DG DemoNetz Validierung

Innovative Spannungsregelung von der Simulation zum Feldtest

EnInnov12 - 12. Symposium Energieinnovation,
TU Graz 15-17.02.2012

Matthias Stifter, B. Bletterie, H. Brunner, D. Burnier, H. Sawsan, F. Andrén, R. Schwalbe, W. Tremmel , A. Abart, R. Nenning, F. Herb, and R. Pointner

DG DemoNet

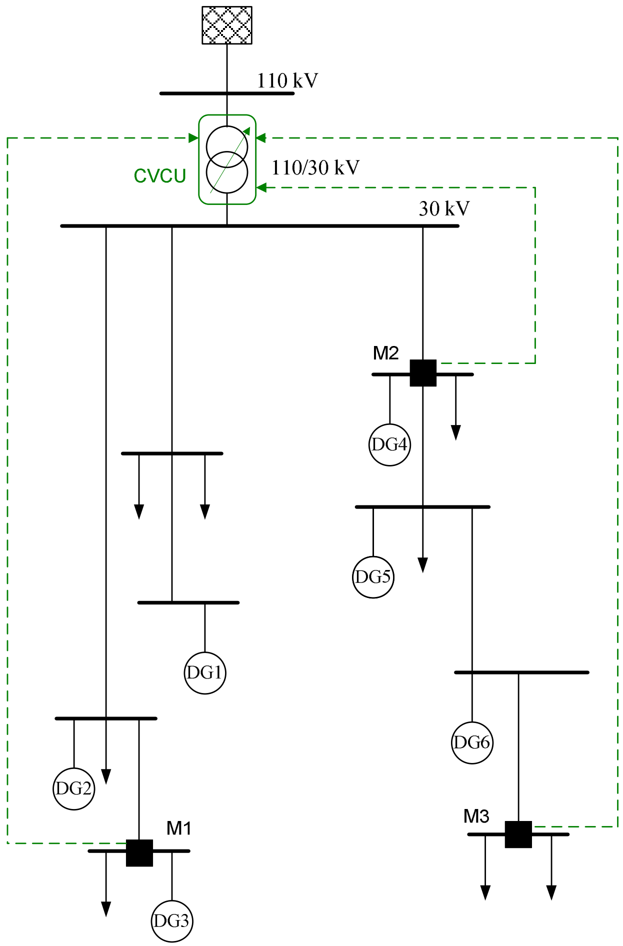
Keeping voltage limits by integration of distributed generation (DG)

DG DemoNet (1)

Distributed control (level control)

- **Control of tap changer** according to **voltage measurements** from the grid (critical nodes)

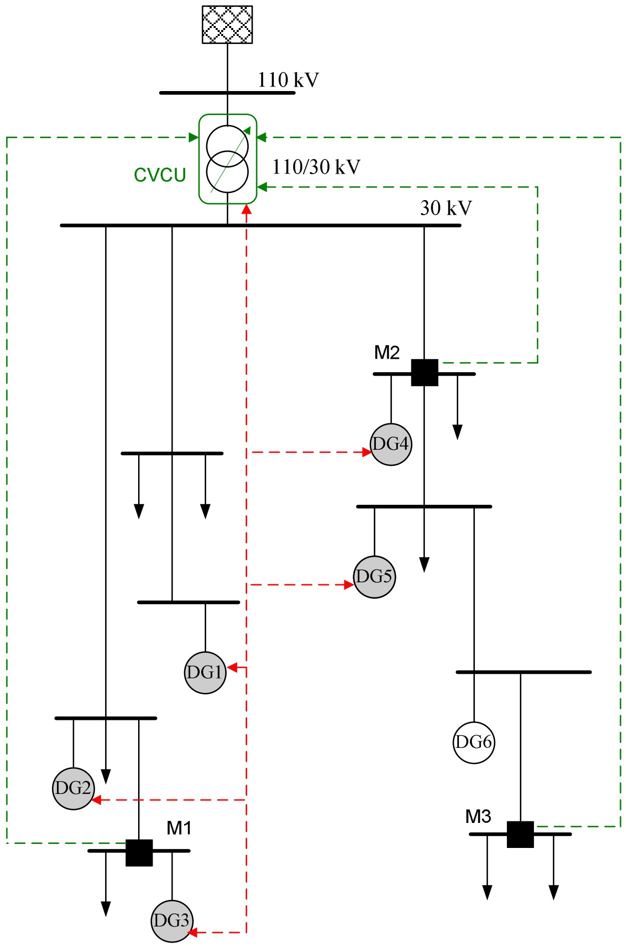
- Information about the grid state is required
  →ICT necessary



DG DemoNet (2)

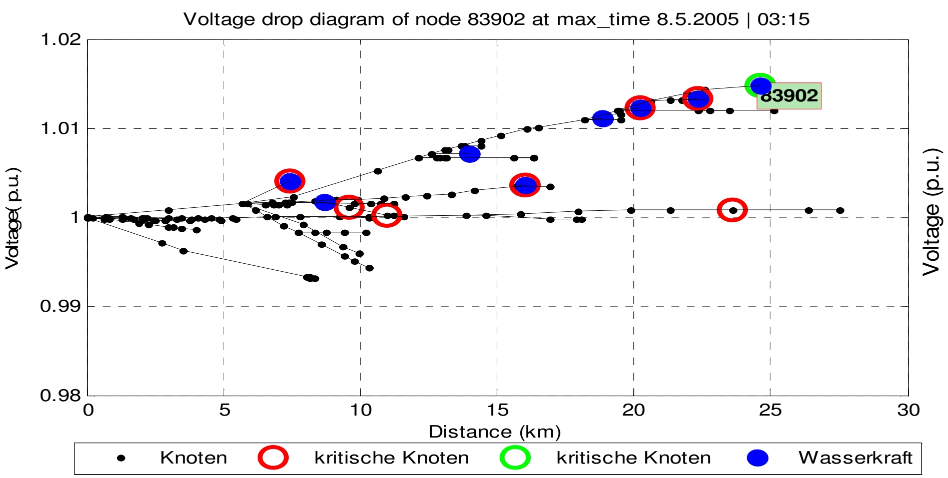
Coordinated control (level + range control)

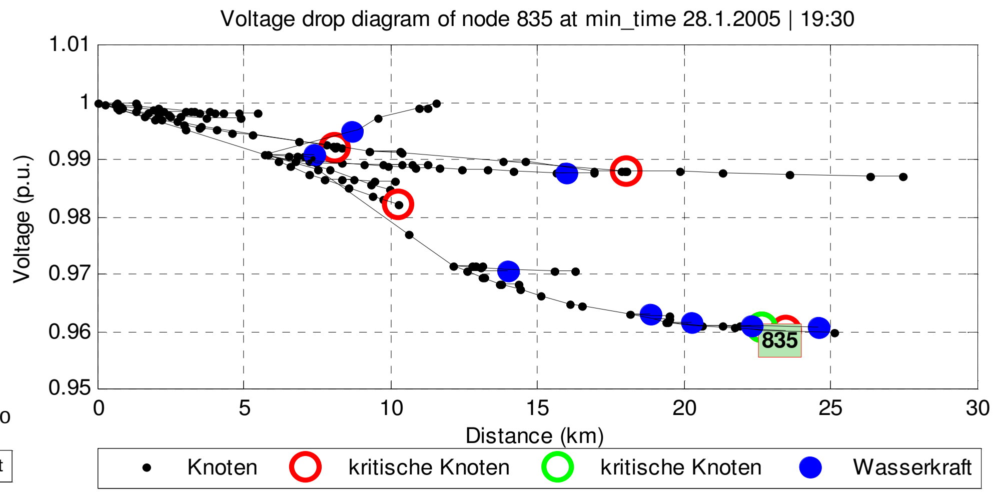
- **Control of tap changer** according to **voltage measurements** from the grid (critical nodes)
- **Control of reactive power (Q)** and as a last measurement **reactive power (P)**
- Impact of Q/P on the critical nodes (voltage sensitivity) are in a linearised model – the **contribution matrix**
- **Local controller** (in case of failure)
- Information about the grid state is required **→ICT necessary**



DG DemoNet – critical nodes

- Nodes which have the **highest** or **lowest** voltage within a year
- Determined by **offline** power flow calculation based on **historical** generation and load profiles
- **Representation of the voltage situation** in the grid during operation





DG DemoNet – contribution matrix

- Linearised model of the network $\Delta \mathbf{U}_{CN} \approx \mathbf{A}_P \Delta \mathbf{P} + \mathbf{A}_Q \Delta \mathbf{Q}$
- With the matrices $\mathbf{A}_P[n \times m]$ and $\mathbf{A}_Q[n \times m]$

CN → $\frac{\partial U}{\partial P}$ CN → $\frac{\partial U}{\partial Q}$

DG ↓

$$\begin{bmatrix} a_{P|1,1} & a_{P|1,2} & \cdots & a_{P|1,m} \\ aP_{P|2,1} & a_{P|2,2} & \cdots & a_{P|2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{P|n,1} & a_{P|n,2} & \cdots & a_{P|n,m} \end{bmatrix}$$

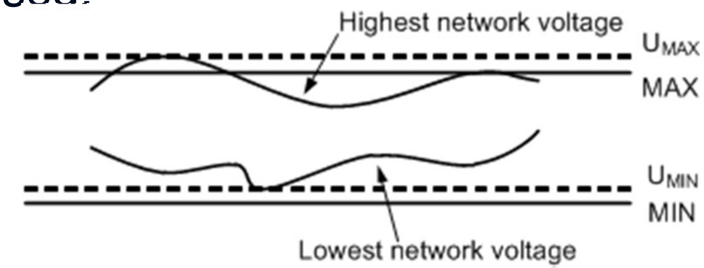
DG ↓

$$\begin{bmatrix} a_{Q|1,1} & a_{Q|1,2} & \cdots & a_{Q|1,m} \\ aP_{Q|2,1} & a_{Q|2,2} & \cdots & a_{Q|2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{Q|n,1} & a_{Q|n,2} & \cdots & a_{Q|n,m} \end{bmatrix}$$

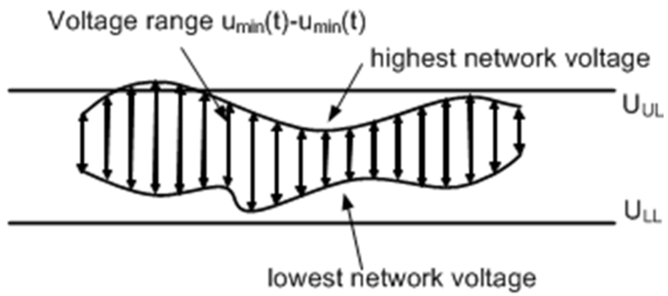
for **active** power and **reactive** power

DG DemoNet – controller concept

- The following indicators are used:
  - **over voltage**
  - **voltage band**
  - **lower voltage**

