Practical Implementation of the **SNOOPI-Box** for a Smart Voltage Control in the Distribution Grid

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IN COLLABORATION WITH ewr netze
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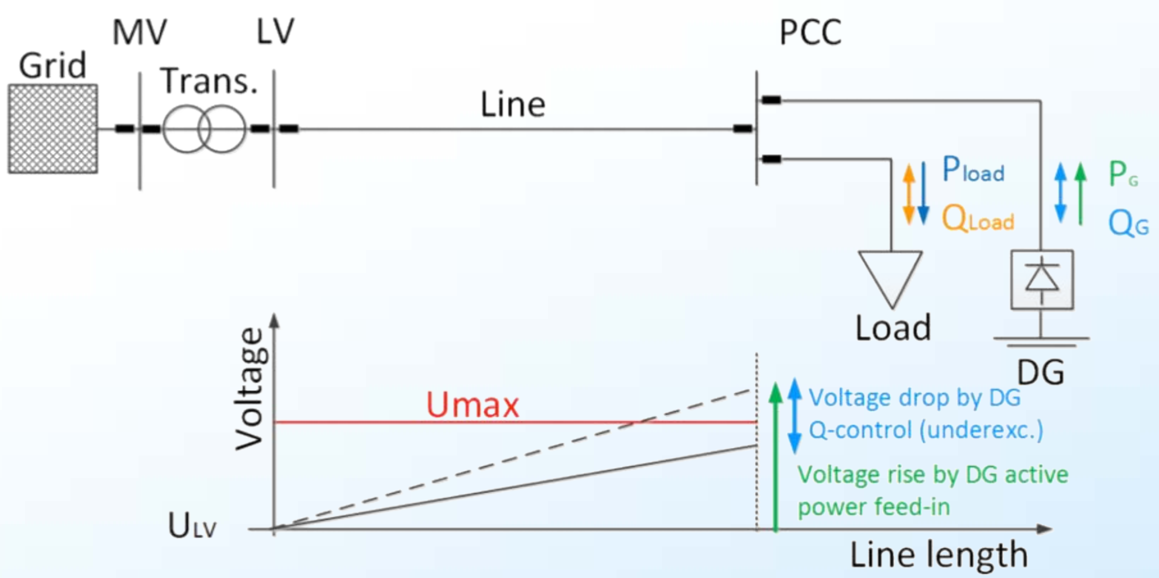
Outline

- Project Background
- Voltage Regulation Tool
- Tests
- Field Test Results
- Conclusion and Outlook

Project Background

Integration of PV plants into the distribution grid

- Increasing amount of PV plants in the distribution grid
  - ➢ Voltage rise along the feeder at times with high PV infeed
  - ➢ Amount of PV plants is limited because of the permitted voltage deviation of ±10%
- By providing reactive power, PV and battery inverter can reduce the voltage



SOURCE: M. Kraiczy, L. Al Fakhri, T. Stetz, and M. Braun, “Do It Locally: Local Voltage Support by Distributed Generation – A Management Summary,” 2017

Project Background

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Our Solution

- Development of a **SNOOPI-Box** to control PV and battery inverter in the distribution grid (SNOOPI = **S**mart **N**etwork C**o**ntrol with C**o**ordinated **P**V **I**nfeed)

SNOOPI

- **Smart**: Contains a smart voltage regulation tool to control reactive power in a coordinated way
- **Autonomous**: Works independently without communicating with other boxes or devices
- **Transferable**: Uses the SunSpec protocol to communicate with the inverter → Applicable to almost any PV or battery inverter

Project Partner

Project Partner

Energynautics GmbH, Germany

- Development of the simulation model , regulation algorithm and the SNOOPI-Box
- Project management

EWR Netz GmbH, Germany

- Supply of grid and measurement data
- Field Test Area

Associated Partner

Fronius International GmbH, Austria

- Assists with the communication

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Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Project Phases

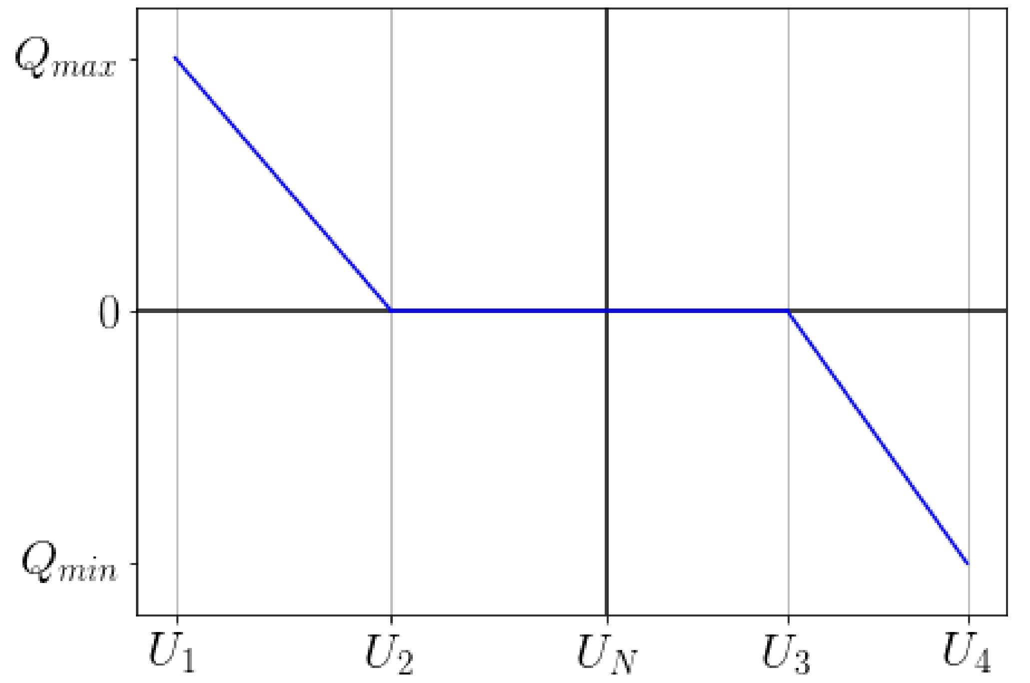
10/2015 – 06/2019

✓	Phase 1	• Identification of possible field test areas • Development of simulation models
✓	Phase 2	• Development of the voltage regulation tool
✓	Phase 3	• Successful tests of the regulation tool in the simulation model
✓	Phase 4	• Successful tests of the regulation tool in the lab tests
✓	Phase 5	• Selection of field test areas • Installation of battery systems
	Phase 6	• Successful tests of the regulation tool in the field test

Voltage Regulation Tool: $Q(U)$ Curve

Voltage Depended Reactive Power Control

- Reactive power setpoints are determined using an autonomously parameterized Q(U) characteristic curve



Parameter:

