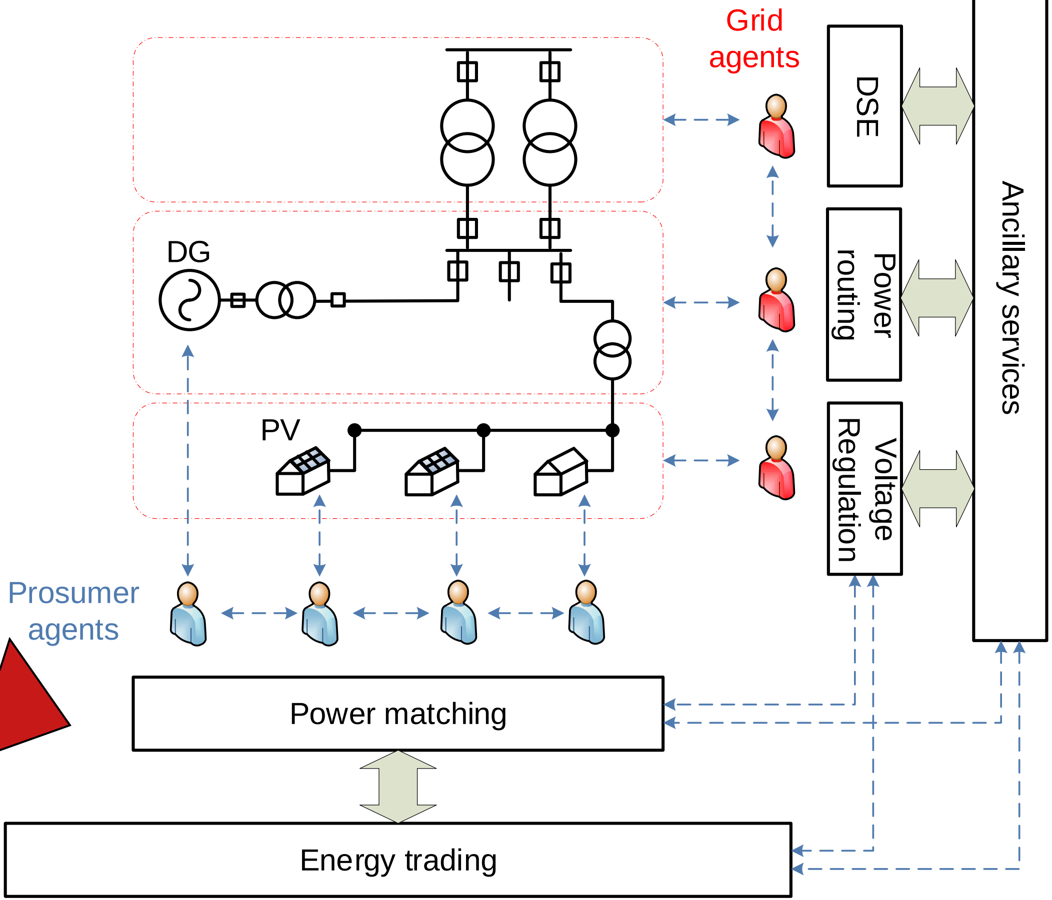
A software agent is a computer program, acting on behalf of its user/owner, pursuing its own goals



Background



The PowerMatcher
(TNO)

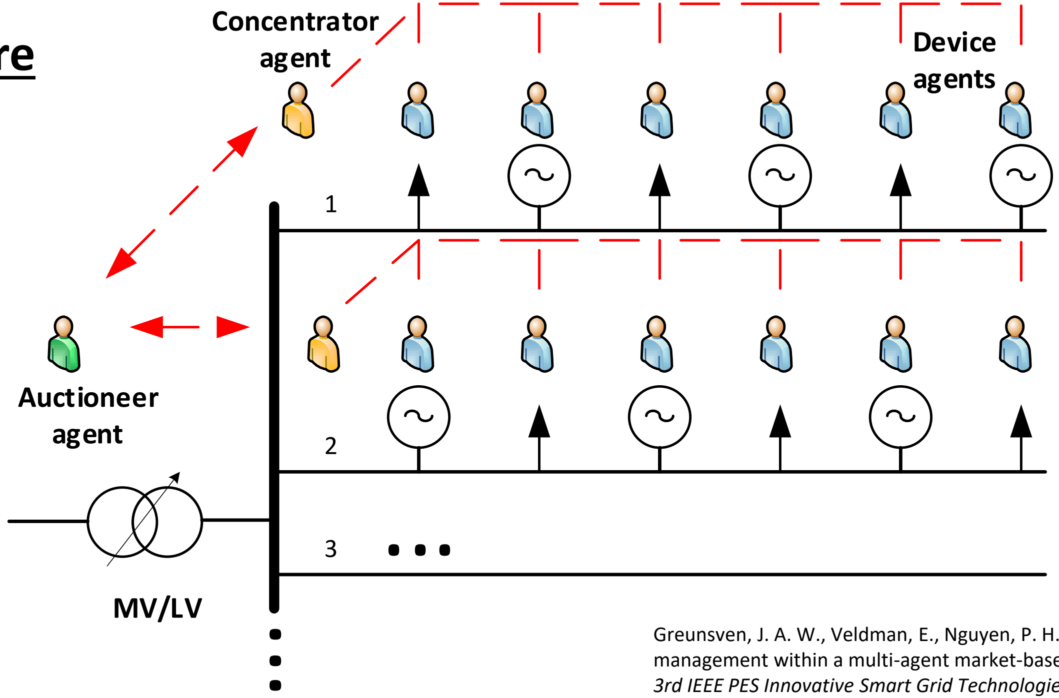


Content

1. Introduction
2. Agent-based modelling
3. Local supply-demand matching
4. Congestion management
5. Overlaying voltage control
6. PV forecasting
7. Conclusion

Local supply and demand matching

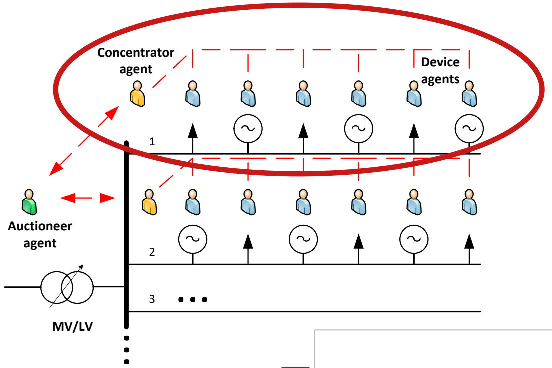
Architecture

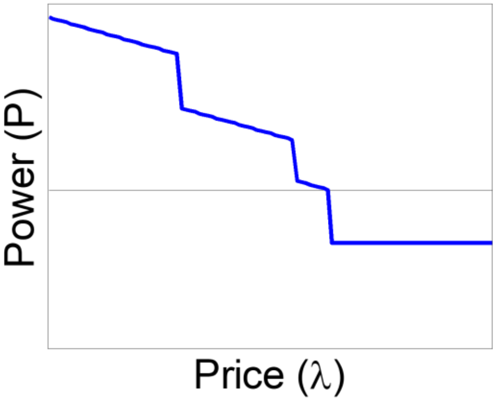


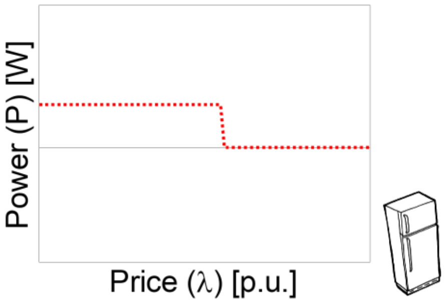
Greunsven, J. A. W., Veldman, E., Nguyen, P. H., Slootweg, J. G., & Kamphuis, I. G. (2012). Capacity management within a multi-agent market-based active distribution network. In *Proceedings of the 3rd IEEE PES Innovative Smart Grid Technologies (ISGT) Europe Conference, 14-17 October 2012, Berlin, Germany* (pp. 1-8). Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/ISGTEurope.2012.6465678