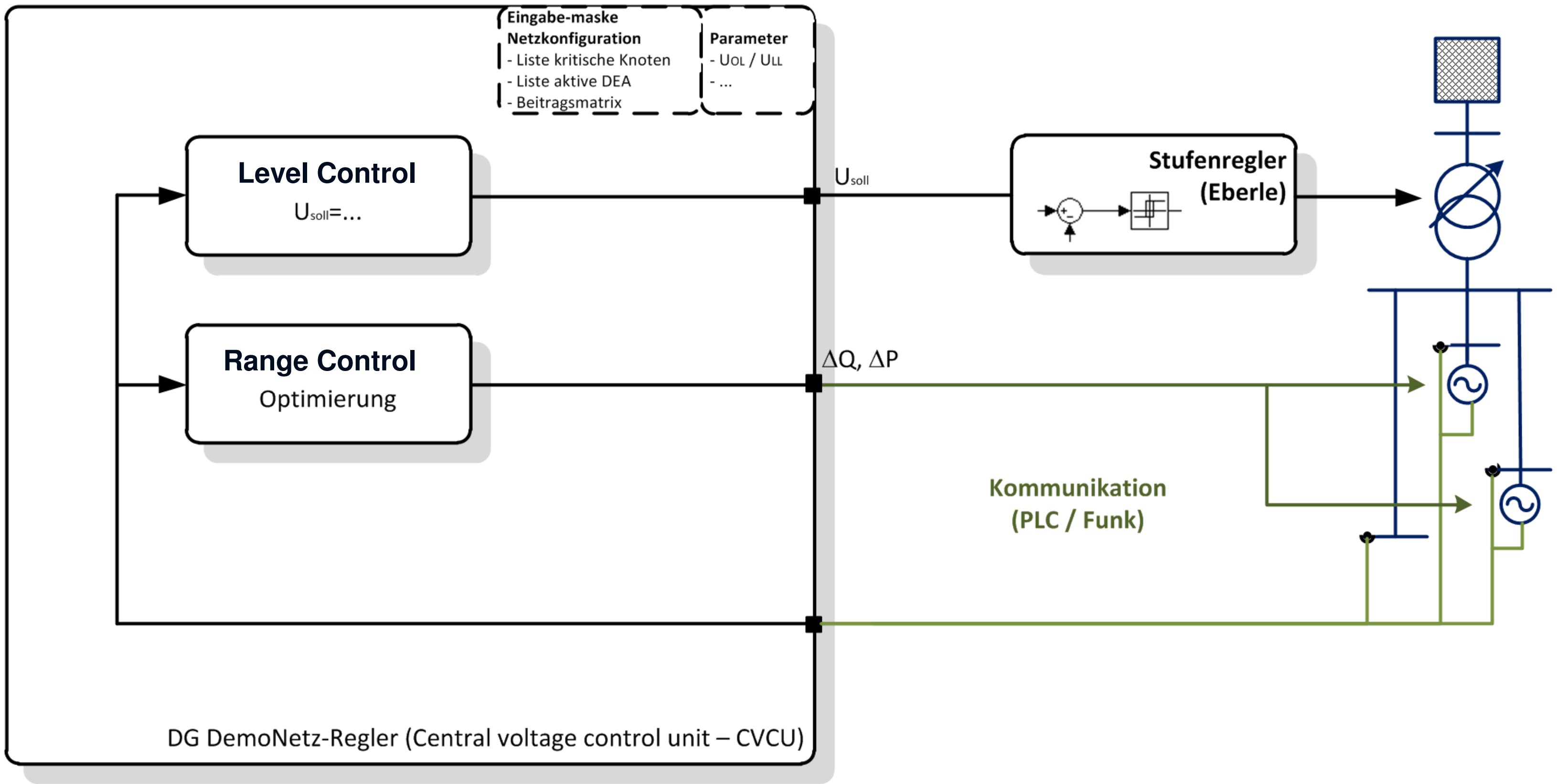


  - **range**: distance between highest and lowest voltage measurement



- Two separate controllers:
  - **level control**: tap changer position at the substation
  - **range control**: control of Q(P) at the distributed generator (if the range is greater than the voltage band)

DG DemoNet – controller design



DG DemoNet – level control

- Level control (centered)

$$U_{set} = U_{UL} - \frac{EVB - Rng}{2} - (u_{max} - u_{curr}) \qquad (1)$$

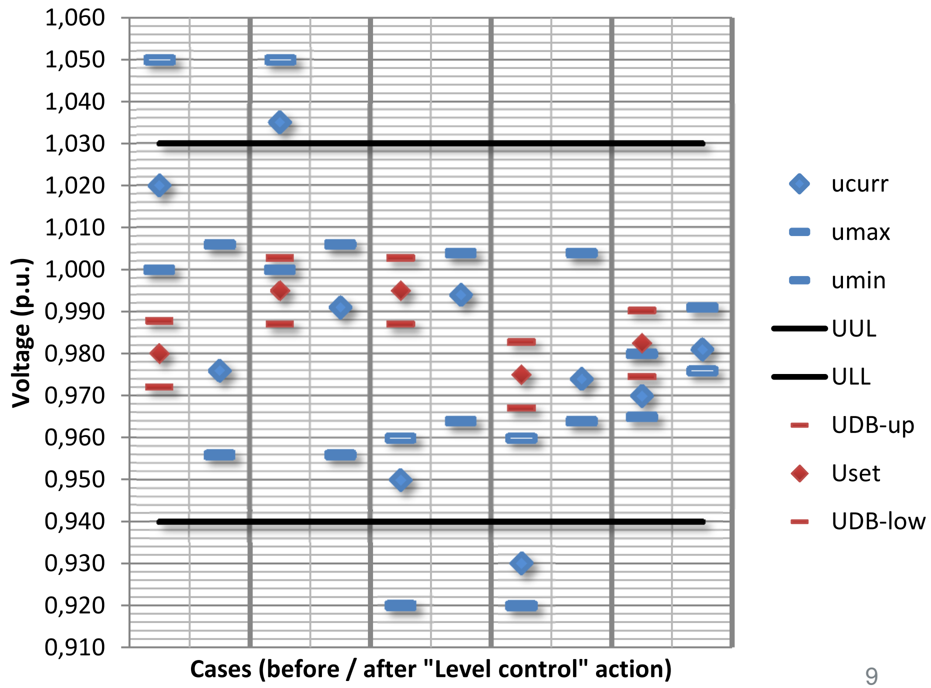
$$Rng = u_{max} - u_{min} \qquad (2)$$

Effective Voltageband

$$EVB = VB - \Delta U_{DB}$$

$$\Delta U_{DB} = \frac{\Delta U_{TAP}}{k_{DB}} = \frac{0{,}011}{0{,}7}$$

- modes of operation
  - centered
  - upper limit
  - lower limit
  - tap only if necessary



DG DemoNet – range control

- Range control

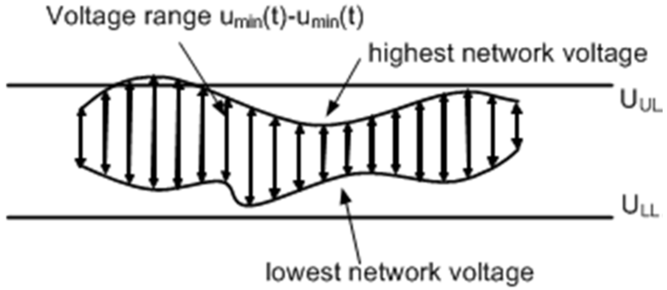
$$\min_{\Delta Q} \sum_{i=1}^{n} (Q_i + \Delta Q_i)^2 \qquad (3)$$

$$|Q_i + \Delta Q_i| \leq P_i \tan(\arccos(PF_{\min})) \qquad (4)$$

$$|Q_i + \Delta Q_i| \leq \sqrt{S_n^2 - P_i^2} \qquad (5)$$

$$\max(U_i + AQ\Delta Q_i) - \min(U_i + AQ\Delta Q_i) \leq EVB \qquad (6)$$

$$EVB = VB - \Delta U_{DB} - \Delta U_{reserve} \qquad (7)$$

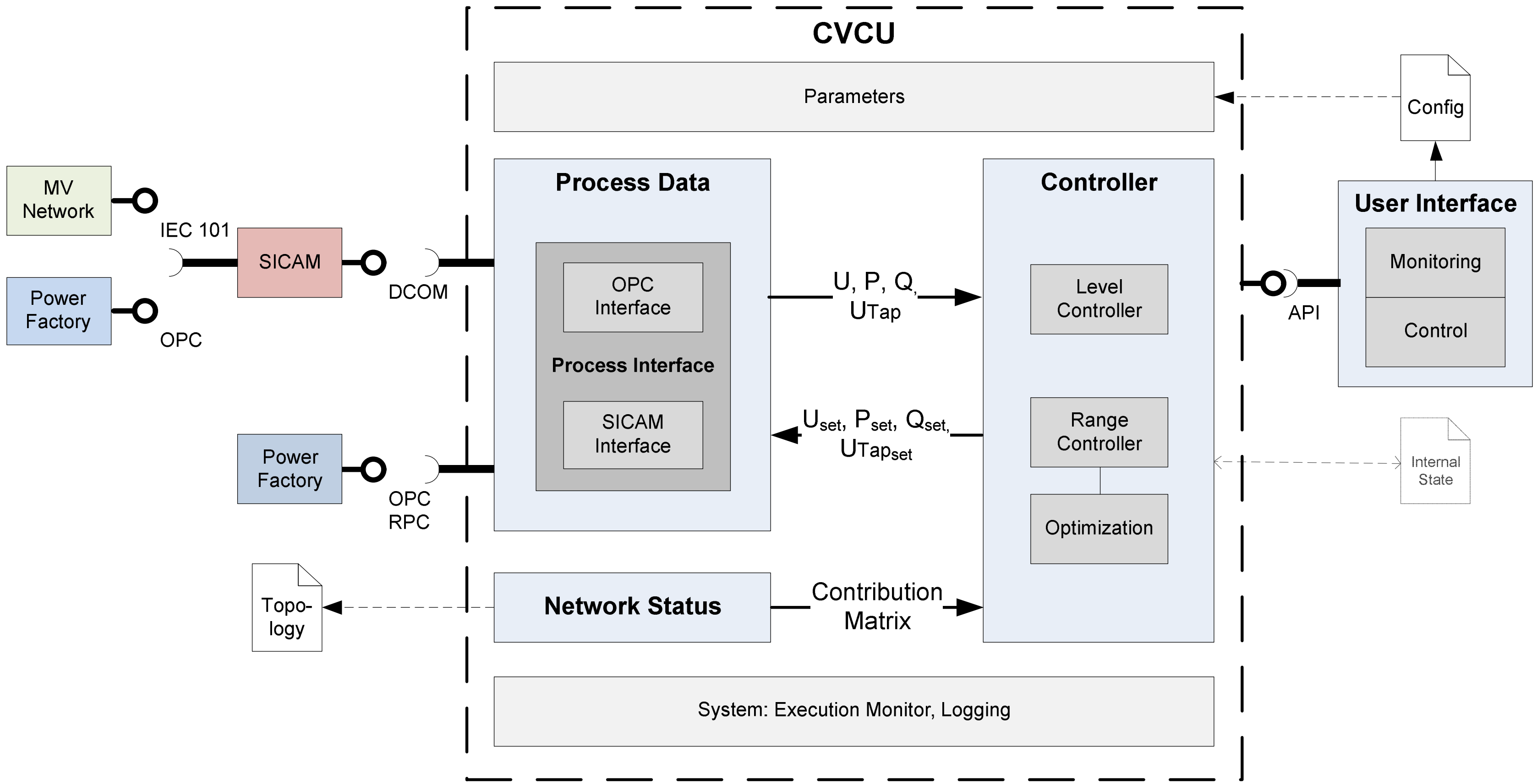


- standalone (without level control)
  - keep within **fixed** voltage band
    → fixed critical node
  - limit voltage rise **relative** to reference node