Q_{max}, Q_{min}: Max./ min. reactive power
U_N: Nominal Voltage
U_{max}, U_{min}: Max./ min. measured voltage

Parameterization:

$$U_4 = U_{max}$$

$$U_3 = U_N + 0.5 \cdot (U_{max} - U_N)$$

$$U_1 = U_{min}$$

$$U_2 = U_{\min} + 0.5 \cdot (U_N - U_{min})$$

Voltage Regulation Tool: $Q(U)$ Curve

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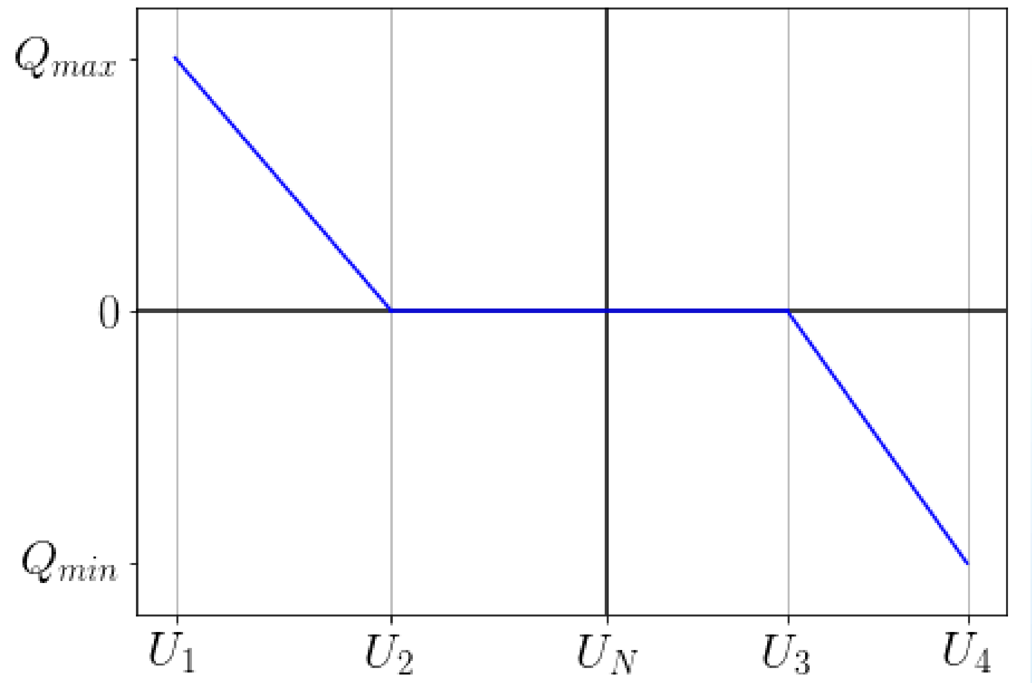
Coordinated Behaviour of all inverters

- Dependency of the starting point U_3 on U_{max} → all inverters will start to provide reactive power at the same time
- The Q(U) curve is steeper if the maximum voltage is smaller → inverters at the beginning of the feeder will have a steeper Q(U) curve



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Voltage Regulation Tool: Change in the Grid Topology

- Grid topology changed:
  - Inverter from the beginning of the feeder is now located at the end of the feeder
    → U_{max} is adjusted automatically by measuring the higher voltages
  - Inverter from the end of the feeder is now located at the beginning of the feeder
    → U_{max} will remain at its high value

- **Solution**: Use the effect that voltage variations at the end of the feeder are larger: $dU \approx \frac{RP+XQ}{U_N^2}$

Measuring voltage changes in a resolution of 200 ms

Determining a reference value $\boldsymbol{\Delta U}$ for each day

Learning the statistical behavior of ΔU

Comparing the newly determined ΔU with the learning phase

Deciding if the topology has changed and the $Q(U)$ curve is reset

Simulations in DIgSILENT PowerFactory

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DIgSILENT PowerFactory

Active Power in kW
Reactive Power in kVar
Voltage in V

Active [kW] and
Reactive Power
Setpoints [kVar]

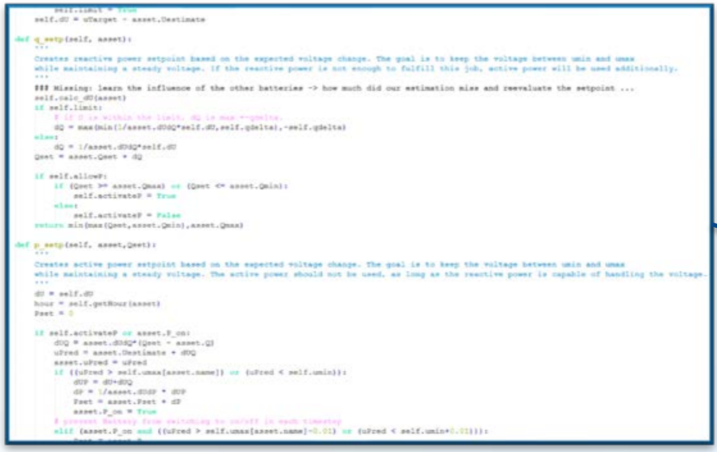
Python Interface for PowerFactory

Active Power in W
Reactive Power in Var
Voltage in V

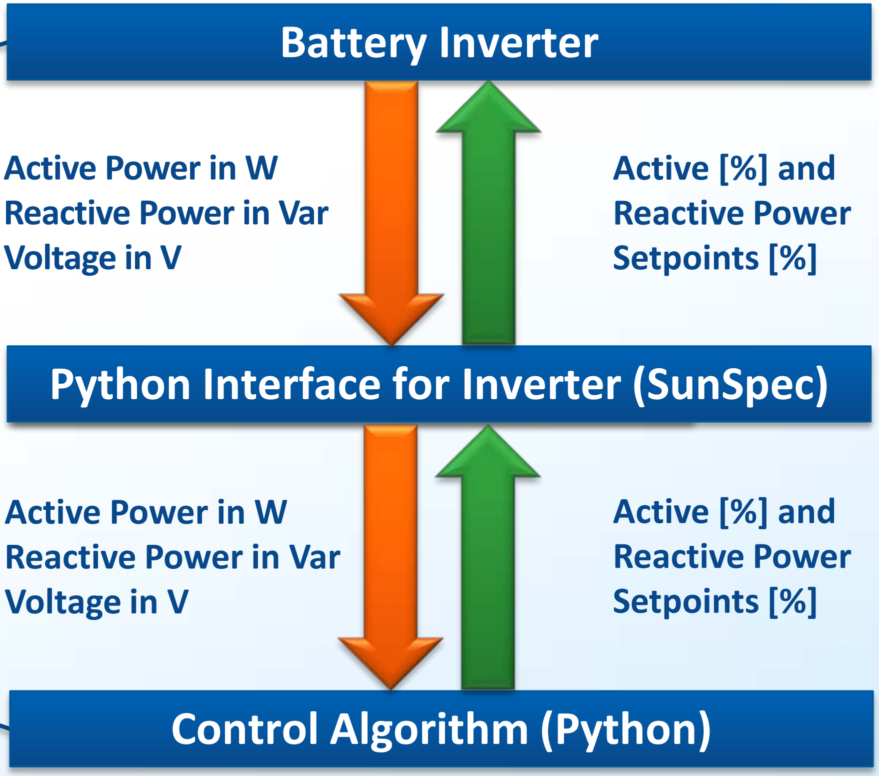
Active [%] and
Reactive Power
Setpoints [%]