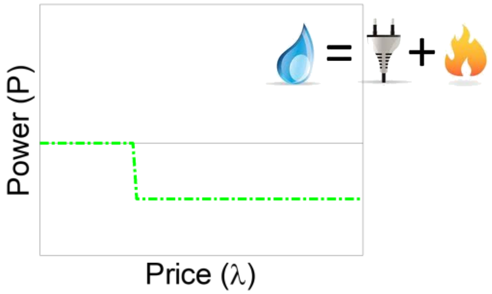
Local supply and demand matching

Coordination mechanism

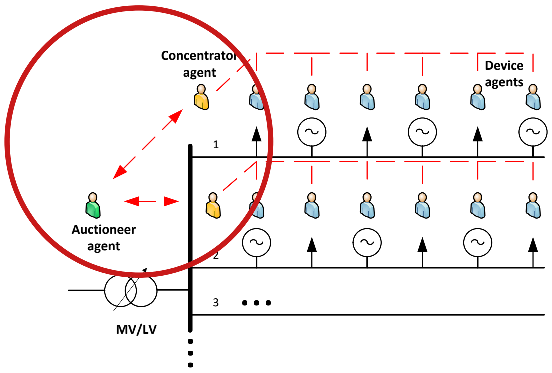








Local supply and demand matching



TU/e

Provided files

Scripts
- main.m
- bidcurves_window.m

Functions
- eqprice.m

Class files
- Controllable and uncontrollable appliances

main.m

```
%% Initialization
% Load input data for simulation
id = [0:0.1:1];    % Resoluation of bid curves
load Load.mat; % Base Load measured from smart meter
load Temp.mat;
load Irrad;
lambda_star = 10;
list_lambda = [];
```

Initialization variables for appliances.
Make sure to change for multiple cases.

```
T_HP_init = 20.5; % Initial internal temperature for HeatPump [deg C]
T_FR_init = -25; % Initial temprature freezer [deg C]
T_CHP_init = 20.5; % Initial internal temperature for CHP [deg C]
status_WM_init = 0; % Initial status for washing machine (0 - waiting; 1 - working;
E_WM_init = 0; % Initial consumed energy from washing machine
```

Use the class files to create and customize the appliances

```
%% Create appliances
bl = bl_class(Load);
pv = pv_class(Irrad);
hp = hp_class(T_HP_init);
fr = fr_class(T_FR_init);
chp = chp_class(T_CHP_init);
wm = wm_class(status_WM_init,E_WM_init);
```

Class files

- *fr*_class.m

Attributes

```
classdef fr_class
    %FR_CLASS Summary of this class goes here
    %   Detailed explanation goes here

    properties
        Tmin = -30; % Coldest setpoint temperature freezer [deg C]
        Tmax = -20; % Hottest setpoint temperature freezer [deg C]
        Pnom = 100;

        Twarmup = 0.2; % Temperature change freezer
        Tcooloff = -0.4; % Temperature change when freezer is turned on

        T_FR
    end

    methods
        function fr = fr_class(T_FR)
            fr.T_FR = T_FR;
        end
    end

end
```

Class files

- bidcurve.m

```matlab
function d = bidcurve(fr, id)

L=(fr.T_FR-fr.Tmin)/(fr.Tmax-fr.Tmin)*max(id);

d=zeros(1,length(id));

for i=1:length(id)        %create demand bid curve
    if(id(i)<=L)
        d(i)=fr.Pnom;
    else
        d(i)=0;
    end
end

end
```

Function to create bid curve

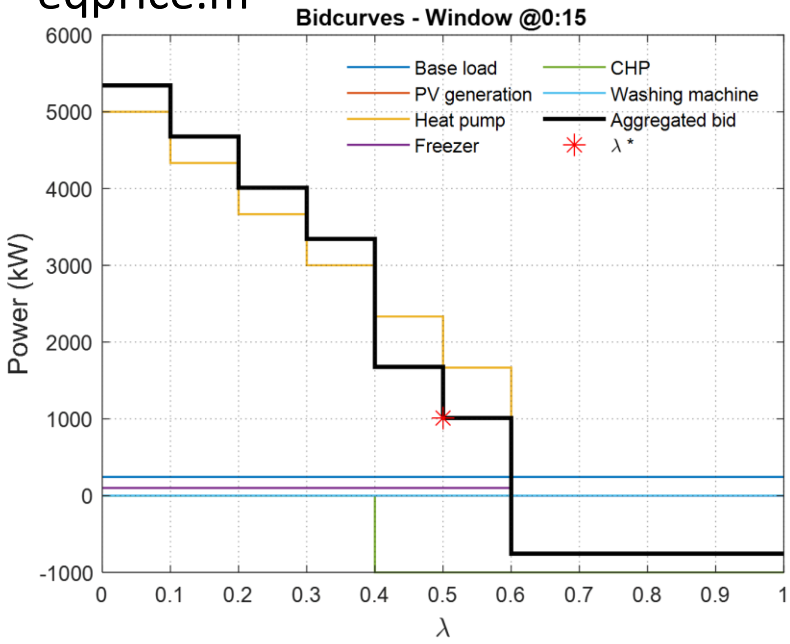
Local variable to measure normalized status

Use it to determine the bid

TU/e

Price calculation

eqprice.m




```
function [lstar, lstar_ind] = eqprice(input)
id = 0:0.1:1;
lstar = length(id);
f = input(input>0);
for l = 1:(length(input)-1)
        if input(l)*input(l+1) <= 0
            if(abs(input(l)) > abs(input(l+1)))
                lstar = l;
            else
                lstar = l+1;
            end
        elseif isempty(f)
            lstar = 1;
        end
end

lstar = id(lstar);
lstar_ind = find(id == lstar);
end
```


TU/e

Device response

```
% Determine the response of the appliances for the equilibrium price

 hp = hp.response(ind_lambda_star,d_HP,Temp(time));
 fr = fr.response(ind_lambda_star,d_FR);
 chp = chp.response(ind_lambda_star,d_CHP,Temp(time));
 wm = wm.response(ind_lambda_star,d_WM);
```

Input required to determine the response

Class files

- response.m

```
function fr = response(fr, lamda, d)

if(d(lamda)==0)
     dT = fr.Twarmup;
else
     dT = fr.Tcooloff;
end

fr.T_FR = fr.T_FR + dT;

end
```

Determine response

Switch on or off?