DG DemoNet implementation (CVCU)

System architecture

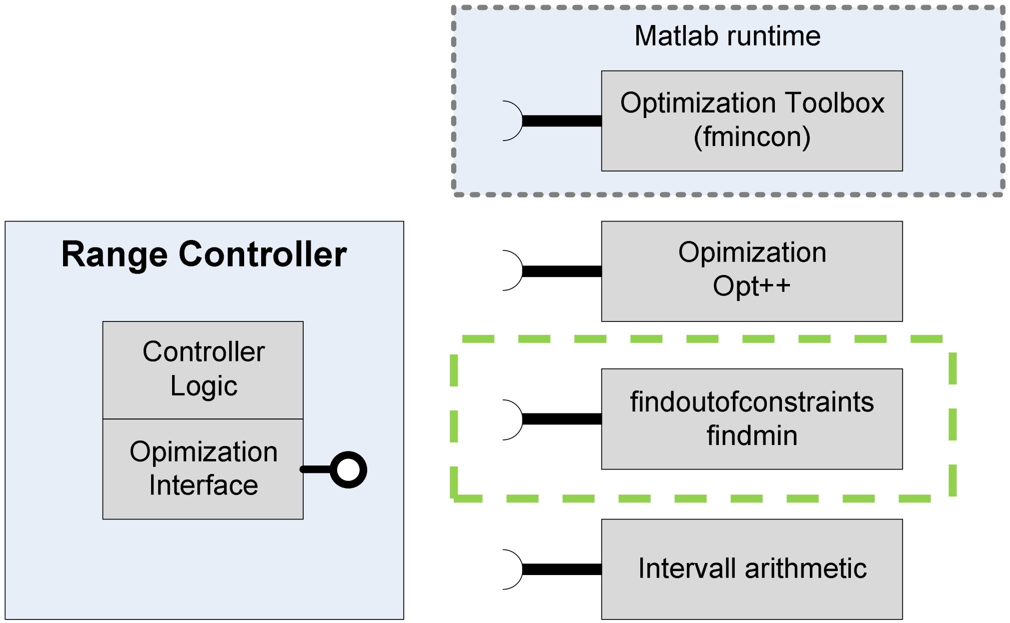
CVCU system architecture



Optimisation

Minimum of a nonlinear function under linear constraints

- Commercial optimisation library Matlab (Optimisation Toolbox)
- Intervallarithmetic (with University of Vienna)
- Open Source Optimisation library (Opt++)
- Development of an optimisation algorithm (constraints + minimum)



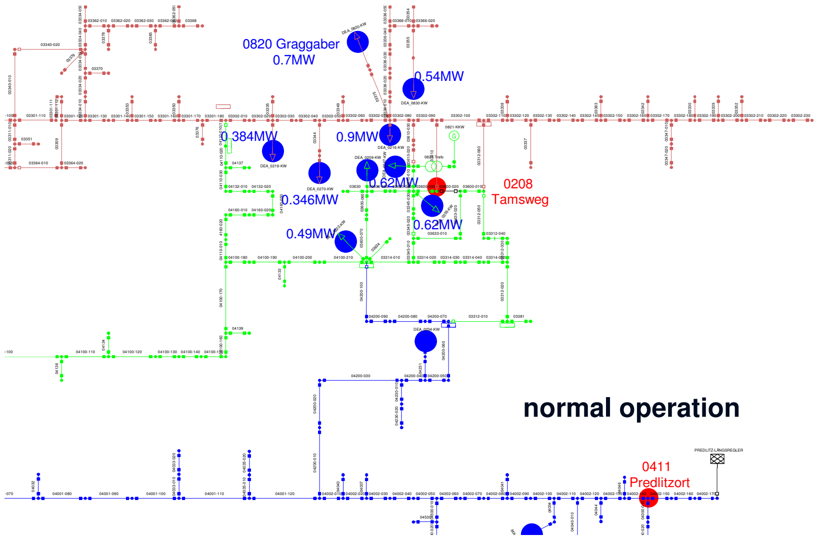
Optimisation algorithm: principle

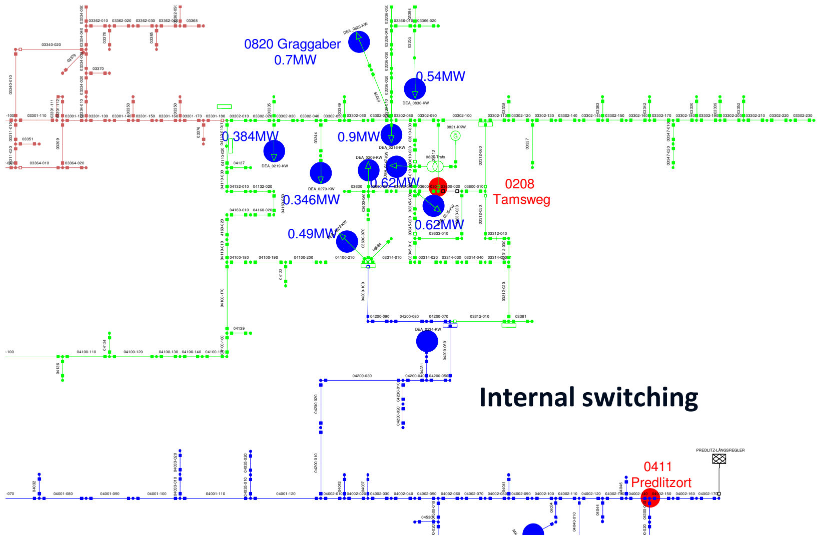
- **Minimum** of a **nonlinear function** under **linear constraints** (Q-control) or **nonlinear constraint** (PQ-control)
  - *convex* problem
    - Constraints define convex polyeder, where the valid minimum can be found
    - Minimum is always definite
  - Solution by declining gradients

- Two steps to solve **two different problems**
  1. *Find the valid area*
  2. *Optimum without leaving the area*

Requirement on topology information

- Information about Critical Node (CN) / Distributed Generation (DG)
  - connection status
  - feeder assignment (DG → CN)
  - intra-feeder changes