Control Algorithm (Python)

Lab Test

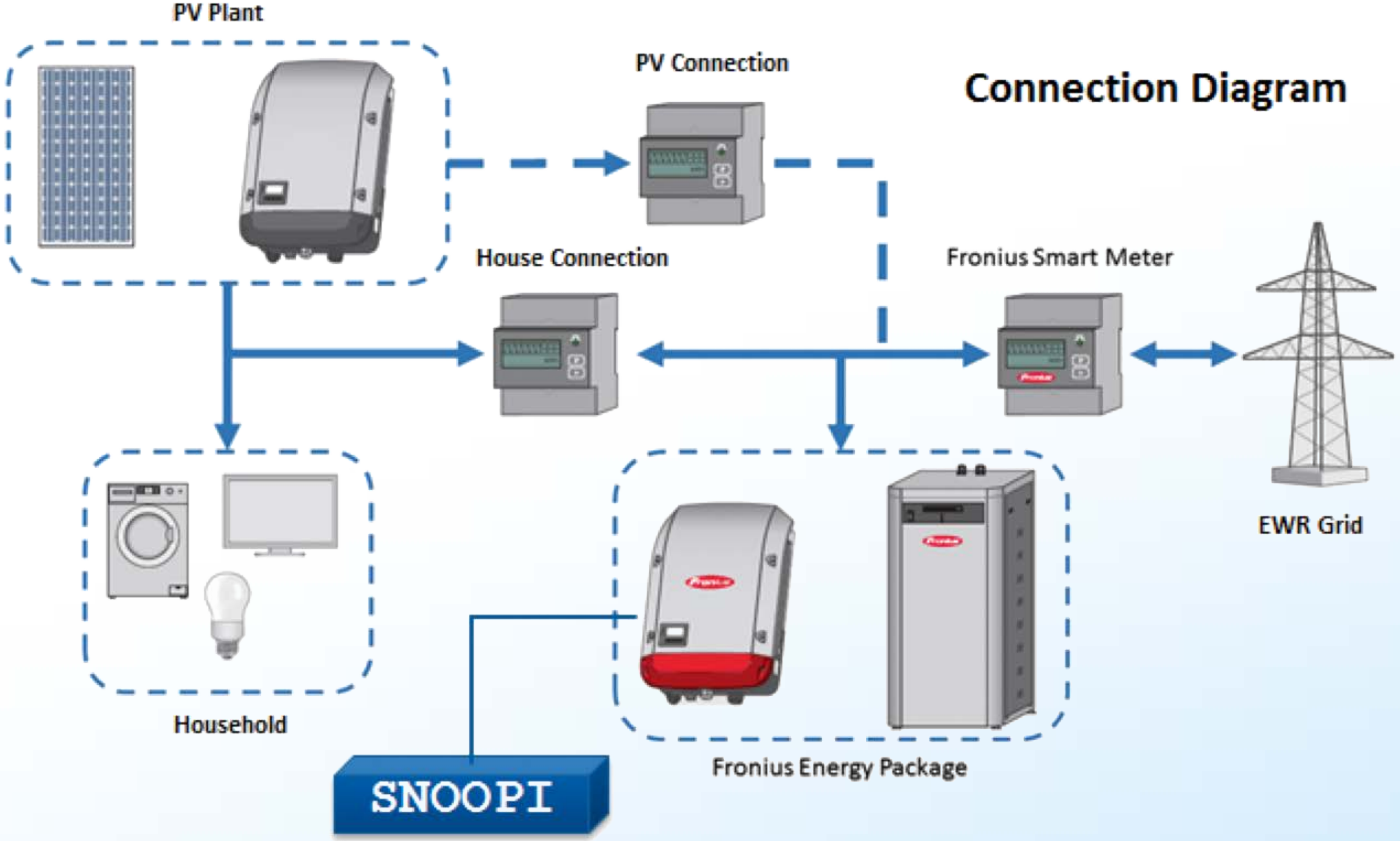


```
self.dU = uTarget - asset.Uestimate

def q_setp(self, asset):
    '''
    Creates reactive power setpoint based on the expected voltage change. The goal is to keep the voltage between umin and umax
    while maintaining a steady voltage. If the reactive power is not enough to fulfill this job, active power will be used additionally.
    '''
    ### Missing: learn the influence of the other batteries -> how much did our estimation miss and reevaluate the setpoint ...
    self.calc_dU(asset)
    if self.limit:
        # if U is within the limit, dQ is max +-qdelta.
        dQ = max(min(1/asset.dUdQ*self.dU,self.qdelta),-self.qdelta)
    else:
        dQ = 1/asset.dUdQ*self.dU
    Qset = asset.Qset + dQ

    if self.allowP:
        if (Qset >= asset.Qmax) or (Qset <= asset.Qmin):
            self.activateP = True
        else:
            self.activateP = False
    return min(max(Qset,asset.Qmin),asset.Qmax)

def p_setp(self, asset,Qset):
    '''
    Creates active power setpoint based on the expected voltage change. The goal is to keep the voltage between umin and umax
    while maintaining a steady voltage. The active power should not be used, as long as the reactive power is capable of handling the voltage.
    '''
    dU = self.dU
    hour = self.getHour(asset)
    Pset = 0

    if self.activateP or asset.P_on:
        dUQ = asset.dUdQ*(Qset - asset.Q)
        uPred = asset.Uestimate + dUQ
        asset.uPred = uPred
        if ((uPred > self.umax[asset.name]) or (uPred < self.umin)):
            dUP = dU+dUQ
            dP = 1/asset.dUdP * dUP
            Pset = asset.Pset + dP
            asset.P_on = True
        # prevent Battery from switching to on/off in each timestep
        elif (asset.P_on and ((uPred > self.umax[asset.name]-0.01) or (uPred < self.umin+0.01))):
```



Field Test

- Installation of 7 battery systems equipped with the SNOOPI-Box in the field test area