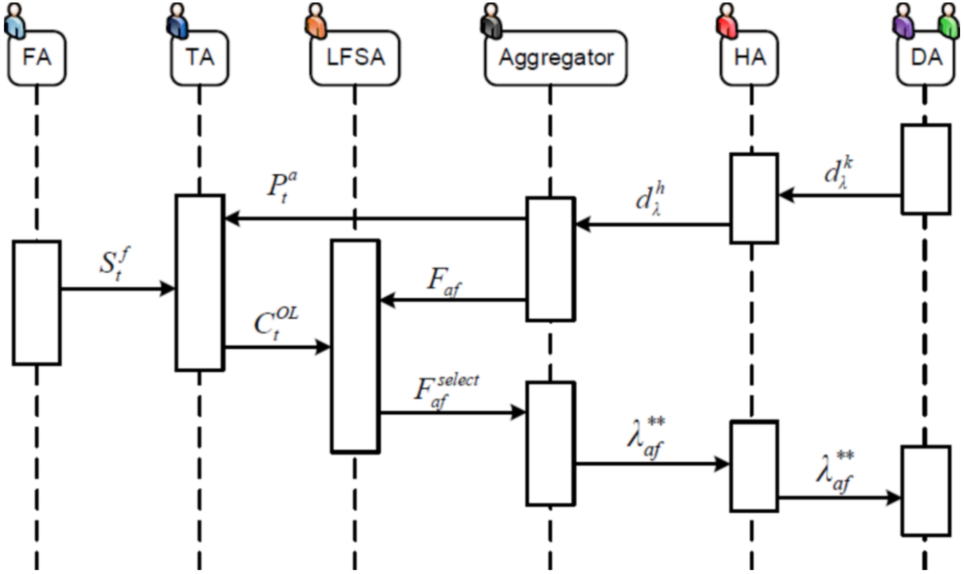
Response in terms of state variable

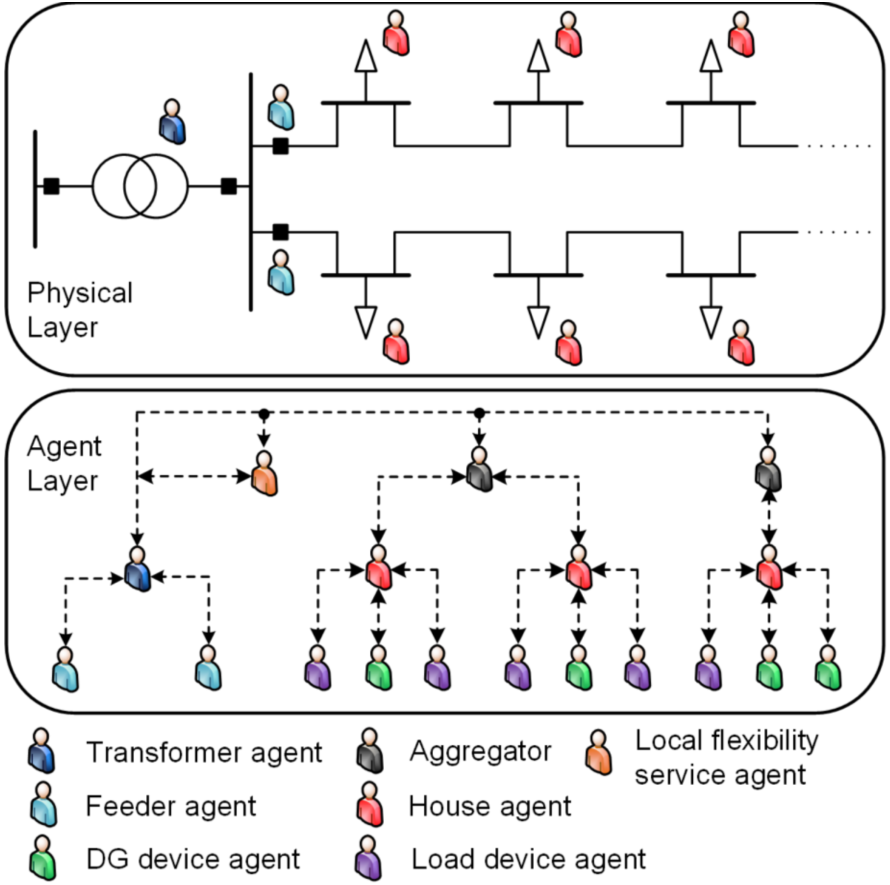
Content

1. Introduction
2. Agent-based modelling
3. Local supply-demand matching
4. Congestion management
5. Overlaying voltage control
6. PV forecasting
7. Conclusion