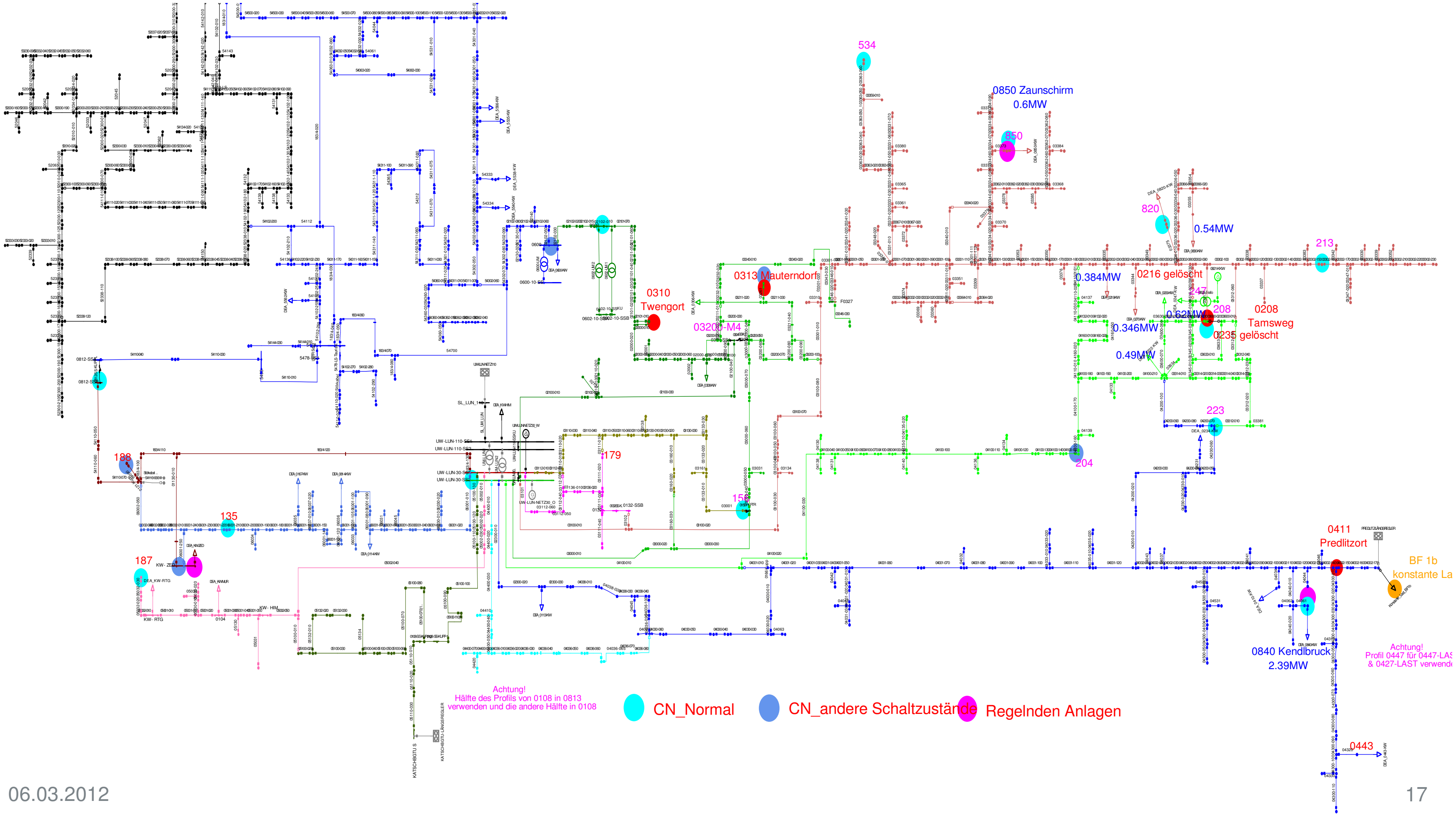
Simulation

Real time behaviour and offline simulation

AUSTRIAN INSTITUTE OF TECHNOLOGY

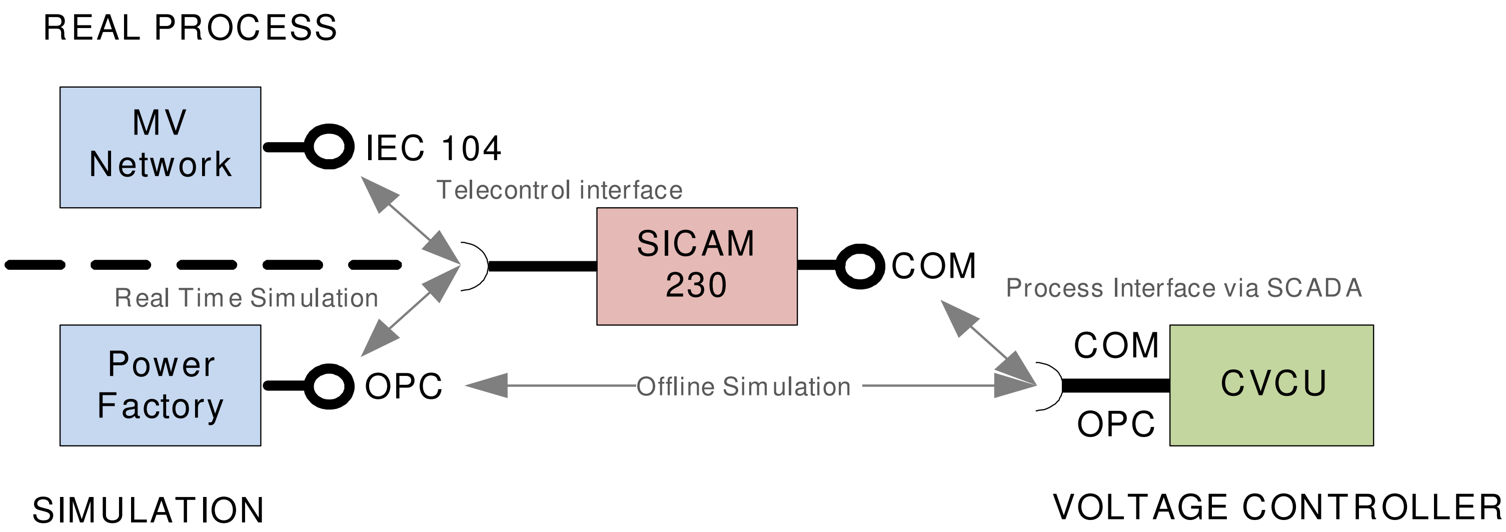
Simulation and testing

- Distribution network „Lungau“



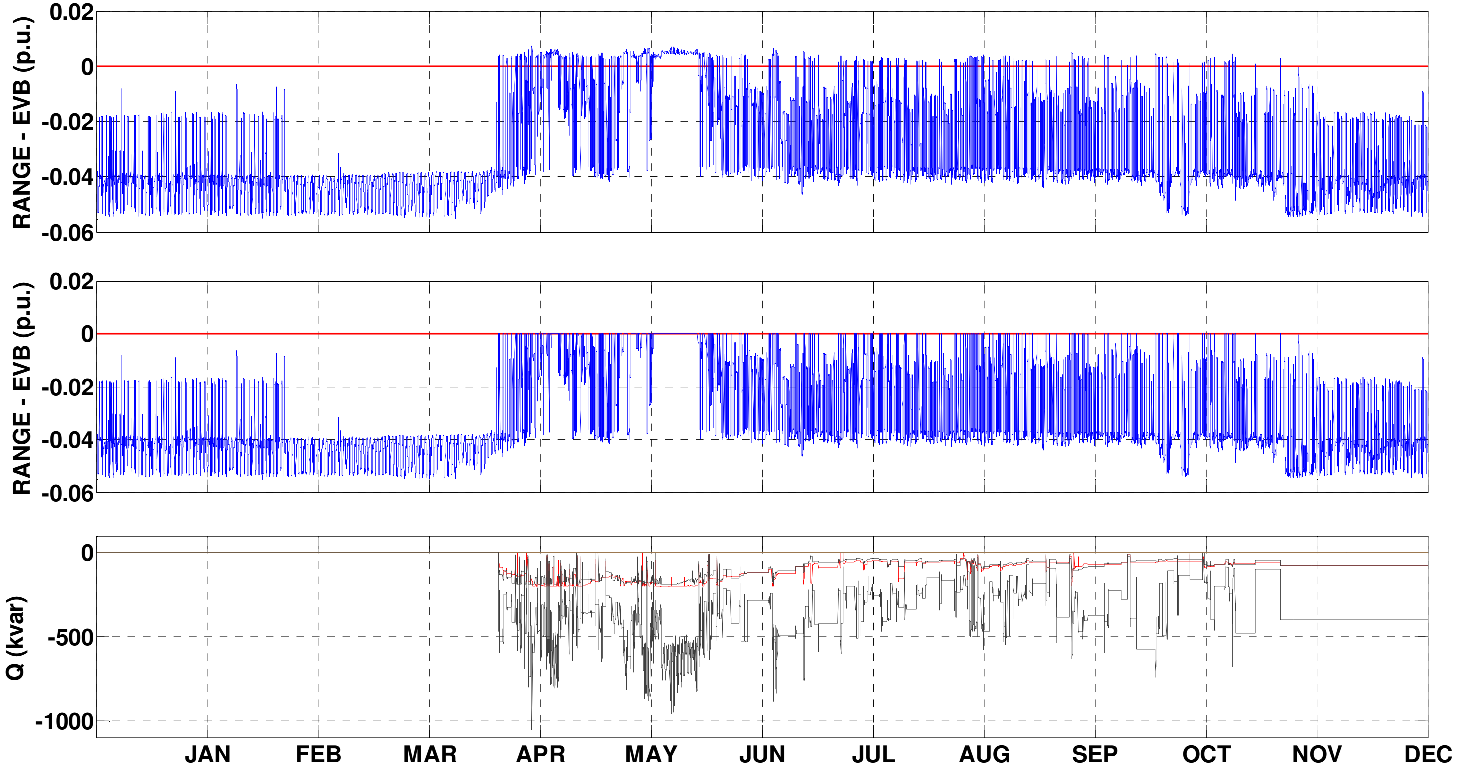
Simulation and testing

- Application in planning and operation



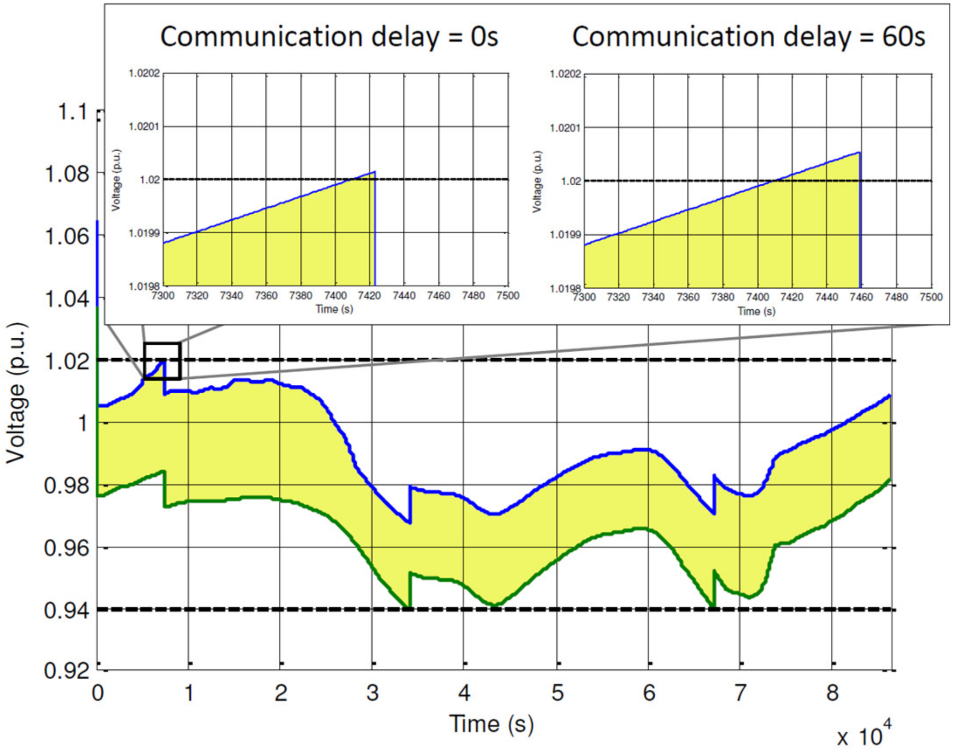
Offline simulation

- **Offline-Simulation**: Simulation and analysis of functionality
  - One year



Realtime simulation

- **Dynamic simulation**
  - controller cycles
  - latency in communication
  - generators and transformer (OLTC)