SOURCE: Fronius, Adjustment: Energynautics

Field Test


snoopibox
smart network control with coordinated pv infeed
by energynautics

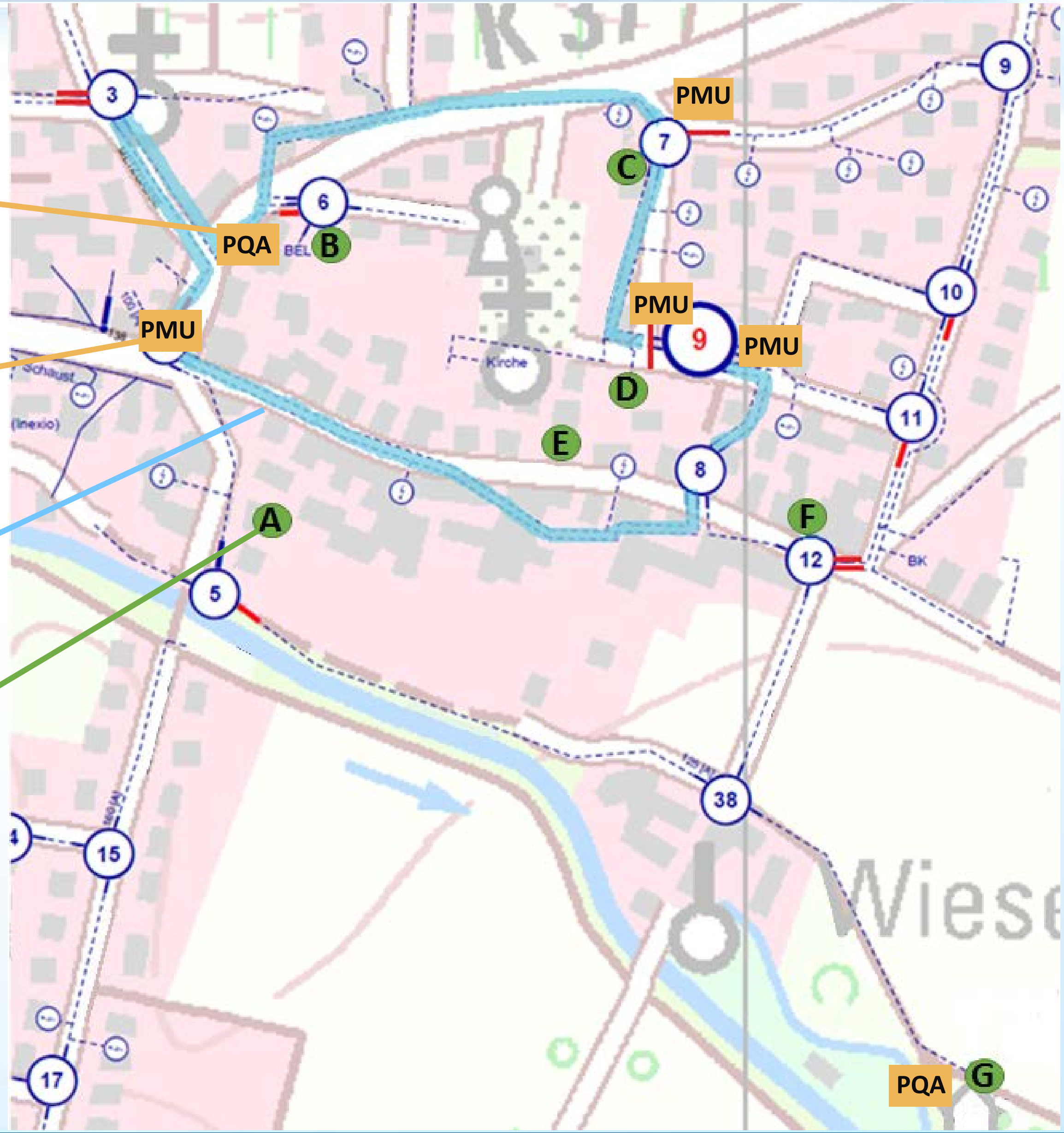
Field Test Area

PQA: Power Quality Analyzer

PMU: Phasor Measurement Unit

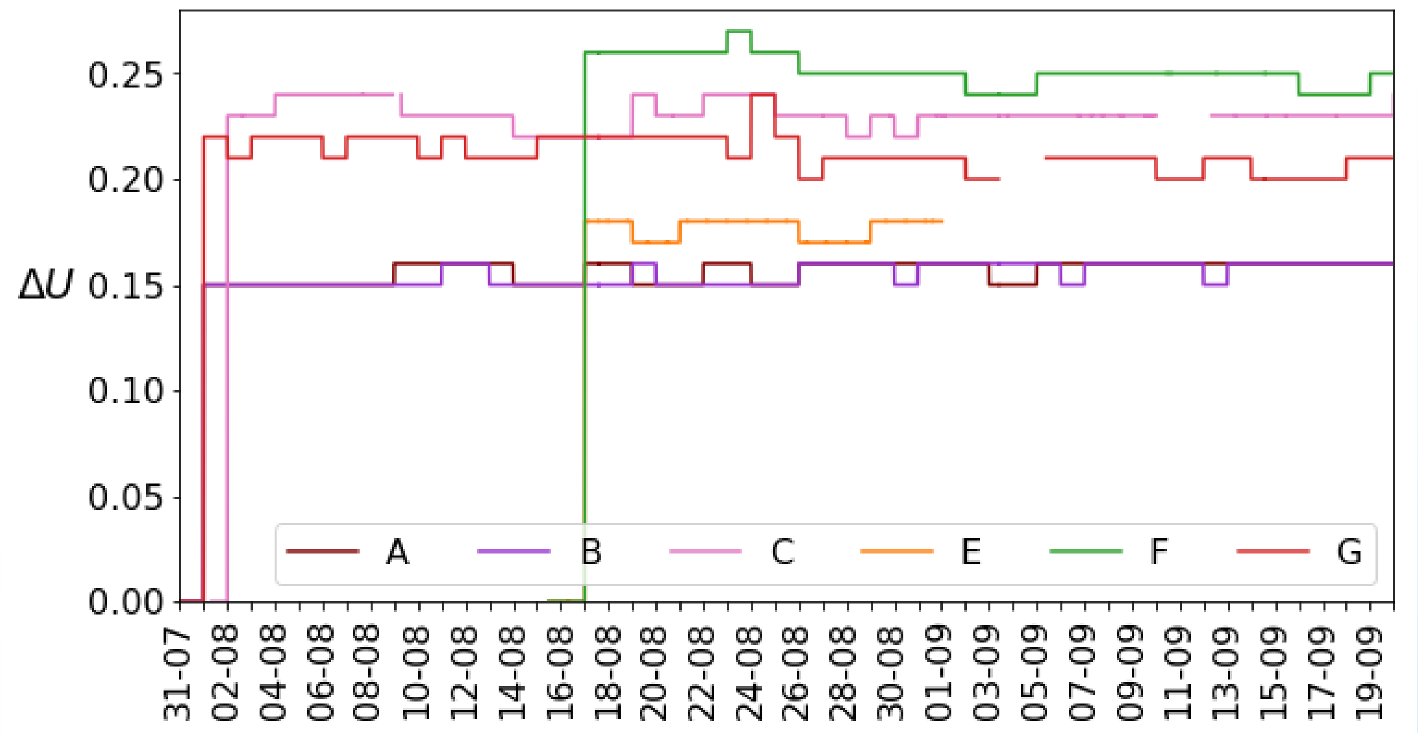
Feeder with Voltages between 0.93 and 1.06 p.u.