Example

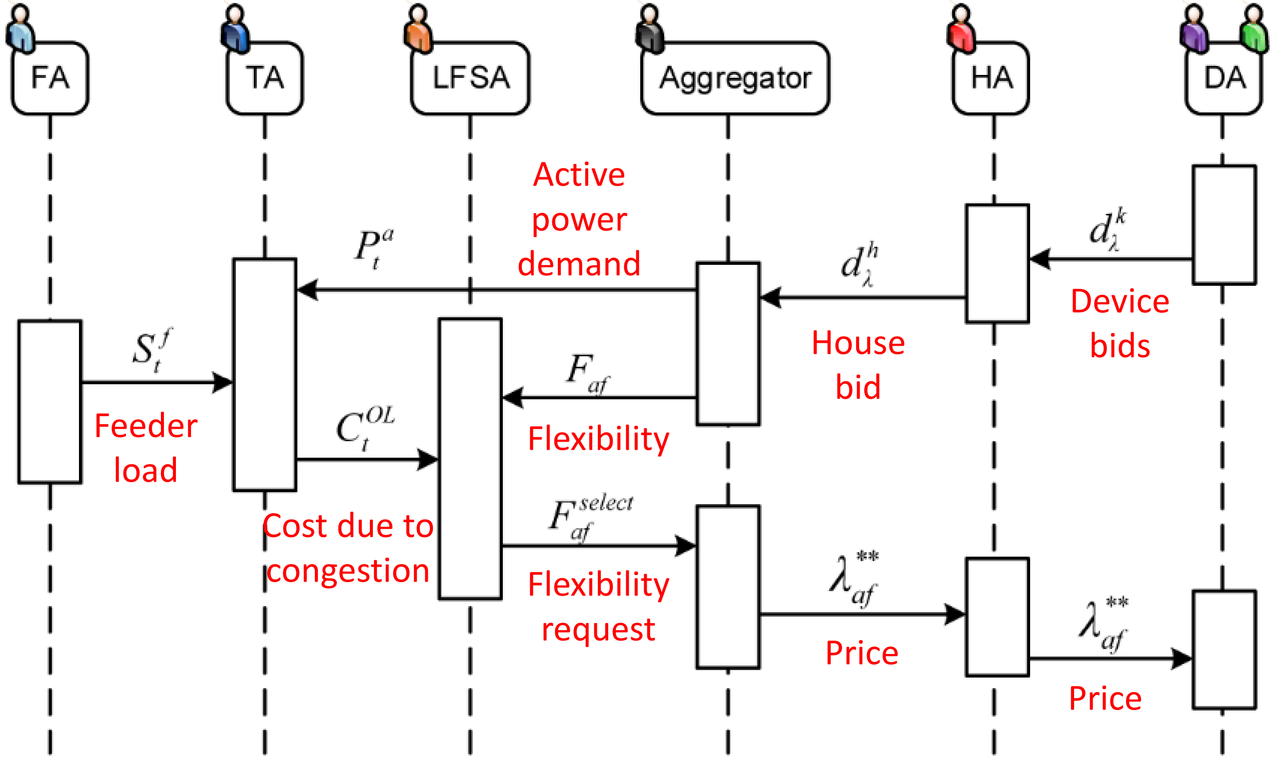
Flexibility for congestion management





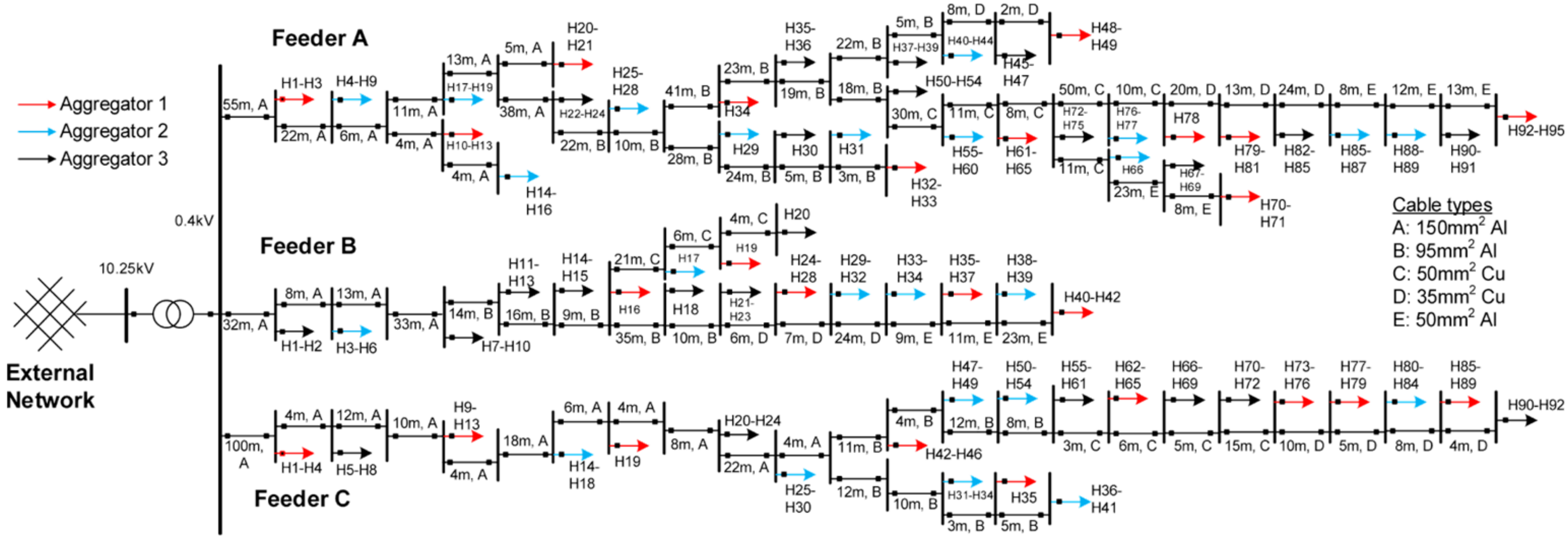
Haque, A. N. M. M., Nguyen, H. P., Bliek, F. W., & Slootweg, J. G. (2017). Demand response for real-time congestion management incorporating dynamic thermal overloading cost. *Sustainable Energy, Grids and Networks*, *10*, 65–74. https://doi.org/10.1016/j.segan.2017.03.002

Example



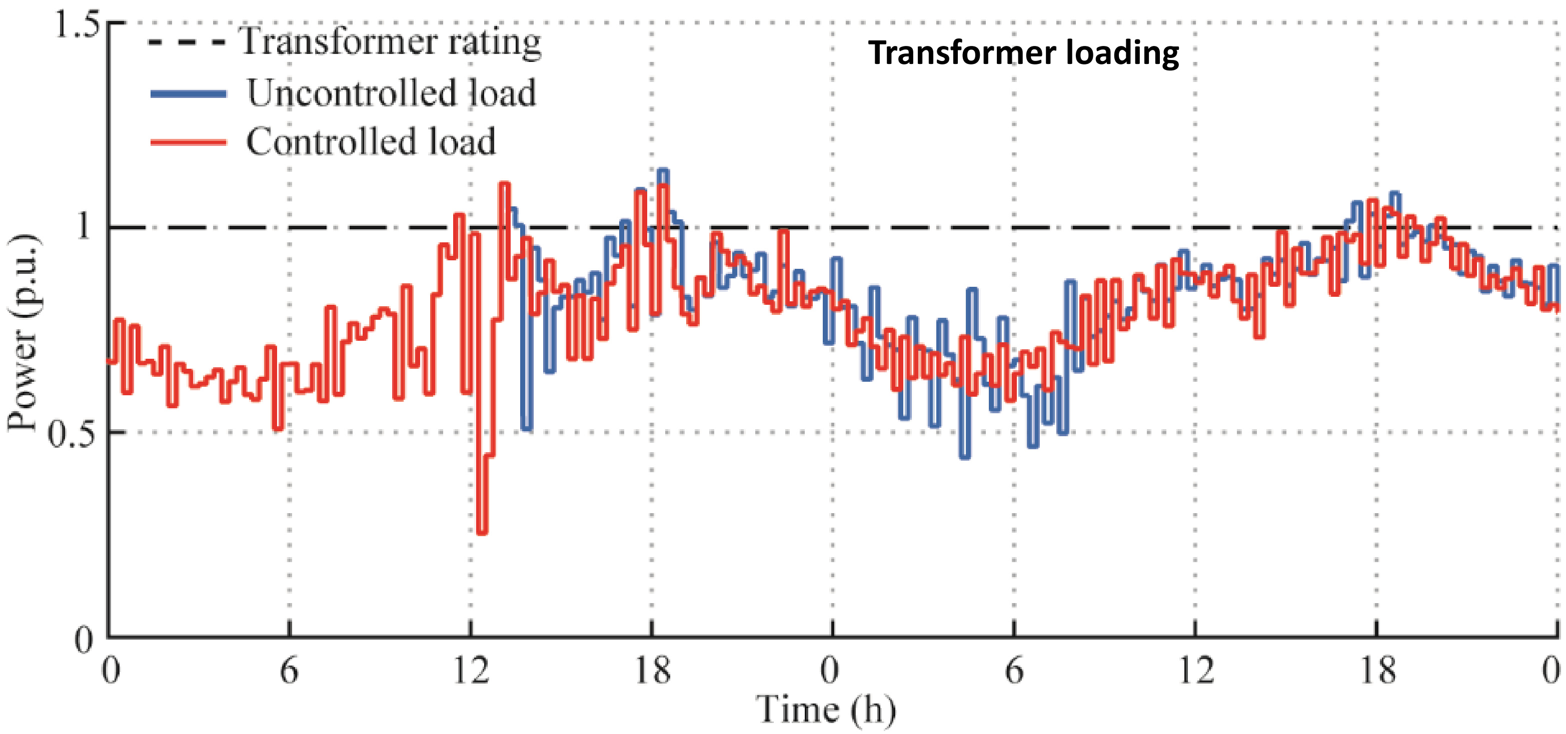
FA
TA
LFSA
Aggregator
HA
DA
Active power demand
P_t^a
d_λ^k
d_λ^h
Device bids
House bid
S_t^f
Feeder load
F_{af}
Flexibility
C_t^{OL}
Cost due to congestion
F_{af}^{select}
Flexibility request
λ_{af}^{**}
Price
λ_{af}^{**}
Price