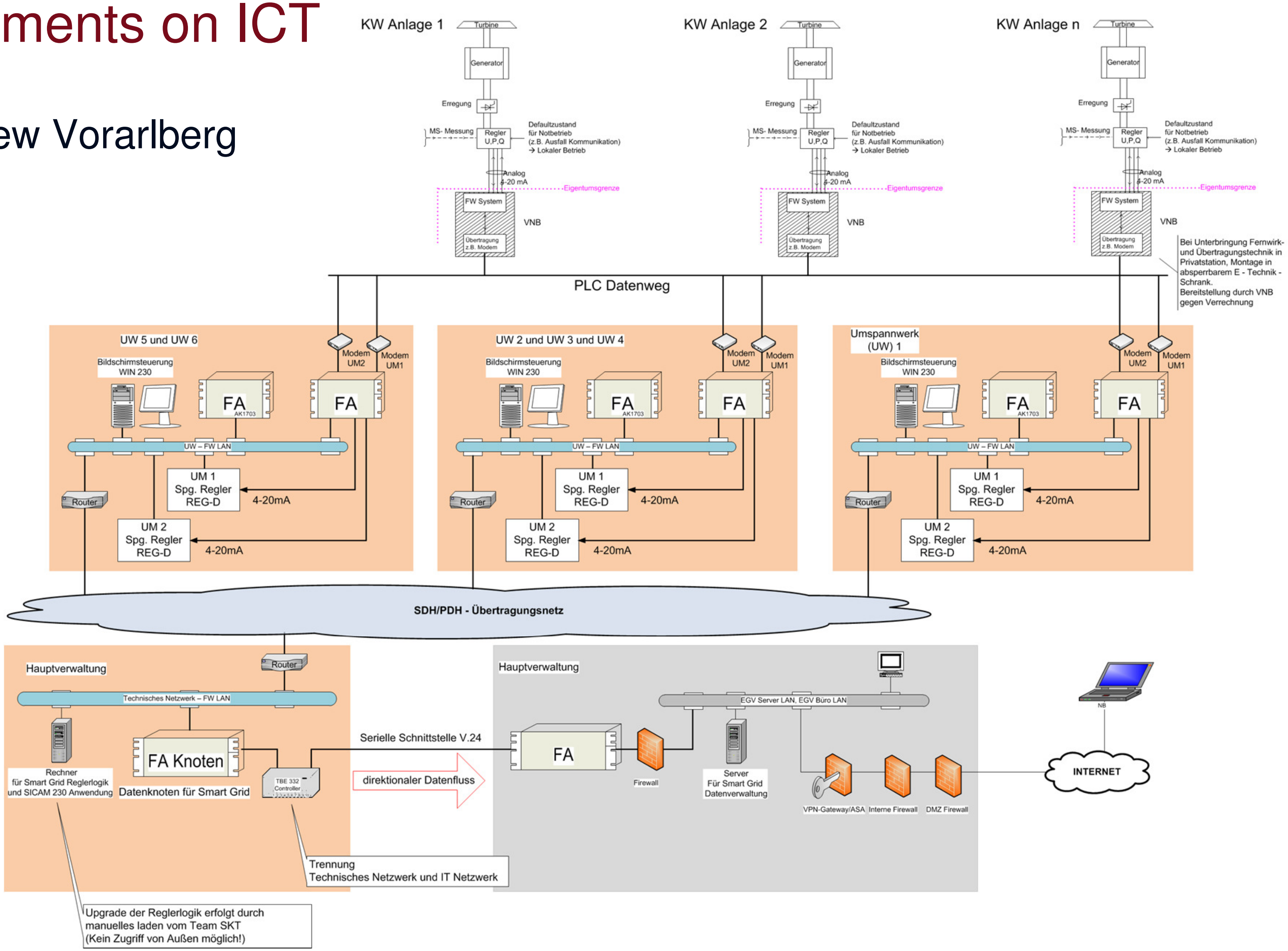


Field tests

Open loop and closed loop tests

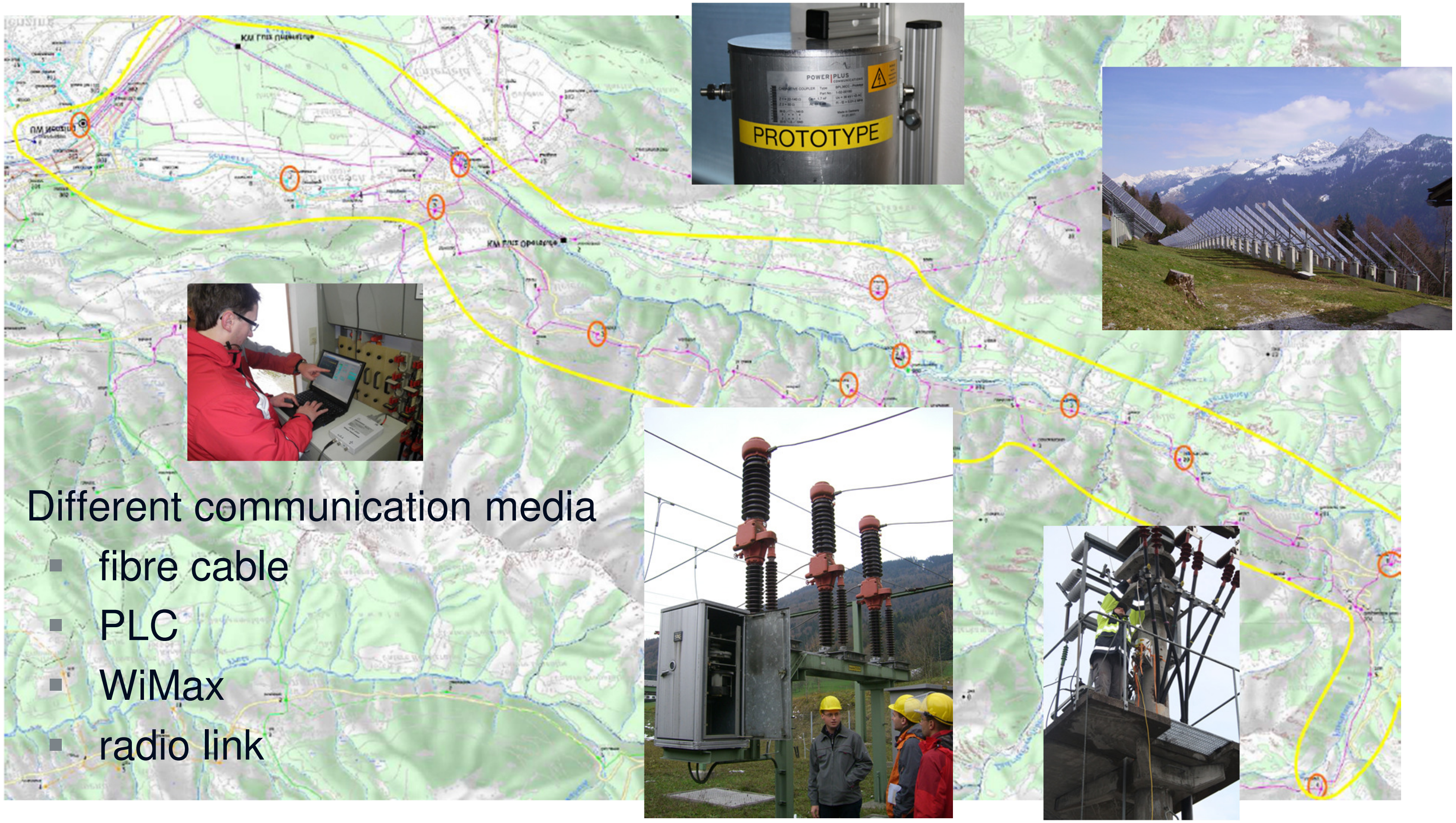
Requirements on ICT

- Overview Vorarlberg



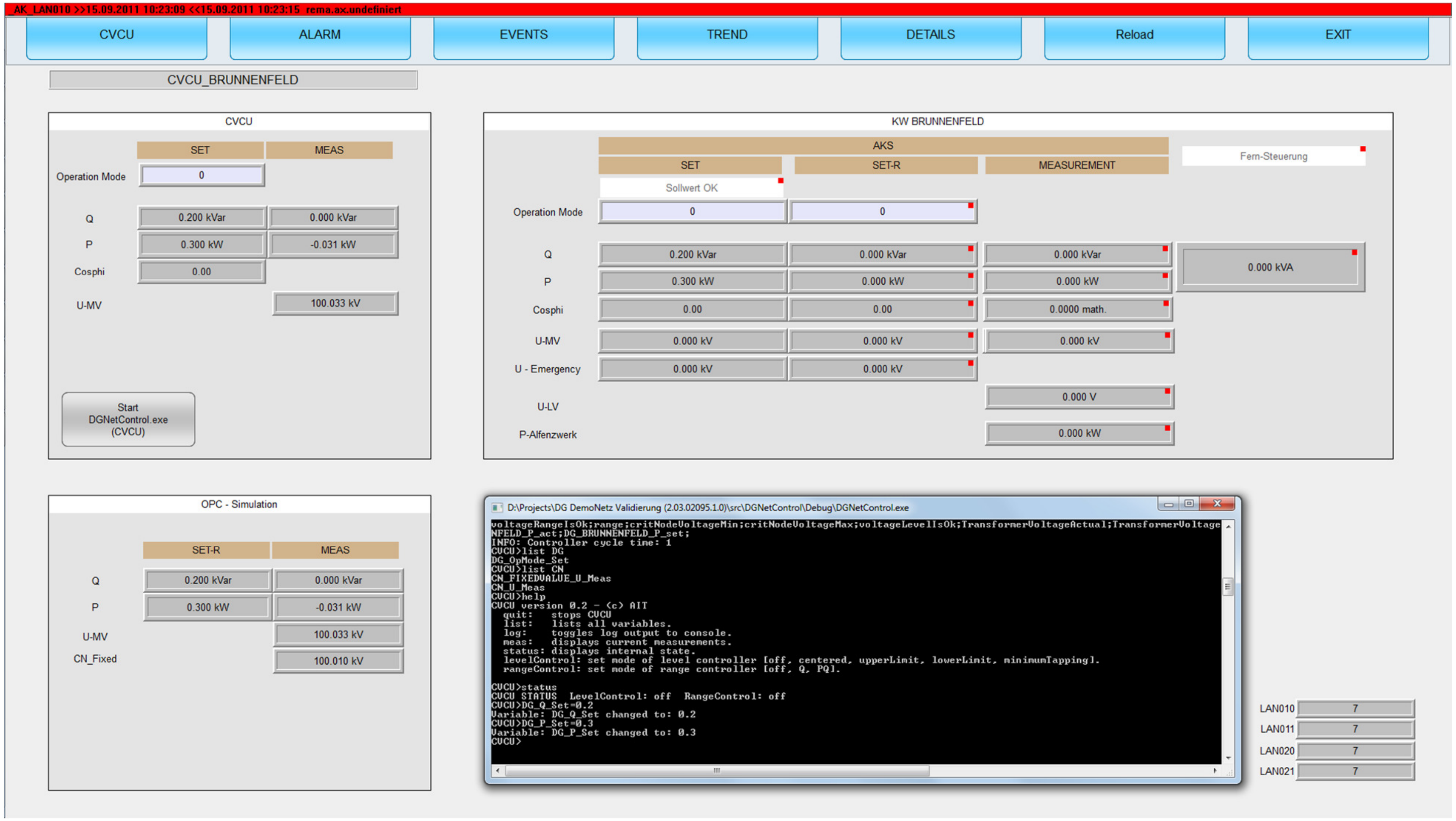
Communication

- Großes Walsertal



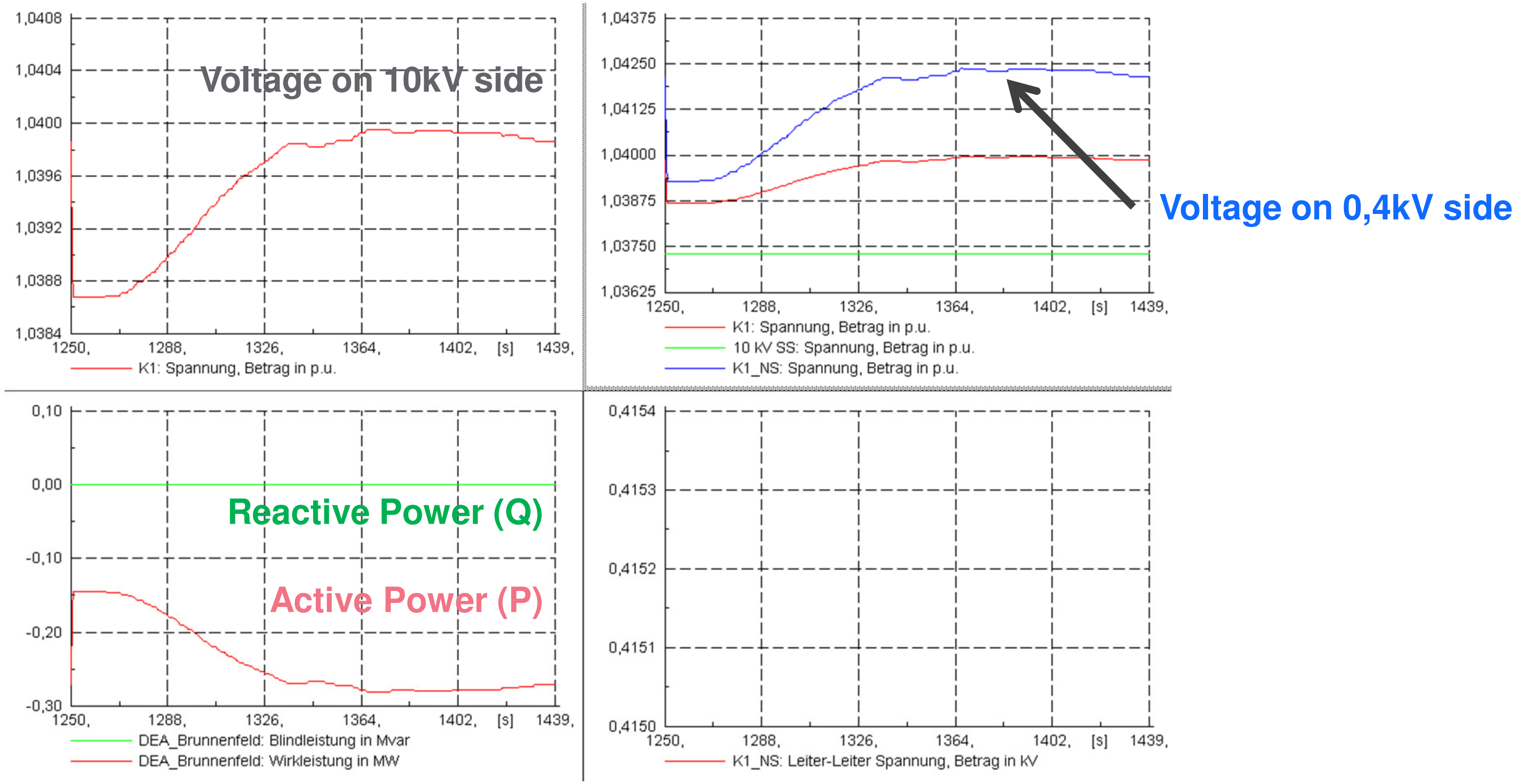
- Different communication media
  - fibre cable
  - PLC
  - WiMax
  - radio link