Battery locations

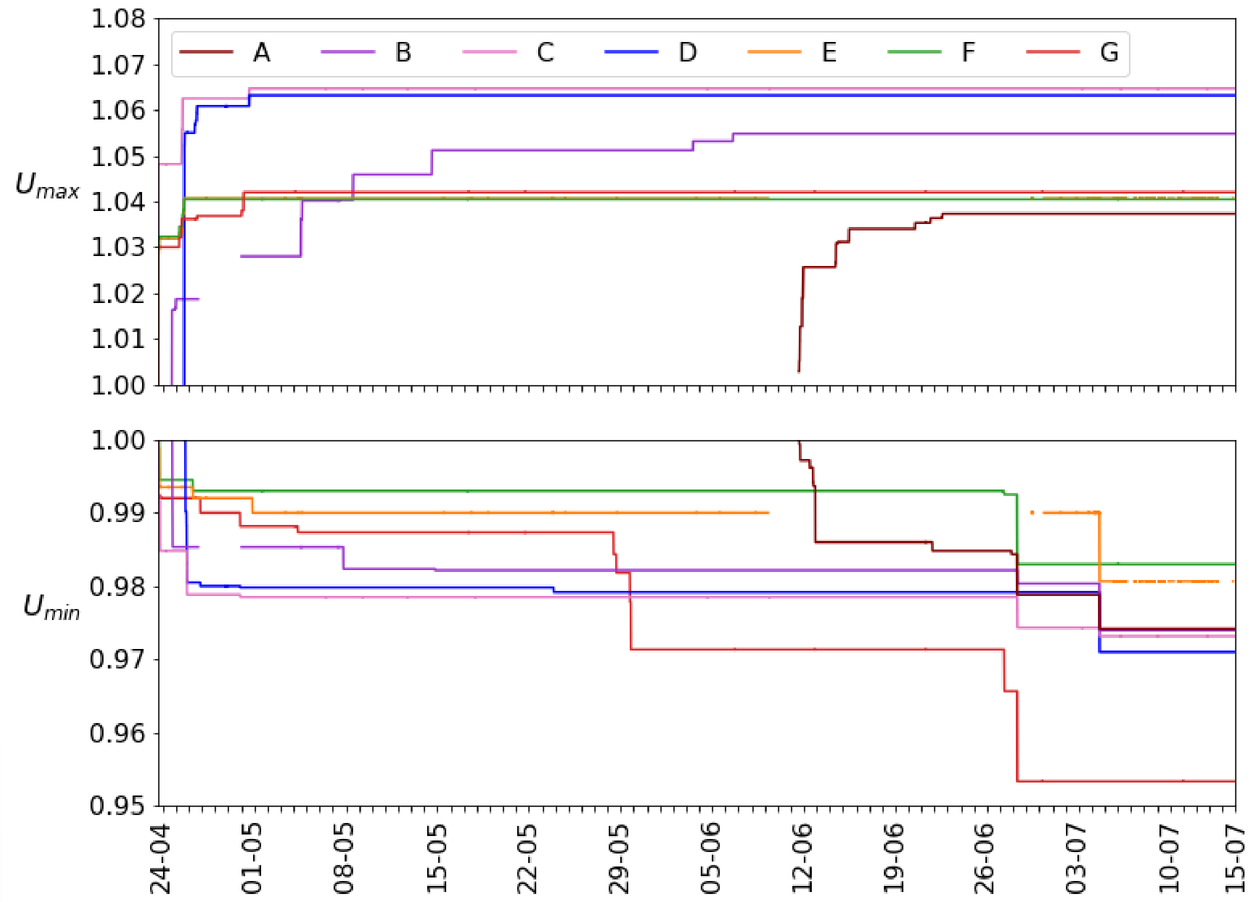


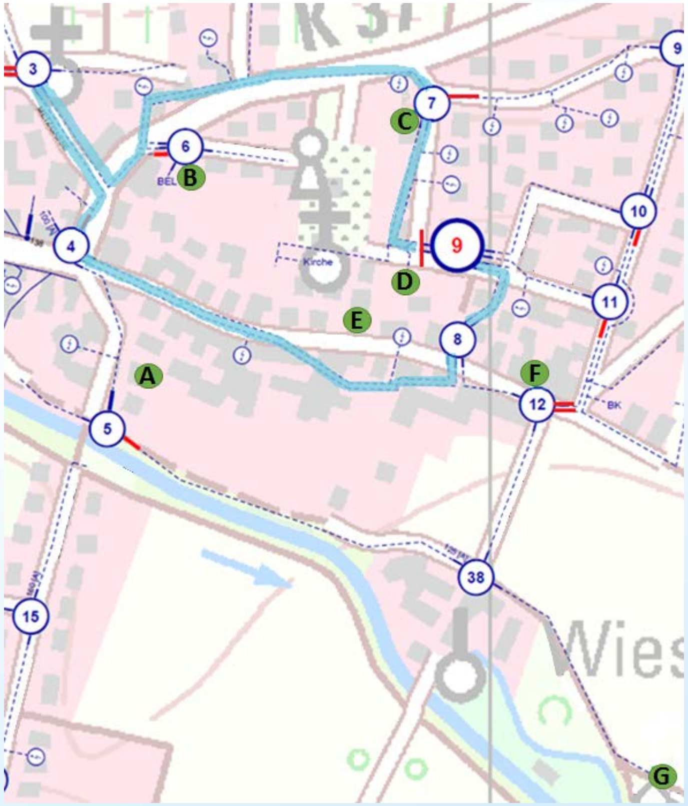
Field Test Results

Learning Behaviour: ΔU



Learning Behaviour: Maximum and Minimum Voltage