Example



Aggregator 1
Aggregator 2
Aggregator 3
External Network
10.25kV
0.4kV
Feeder A
Feeder B
Feeder C
55m, A
H1-H3
22m, A
H4-H9
6m, A
11m, A
4m, A
13m, A
H17-H19
H10-H13
4m, A
H14-H16
5m, A
38m, A
H20-H21
H22-H24
22m, B
H25-H28
10m, B
41m, B
28m, B
23m, B
H34
H29
24m, B
H35-H36
19m, B
H30
5m, B
22m, B
18m, B
H31
3m, B
5m, B
H37-H39
H50-H54
30m, C
H32-H33
8m, D
H40-H44
2m, D
H45-H47
H48-H49
11m, C
H55-H60
8m, C
H61-H65
50m, C
H72-H75
11m, C
10m, C
H76-H77
H66
23m, E
20m, D
H78
H67-H69
8m, E
H70-H71
13m, D
H79-H81
24m, D
H82-H85
8m, E
H85-H87
12m, E
H88-H89
13m, E
H90-H91
H92-H95
32m, A
H1-H2
8m, A
13m, A
H3-H6
33m, A
14m, B
H7-H10
H11-H13
16m, B
H14-H15
9m, B
21m, C
H16
35m, B
6m, C
H17
H18
10m, B
4m, C
H19
H21-H23
6m, D
H20
H24-H28
7m, D
H29-H32
24m, D
H33-H34
9m, E
H35-H37
11m, E
H38-H39
23m, E
H40-H42
100m, A
H1-H4
4m, A
12m, A
H5-H8
10m, A
H9-H13
4m, A
18m, A
6m, A
H14-H18
4m, A
H19
8m, A
H20-H24
22m, A
4m, A
H25-H30
11m, B
12m, B
4m, B
H42-H46
10m, B
H31-H34
3m, B
H35
5m, B
H36-H41
H47-H49
12m, B
H50-H54
8m, B
H55-H61
3m, C
H62-H65
6m, C
H66-H69
5m, C
H70-H72
15m, C
H73-H76
10m, D
H77-H79
5m, D
H80-H84
8m, D
H85-H89
4m, D
H90-H92
Cable types
A: 150mm² Al
B: 95mm² Al
C: 50mm² Cu
D: 35mm² Cu
E: 50mm² Al

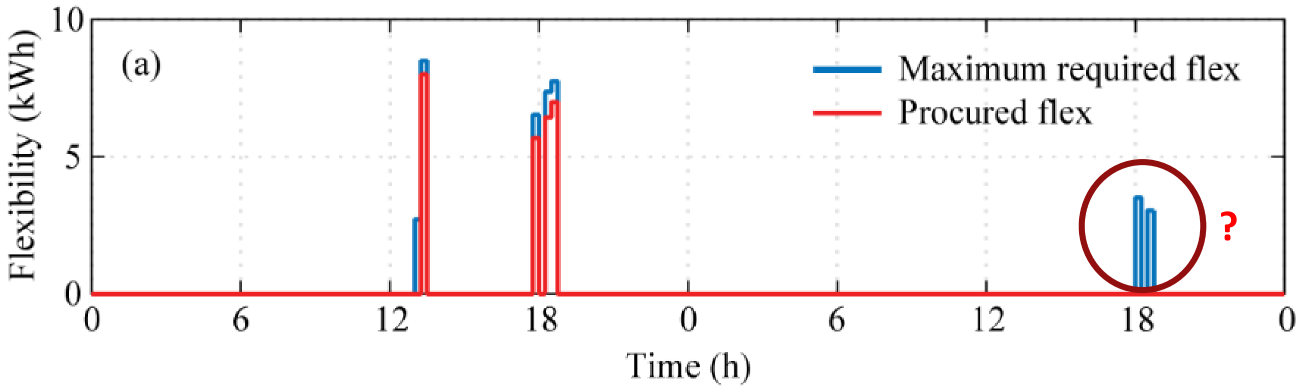
Example



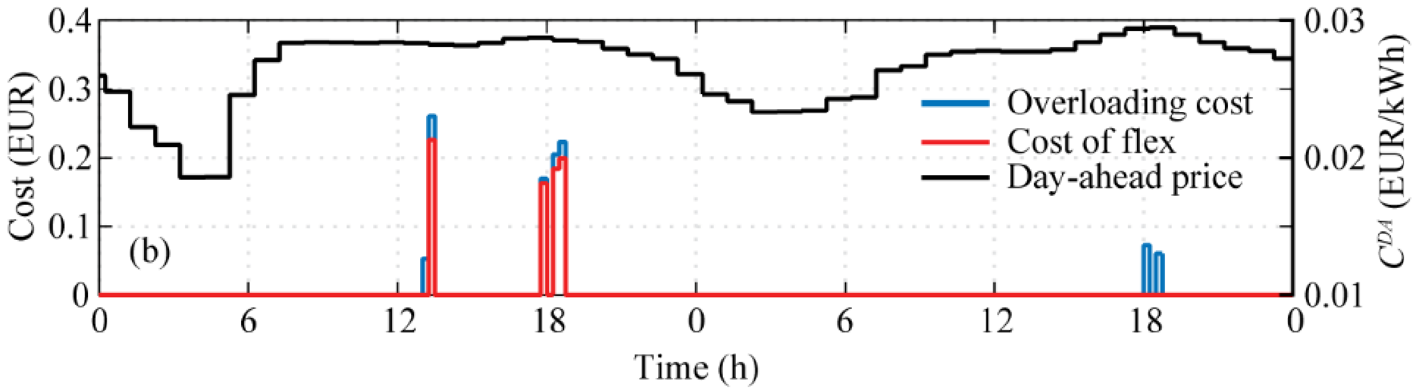
Transformer loading
Transformer rating
Uncontrolled load
Controlled load
1.5
1
0.5
0
Power (p.u.)
0
6
12
18
0
6
12
18
0
Time (h)