Field test - DG Brunnenfeld / Substation Bürs



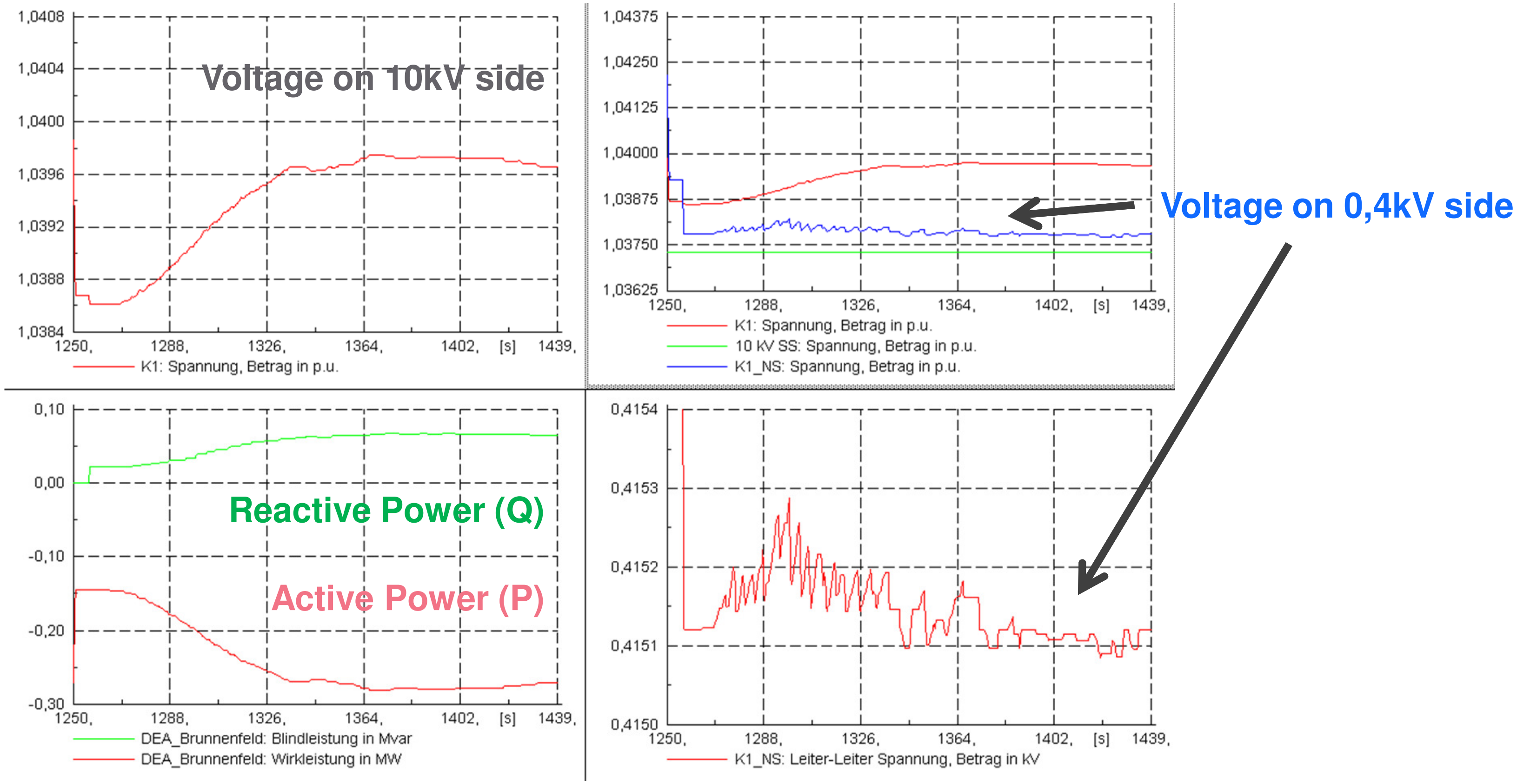
Field test DG Brunnenfeld (Substation Bürs)

- Without range control



Field test DG Brunnenfeld (Substation Bürs)

- With range control



Experiences from the field tests

- dUTap: **Voltage step of a tap is not linear**: 1,667% at 110kV/30kV nominal

→ Depending on primary voltage and the current tap position

- Lungau: **Narrow voltage band**. Range not controllable and higher than EVB

→ Danger of „Hunting“: Adaption of the controller algorithm

- **Different communication bandwidths** and **delays of measurements**

→ Event filtering and analysis of timestamps

- **Tresholds** to reduce communication bandwidth and keep the dynamic low
- **Filtering** of measurement samplings
- **Deviations** of setpoints and actual measurements – robustness

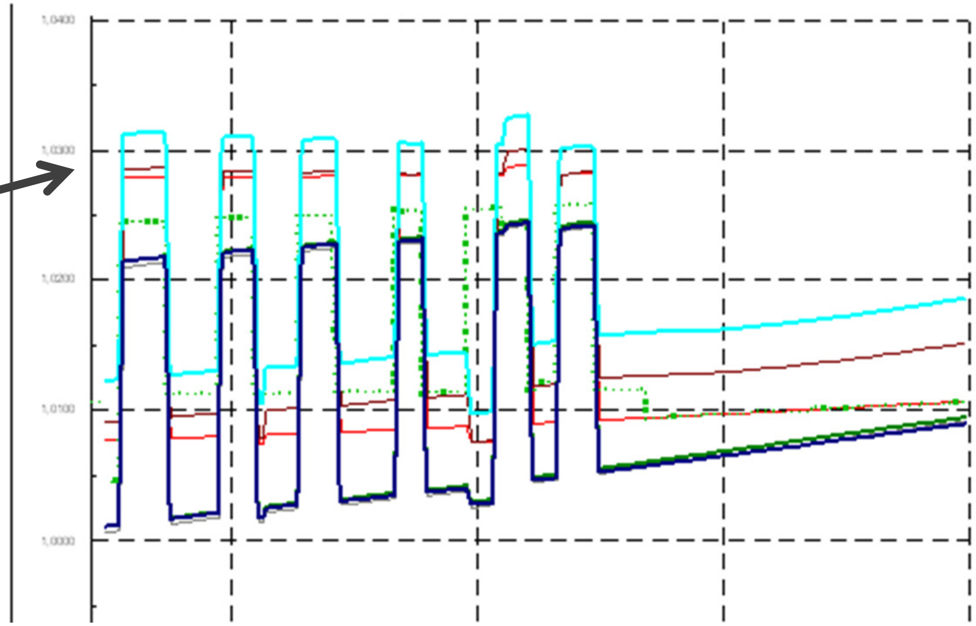
Comparision of the tap steps

$$U_{MS} = \frac{U_{NMS}}{U_{NHS} + k \cdot \Delta U_{TAP}} \cdot U_{HS}$$

	Salzburg		Vorarlberg	
	dU_{Tap}	Minimales $U_{Deadband}$	dU_{Tap}	Minimales $U_{Deadband}$
Nennwert Neutralstellung	1,667%	2,000%	1,062%	1,274%
-10 Taps von Neutralstellung	1,96%	2,35%	1,17%	1,40%
+10 Taps von Neutralstellung	1.43%	1,72%	0,96%	1.15%

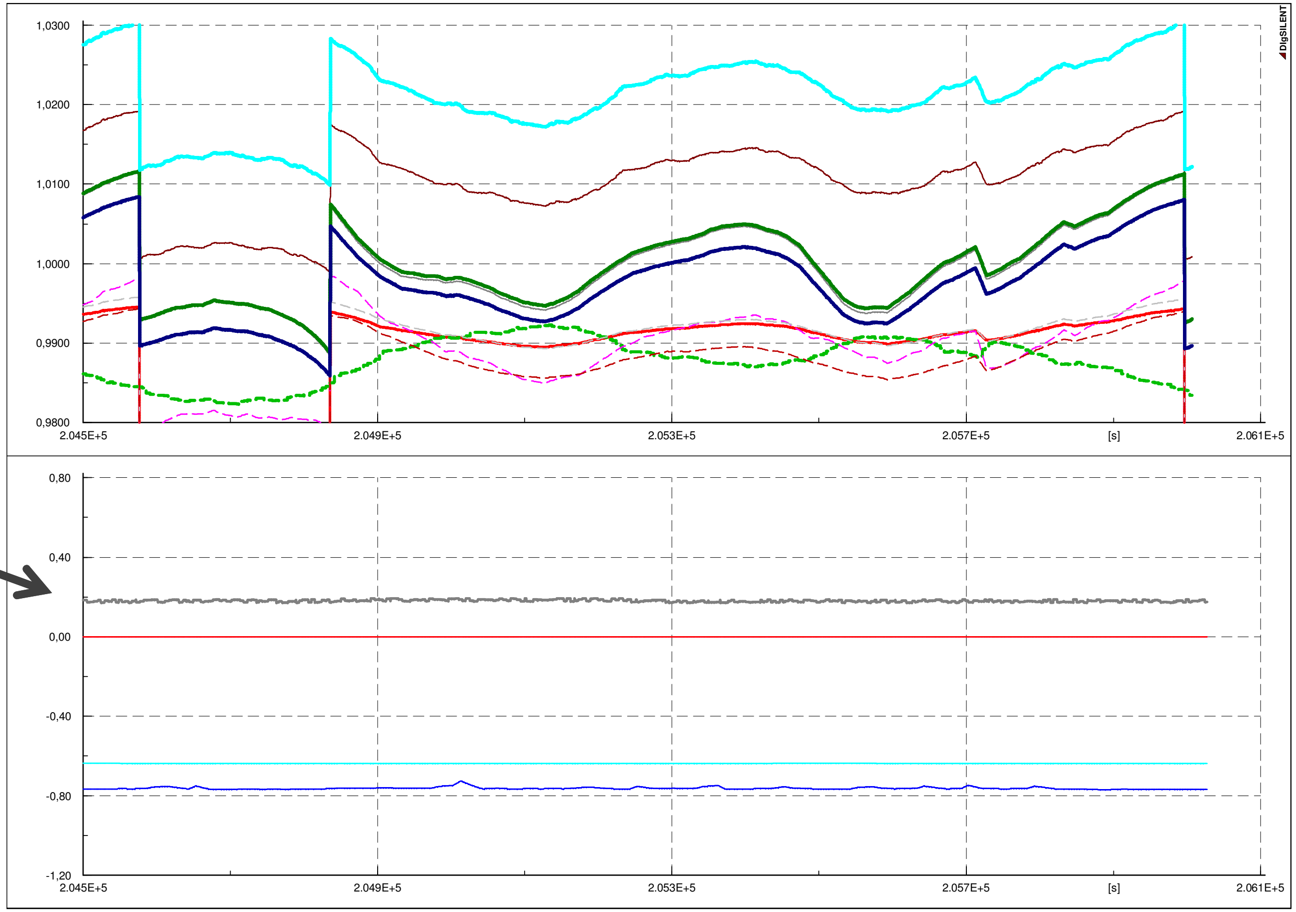
„Hunting effect“ (wrong dU_{Tap})