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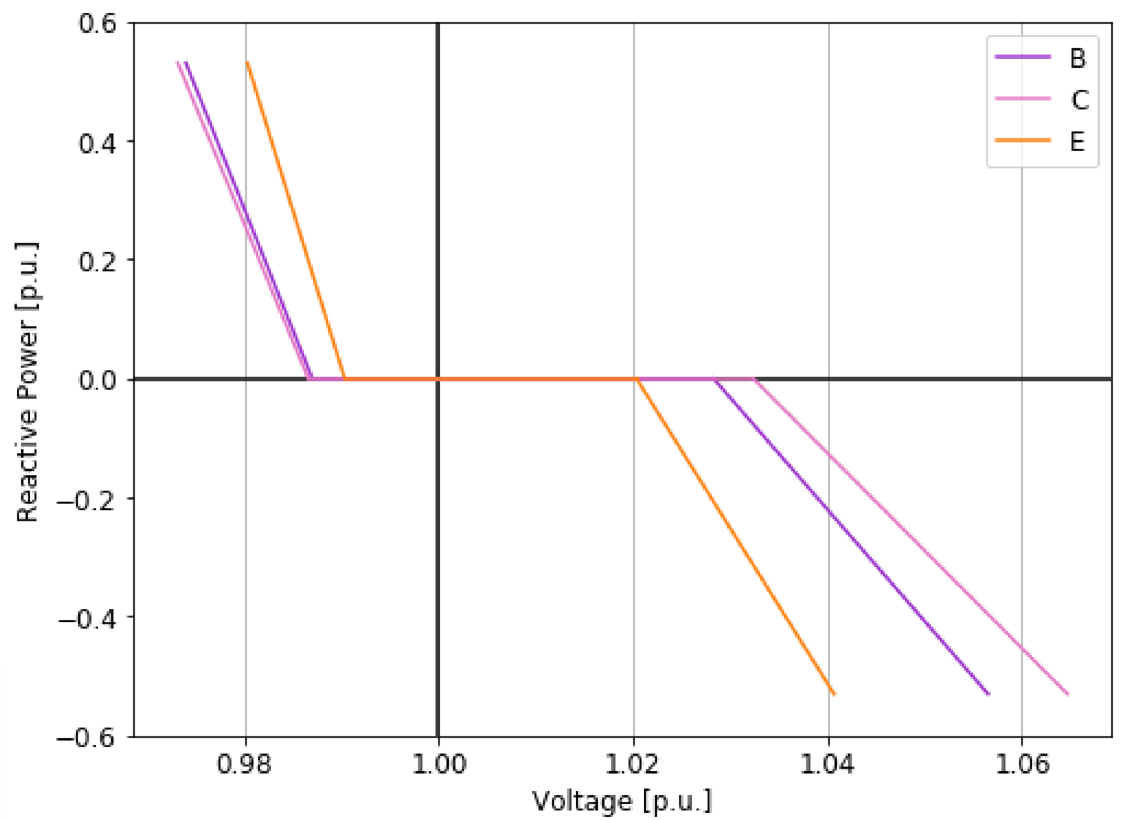
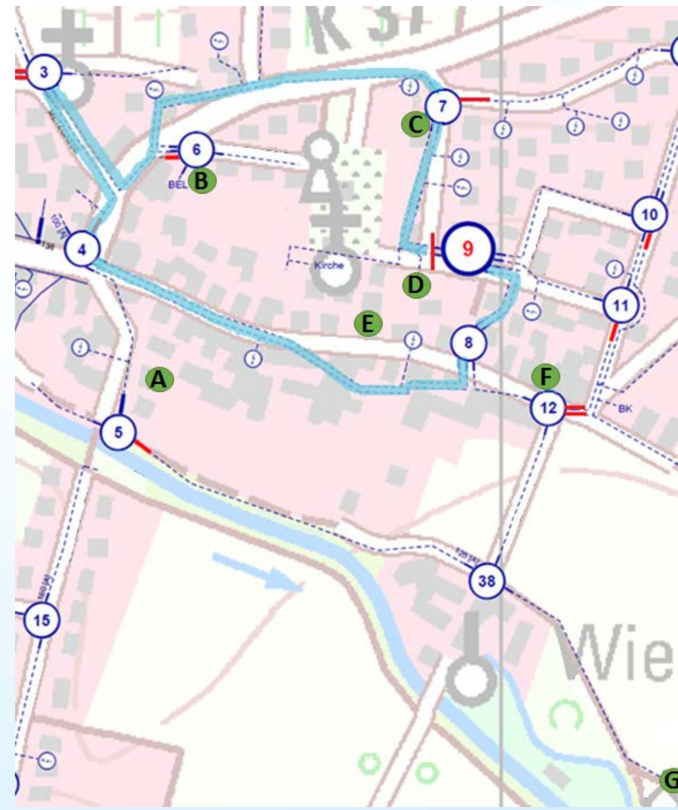
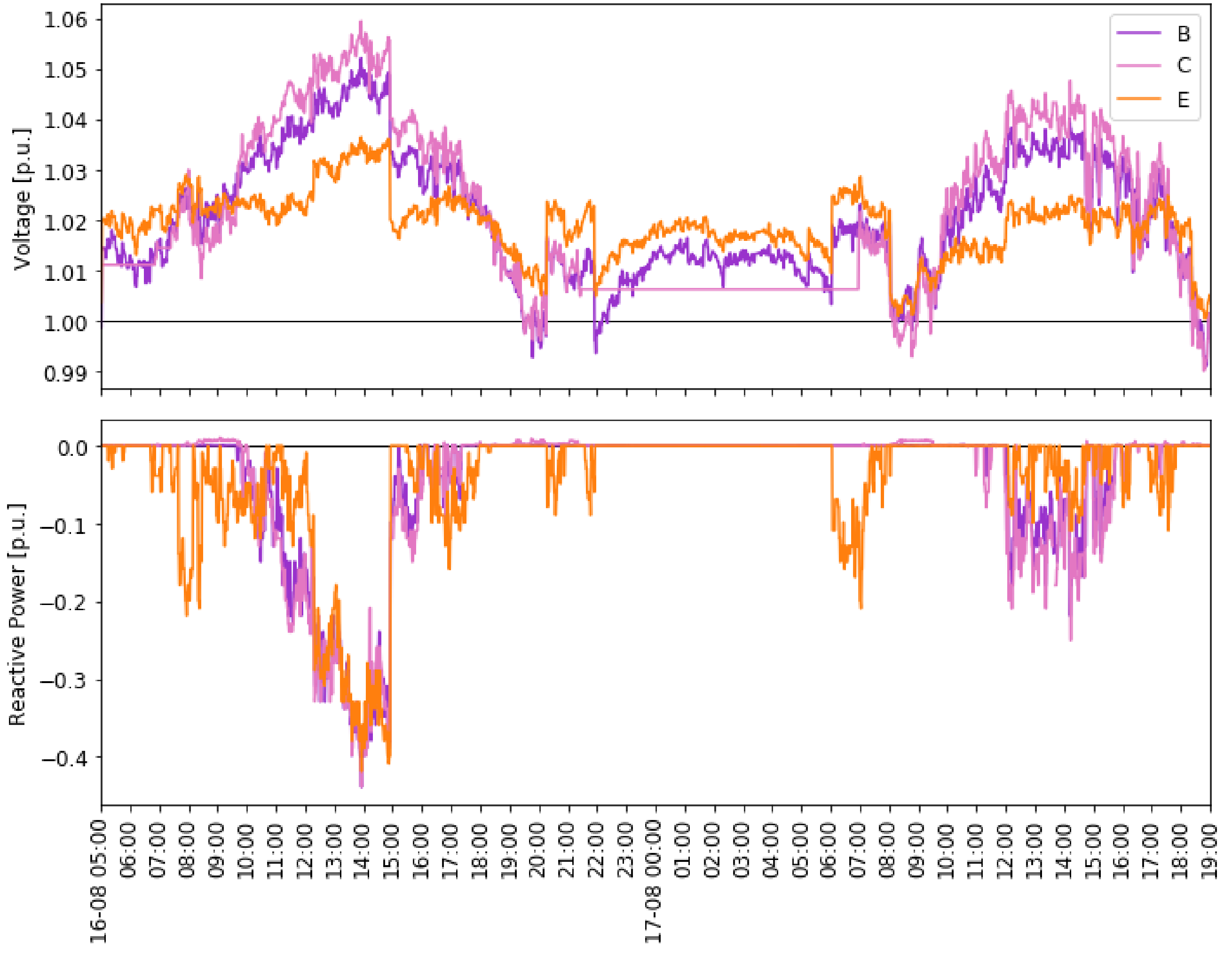
$Q(U)$ Characteristic Curve