Example

Required and procured flexibility



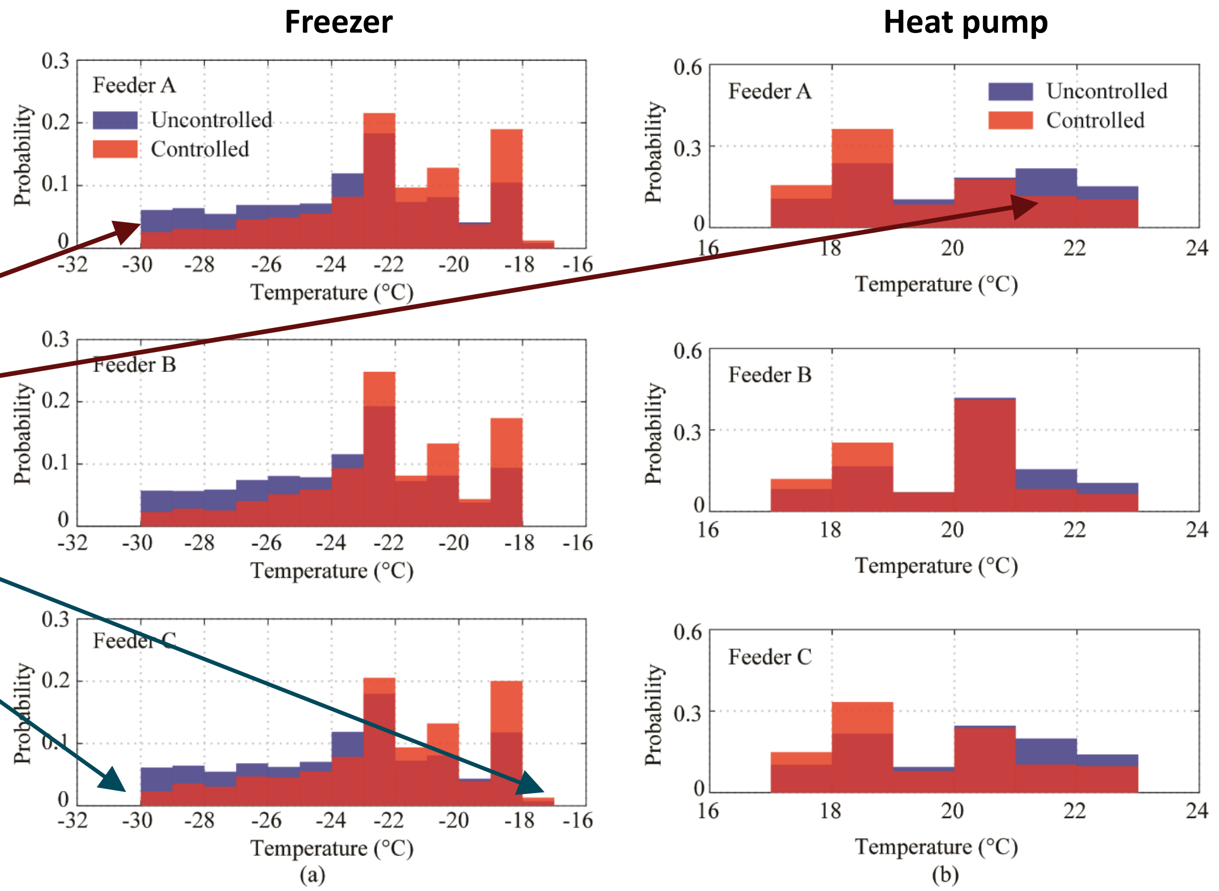
Overloading cost and electricity price



Example

Load shifting forces the device to operate in different temperature.

Note: It does not violate the preferred set points.

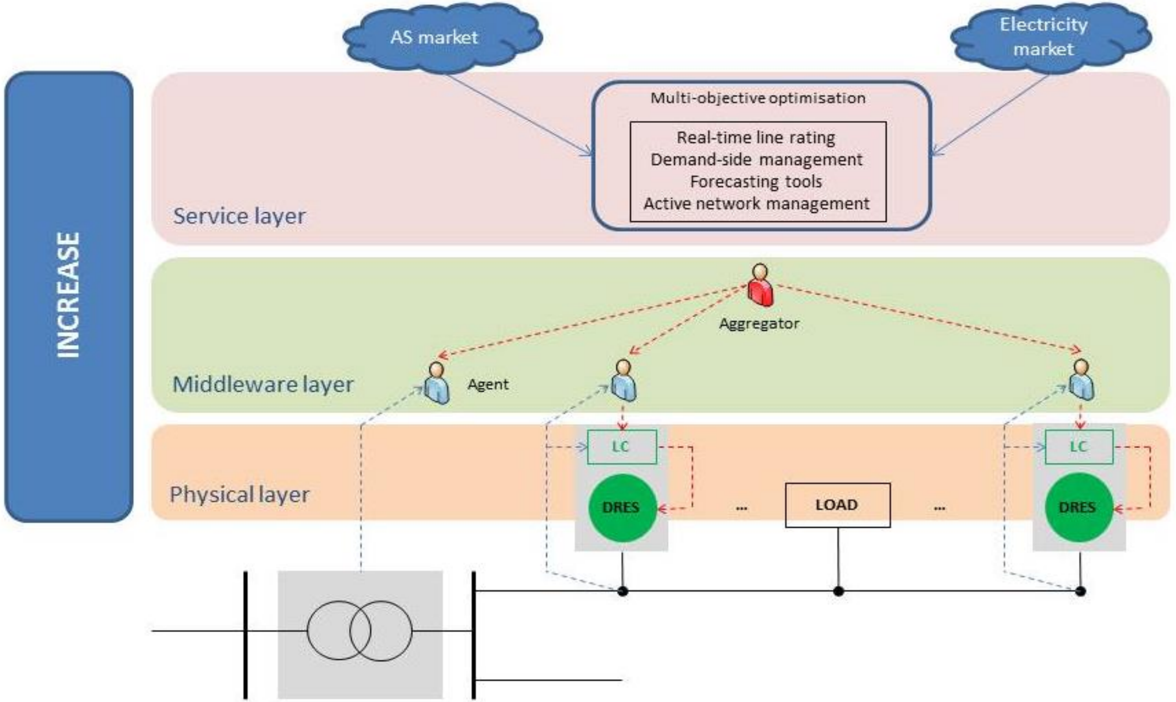


Content

1. Introduction
2. Agent-based modelling
3. Local supply-demand matching
4. Congestion management
5. Overlaying voltage control
6. PV forecasting
7. Conclusion

FP7 – INCREASE project

- Control architecture layers

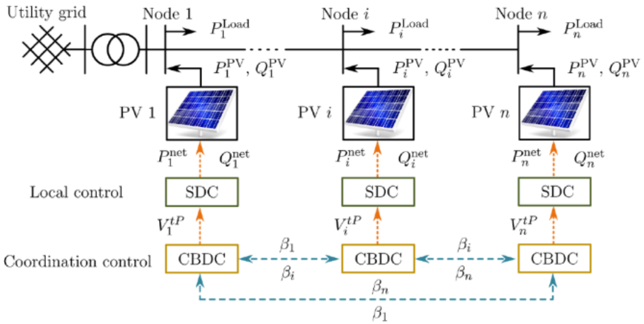


Scheduling control

Overlaying control

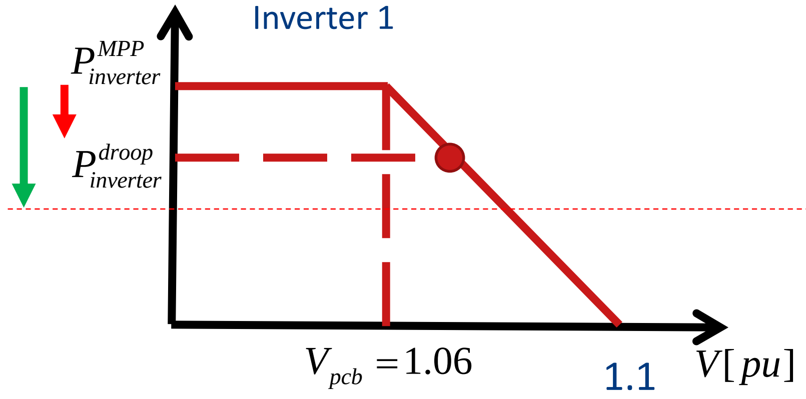
Local control

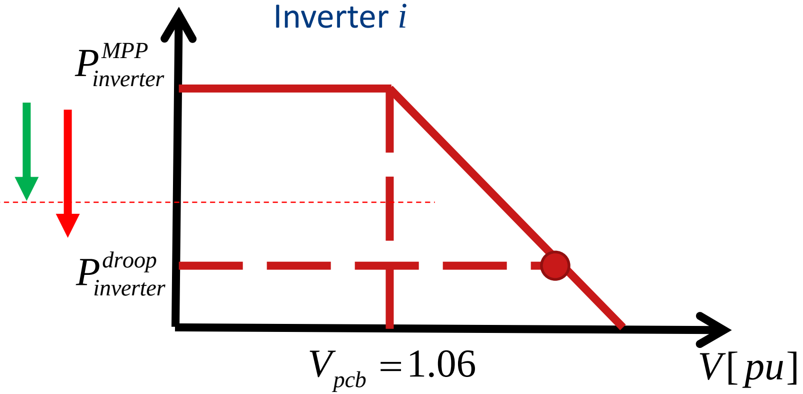
FP7 – INCREASE project



- Mitigating voltage rise in PV-rich networks
  - Fair *P-V* curtailment

$$P_{curt}^{1} \neq \cdots \neq P_{curt}^{n}, \leftrightarrow V_g^1 \neq \cdots \neq V_g^n, \in V_{cpb} < V_g^i \leq V_{max}$$