- Real dUTap is higher than estimated and voltageband is violated



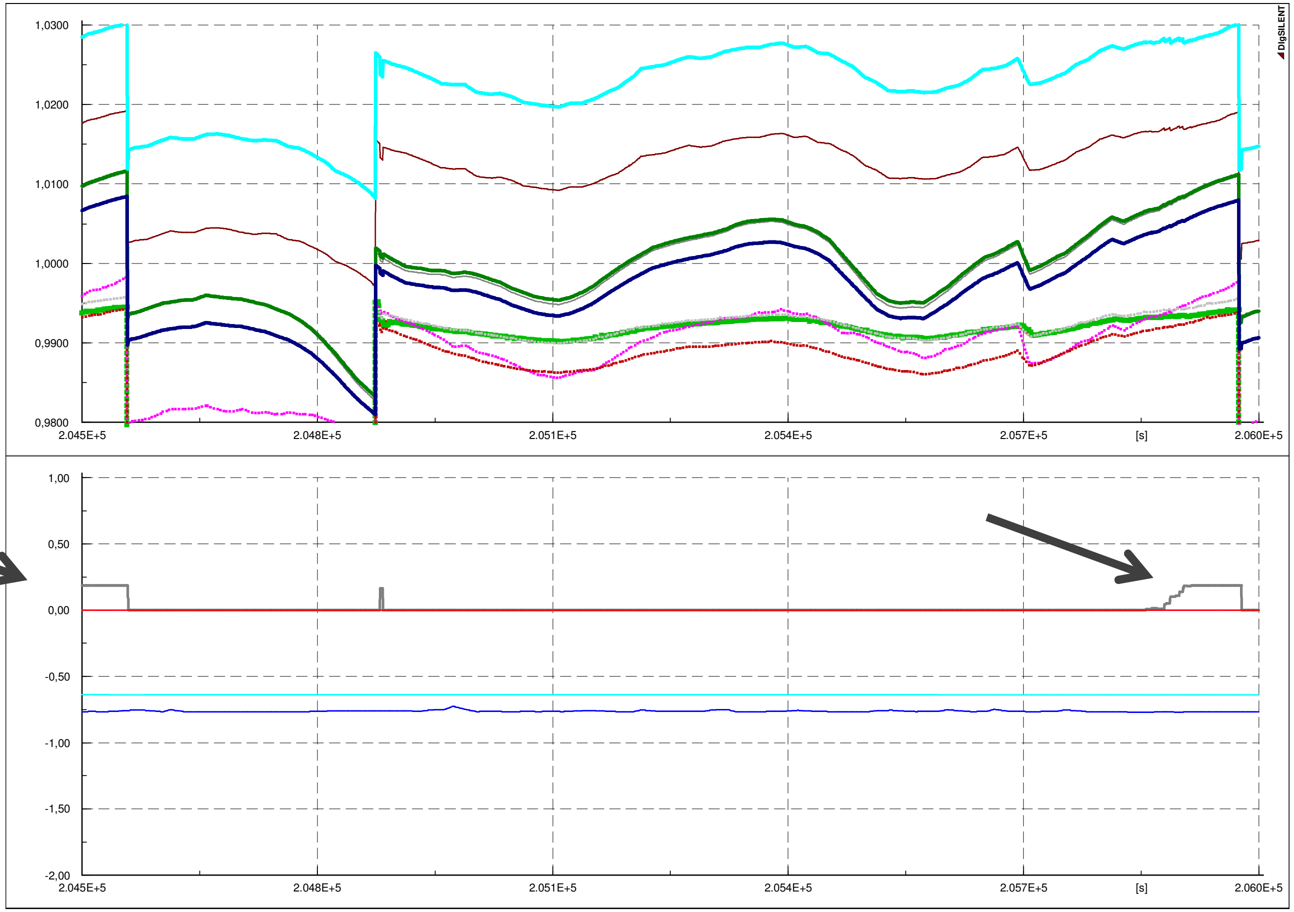
Control strategy: Effective voltage band (independent)

- Range control tries to keep voltages within EVB with Q from the DG



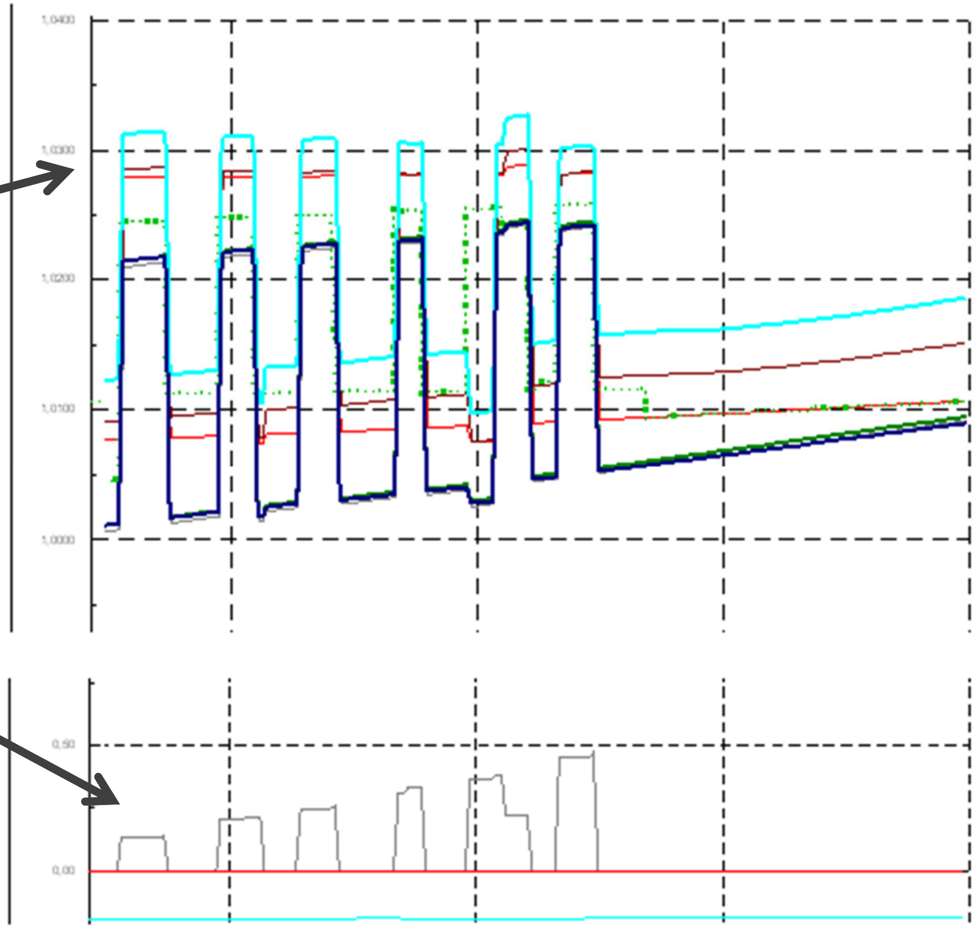
Control strategy: Full voltage band (cooperative)

- Range control only activates Q when voltage limits are to get violated

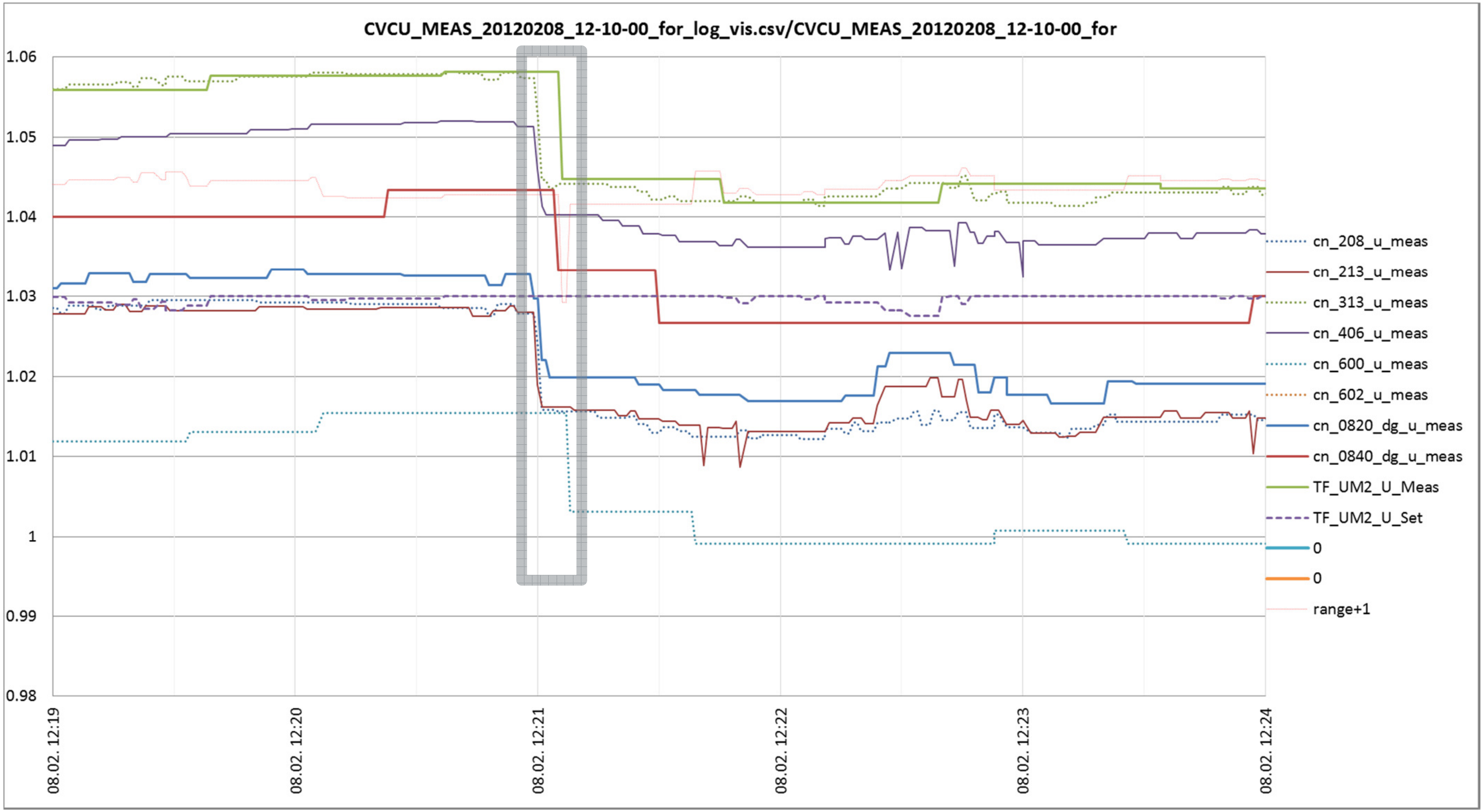


„Hunting effect“ (wrong dU_{Tap})