Field Test Results

Reactive Power Infeed



Field Test Results

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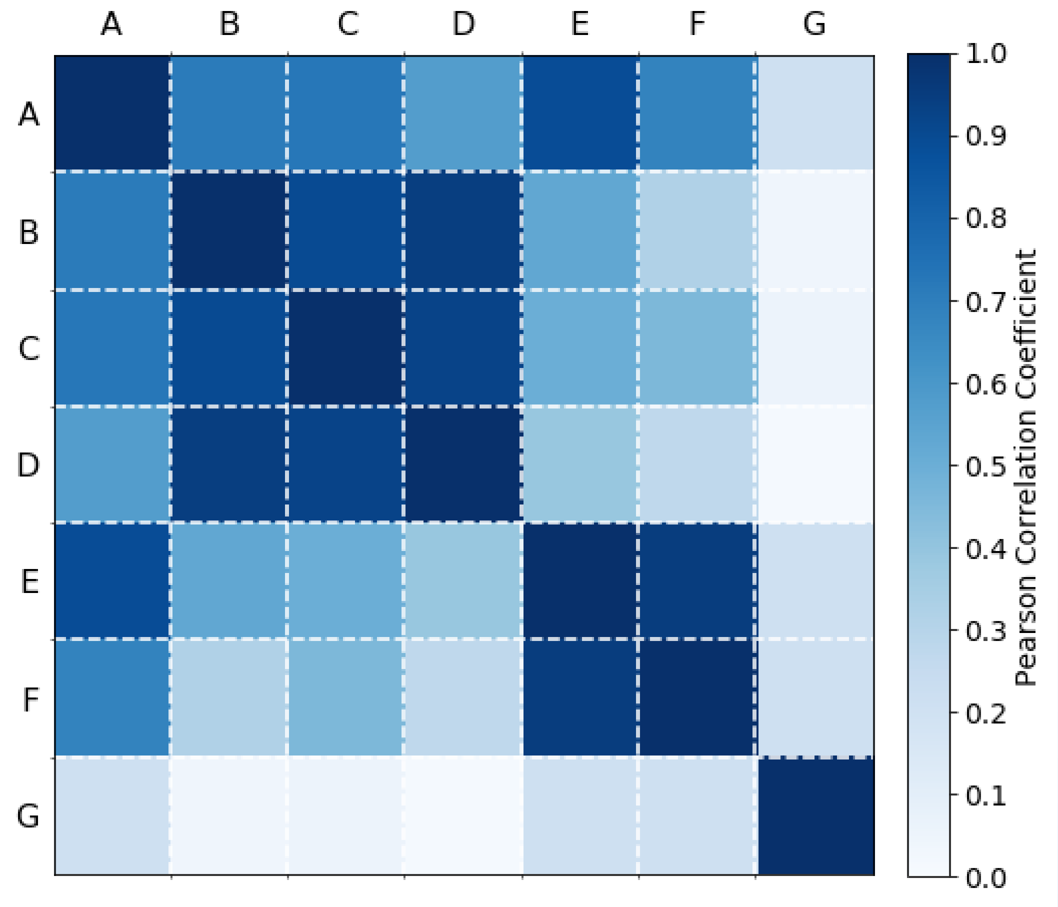
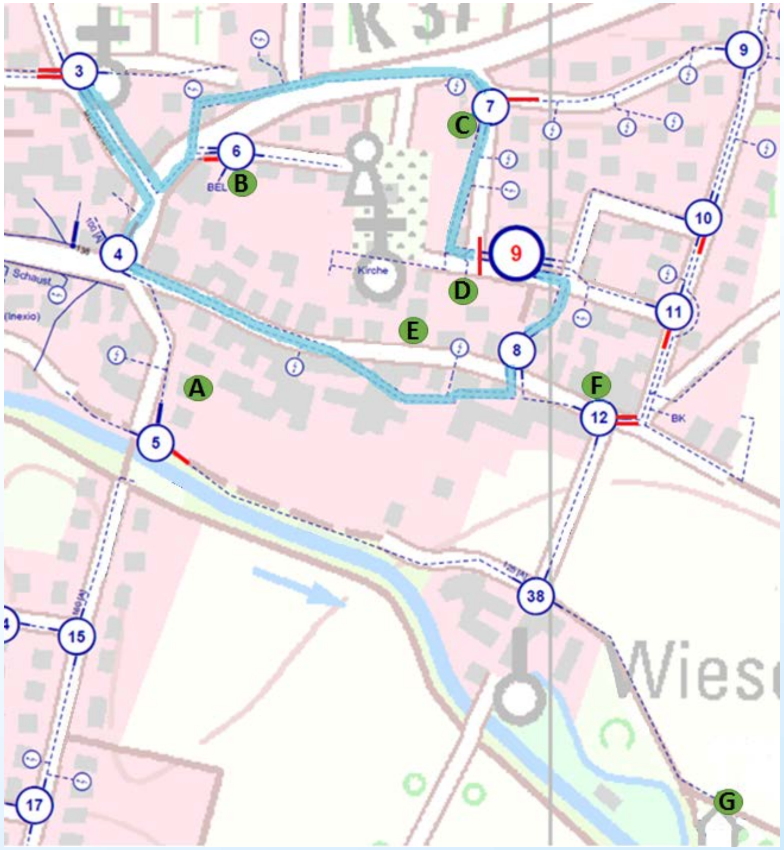
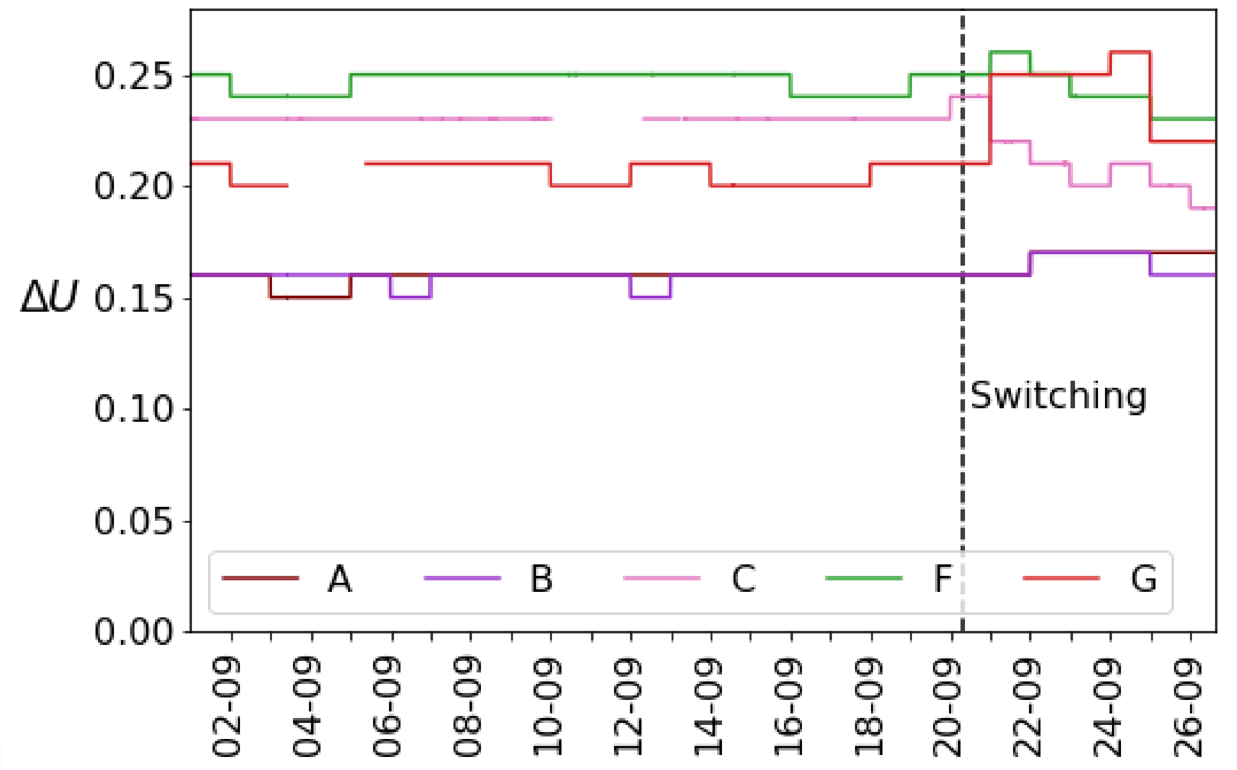
Correlation