FP7 – INCREASE project

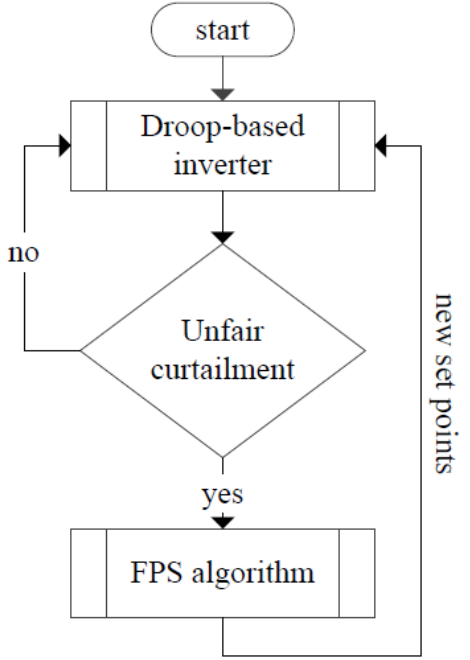
- Principal

$$\frac{\Delta|V_i|}{\Delta P_j} = [J^{*\,-1}] = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nn} \end{bmatrix}$$

$$\Rightarrow \quad \Delta|V_g^i| = [x_{i1} \quad \cdots \quad x_{ij}][\Delta P_j]$$

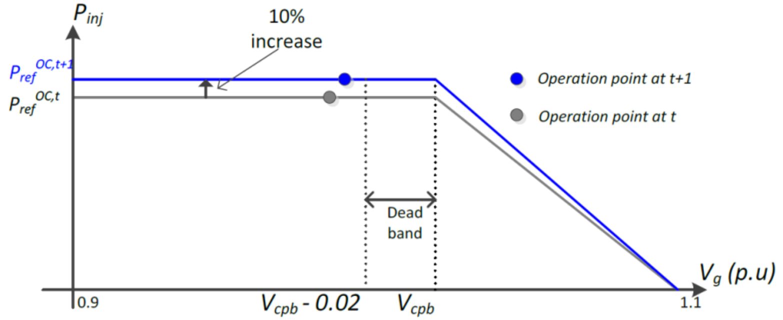
$$\boxed{P_{curt}^1 = \cdots = P_{curt}^n} \quad \Rightarrow \quad \Delta P_1 = \cdots = \Delta P_n = \Delta P$$

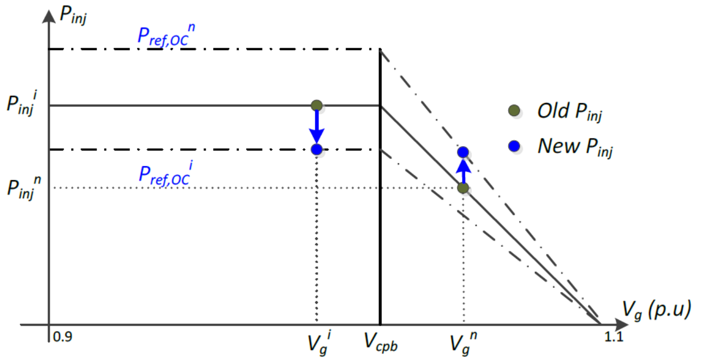
$$\Rightarrow \quad \boxed{\Delta P = \frac{\Delta|V_g^i|}{\sum_{j=1}^{n} x_{ij}}}$$



FP7 – INCREASE project

- Other considerations:
  - Dead band to avoid oscillation
  - Virtual maximum power point
  - Different sizes of the inverters
  - Communication time delay