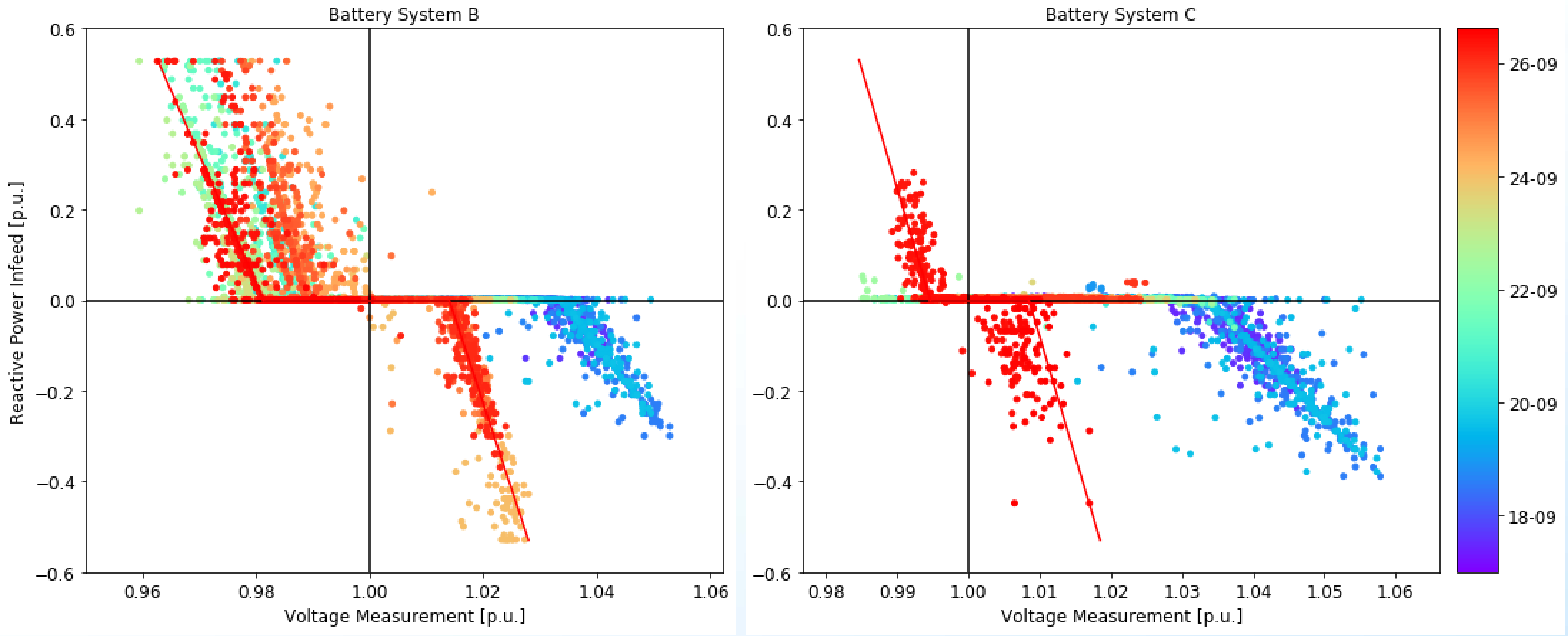
Field Test Results - Switching

Influence on ΔU



Field Test Results - Switching

Reset of the $Q(U)$ Curve



Conclusion and Outlook

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Conclusion

- By an autonomous parameterization of the Q(U) curve, the inverters in a distribution grid are coordinated and help to reduce the voltage to the same extend
- Advantage of a coordinate behaviour: Inverters placed at the beginning of a feeder also help to reduce the voltage although they don’t measure high voltages

Outlook

- Include **active power control**: Cut the midday peak of the PV generation by charging the battery without having a major impact on the self consumption rate
- Building up a communication to the **smart meter gateway**
  → SNOOPI-Box can report voltage deviations to the grid operator
  → the grid operator can access and control the battery or PV system remotely
- **Final outcome**: Device which reduces the voltage considerably by controlling reactive and active power without impairing the system operator and without the need of any presettings or reconfigurations

THANK YOU FOR YOUR ATTENTION!

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