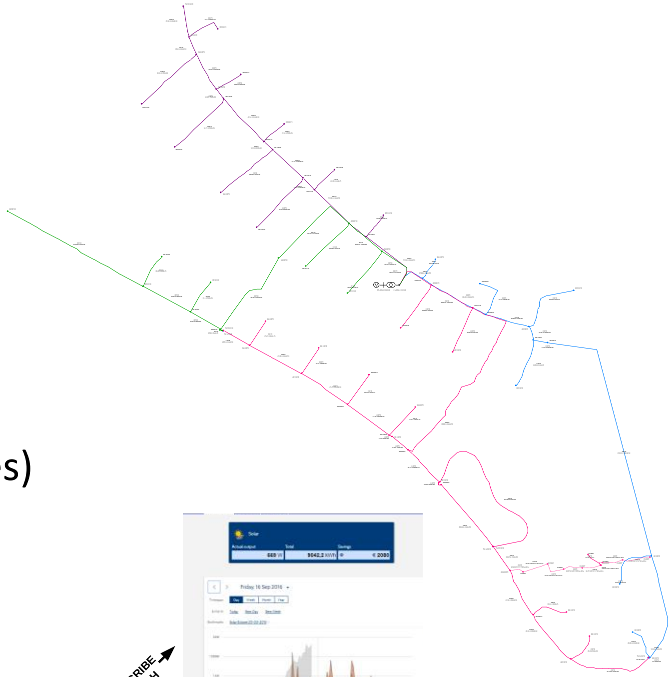


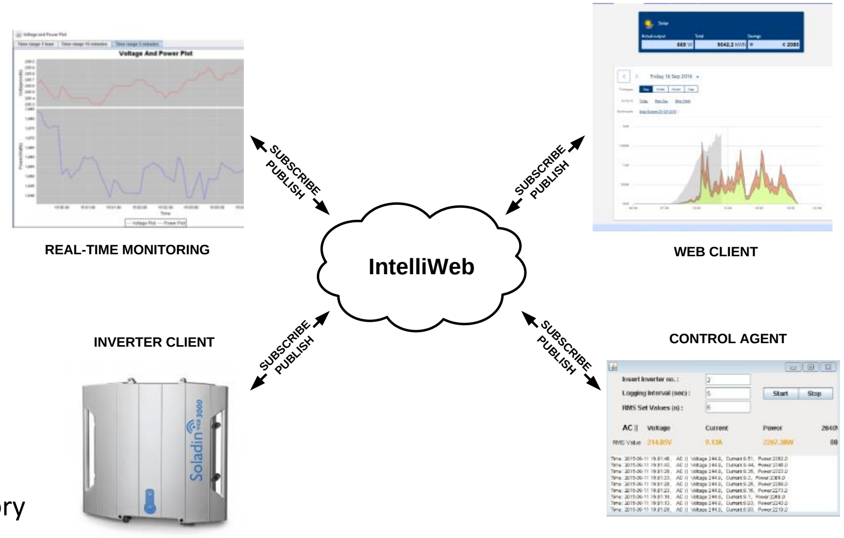


TU/e

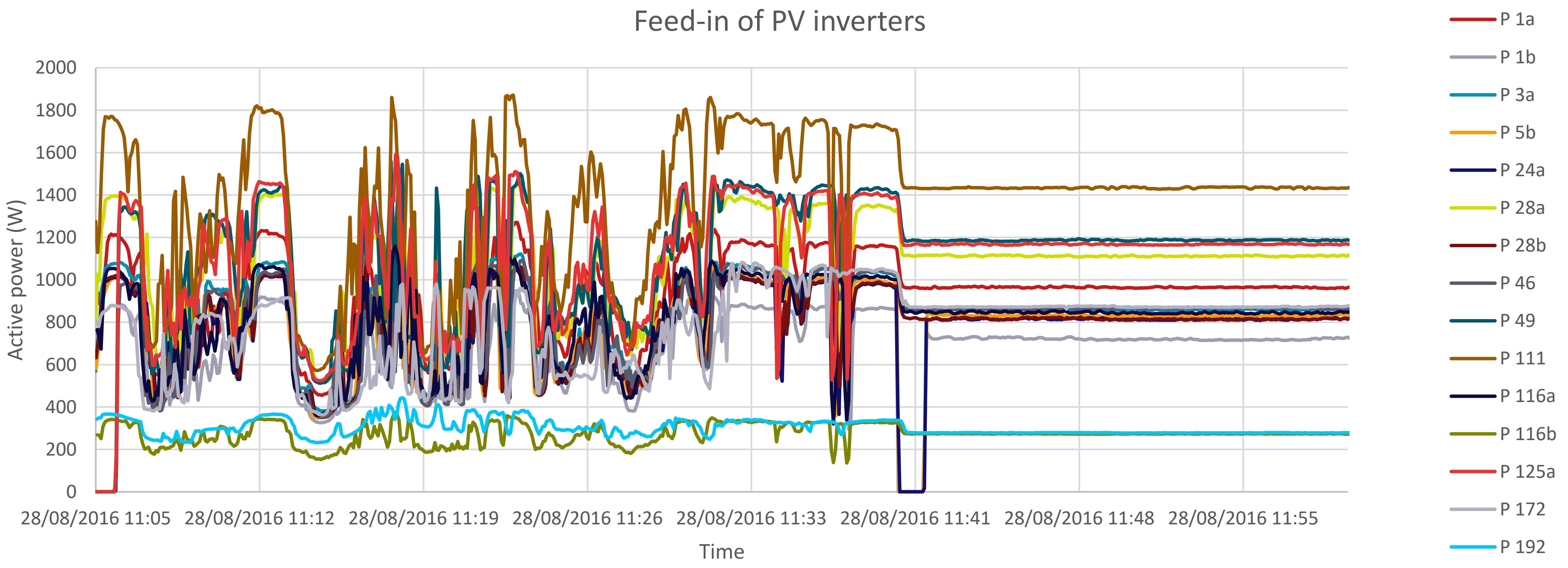
FP7 – INCREASE project

- LV network of holiday park Bronsbergen
  - First micro-grid in Netherlands
  - High penetration of PV: 315 kWp (~50% of cottages)
  - Well designed (400 kVA transformer, 150 mm2 Al cables)





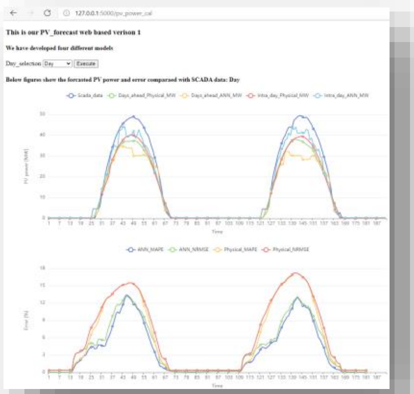
FP7 – INCREASE project



Content

1. Introduction
2. Agent-based modelling
3. Local supply-demand matching
4. Congestion management
5. Overlaying voltage control
6. PV Forecasting
7. Conclusion

Single-point forecasting



Renewable forecast:

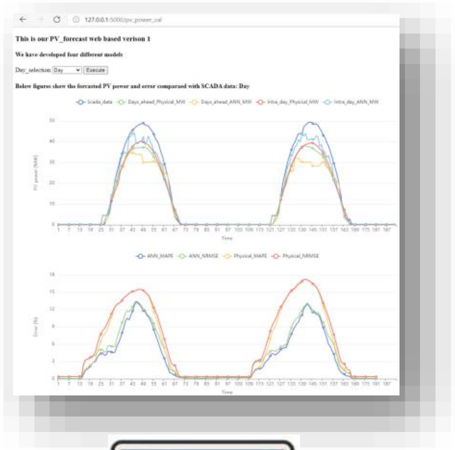
Fuel condition
Irradiance
Temperature
Wind speed
Maintenance schedule...

Forecasting model:
- Physical model
- Data-driven based model

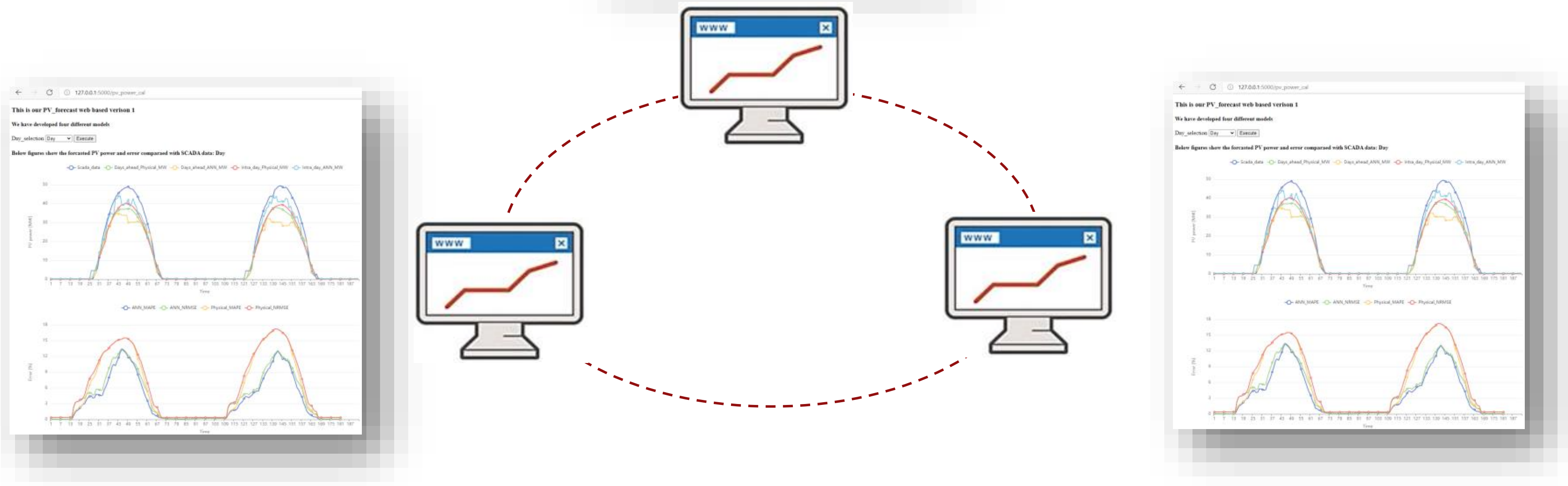
State estimation model:
- Physical based
- Data-driven

Web App

Collaborative learning



- Baselining assessment
- Anomaly detection



TU/e

Conclusions

- Massive integration of distributed energy resources can be supported by agent-based modeling techniques.
- Development of agent-based modelling and control solutions needs to be simple, replicable, and scalable.
- Digital transformation creates a cyber-physical ecosystem to attach advanced (distributed) intelligence on the power grid.

Thank you!