- Real dUTap is higher than estimated and voltageband is violated
- Range control activates DG to consume Q to keep voltages within limits

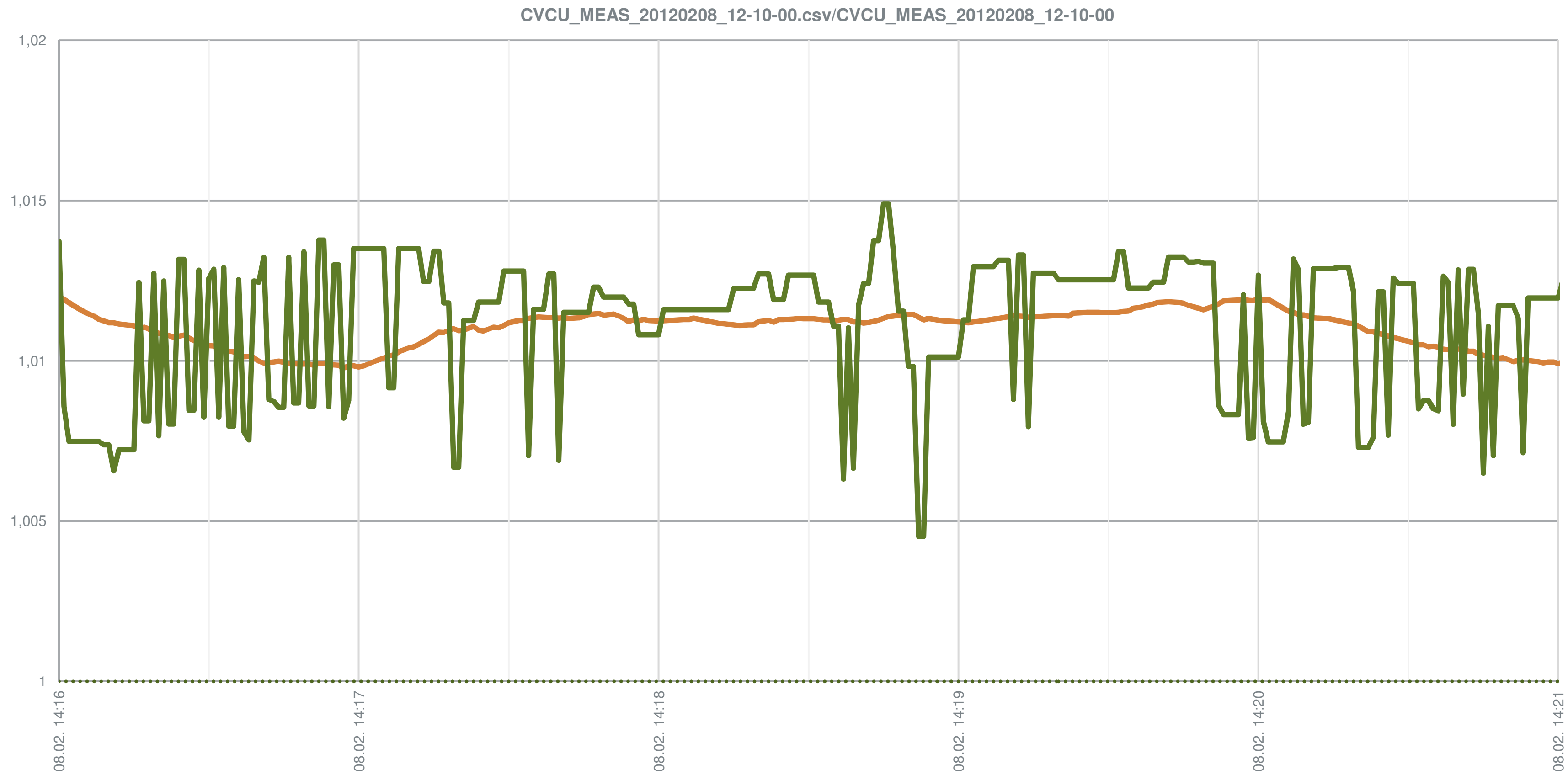


Communication delay of measurements



Filering

- E.g.: 1min RMS



Outlook

Next steps

Outlook

DG DemoNet Validation

- **Open und closed loop operation** in „Großes Walsertal“ and „Lungau“
  → experiences and long term tests
- Mastering **different network states**
  → topology recognition
- Interaction with **local controller**
- Strategies to **start and stop** the controller
- **Analyse** influence of the HV grid
- **Interoperability** with other simulation and SCADA systems
  → Communication based on IEC61850
- **Optimise overall losses** (reactive power)
- Consider **thermal constraints** in addition to voltage constraints
- **Dynamic** assessment of voltage sensitivity / topology
  → coupling with state estimator

AIT Austrian Institute of Technology

your ingenious partner

Matthias Stifter

Energy Department

Electric Energy Systems

AIT Austrian Institute of Technology

Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.H.

Giefinggasse 2 | 1210 Vienna | Austria

T +43(0) 50550-6673 | M +43(0) 664 81 57 944 | F +43(0) 50550-6613

matthias.stifter@ait.ac.at | http://www.ait.ac.at

Zusätzliche Folien

Backup

„Range Control“: Beitragsmatrix-Konzept

$$\frac{\partial U}{\partial P} \qquad \frac{\partial U}{\partial Q}$$

$$\begin{bmatrix} a_{P|1,1} & a_{P|1,2} & \cdots & a_{P|1,m} \\ aP_{P|2,1} & a_{P|2,2} & \cdots & a_{P|2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{P|n,1} & a_{P|n,2} & \cdots & a_{P|n,m} \end{bmatrix} \qquad \begin{bmatrix} a_{Q|1,1} & a_{Q|1,2} & \cdots & a_{Q|1,m} \\ aP_{Q|2,1} & a_{Q|2,2} & \cdots & a_{Q|2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{Q|n,1} & a_{Q|n,2} & \cdots & a_{Q|n,m} \end{bmatrix}$$

- In der Beitragsmatrix wird in der CVCU hinterlegt wie groß die Auswirkung einer regelbaren Erzeugungsanlage auf die Spannungen an den einzelnen kritischen Knoten ist (Basis für die Verkleinerung der Spreizung)
- Entsprechend der Reihung in der Beitragsmatrix werden Blindleistungssollwerte an die Anlagen gesendet bis die Spreizung der Spannung der kritischen Knoten wieder innerhalb des zur Verfügung stehenden Spannungsbandes liegt bzw. so klein ist, dass eine Stufenschaltung (über den Level Controller) möglich ist

„Range Control": Berechnung der Blindleistungssollwerte für die zu regelnden Anlagen

Minimiere $\sum_{i}^{n\_DG} (Q_i + \Delta Q_i)^2$

unter den Randbedingungen

$$0.94 < \begin{bmatrix} U_{CN1} \\ U_{CN2} \\ \vdots \\ U_{CNn} \end{bmatrix} + \begin{bmatrix} \Delta U_{CN1} \\ \Delta U_{CN2} \\ \vdots \\ \Delta U_{CNn} \end{bmatrix} = \begin{bmatrix} U_{CN1} \\ U_{CN2} \\ \vdots \\ U_{CNn} \end{bmatrix} + \begin{bmatrix} a_{Q|1,1} & a_{Q|1,2} & \cdots & a_{Q|1,m} \\ a_{Q|2,1} & a_{Q|2,2} & \cdots & a_{Q|2,m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{Q|n,1} & a_{Q|n,2} & \cdots & a_{Q|n,m} \end{bmatrix} \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \vdots \\ \Delta Q_m \end{bmatrix} < 1.03$$

$$|Q_i + \Delta Q_i| \leq P_i \tan(\arccos(PF_{\min}))$$

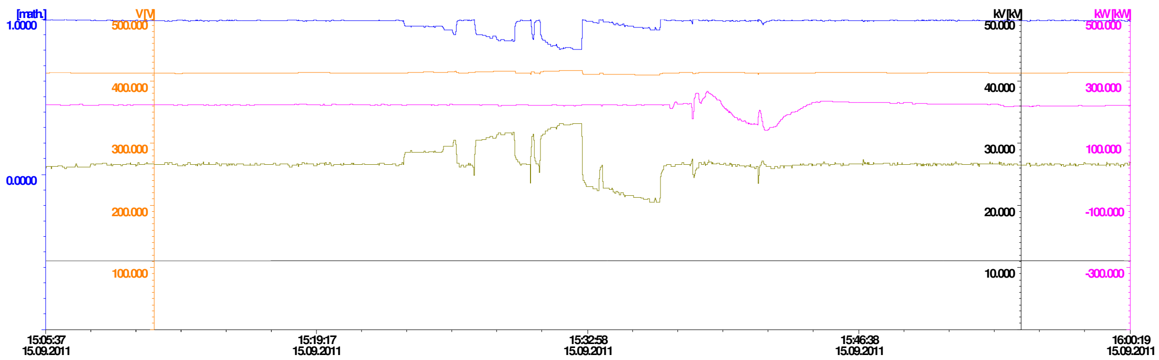
$$|Q_i + \Delta Q_i| \leq \sqrt{S_{i,\max}^2 - P_i^2}$$

Topologieerkennung

- Ausgehend von einem Normalschaltzustand des Netzes müssen Änderungen der Topologie dem Regelalgorithmus mitgeteilt werden, damit die CVCU mit dem richtigen Netzmodell (Beitragsmatrix) arbeiten kann. Die Änderung des Einflusses eines regelbaren Kraftwerks auf die korrespondierenden kritischen Knoten (Messpunkt) kann zu falschen Berechnungen führen.
- Die Anforderungen für den zuverlässigen Betrieb der CVCU an die Fernwirktechnik werden in vier Stufen eingeteilt, wobei die Informationen für die ersten beiden Stufen unbedingt notwendig sind:
  1. Kritischer Knoten (KK) oder regelbares Kraftwerk (rKW) *am Netz.*
  2. Kritischer Knoten (KK) oder regelbares Kraftwerk (rKW) *im Einflussbereich des Umspanners*
  3. Änderung der *Zugehörigkeit zum Abzweig* eines kritischen Knotens (KK) oder eines regelbaren Kraftwerks (rKW)
  4. *Dynamische Ermittlung der Beitragsmatrix* nach Änderung der Topologie

Field test - DG Brunnenfeld (Substation Bürs)

- Set points for reactive and active power



Datum	Kurve	Wert	Einheit	Zust...	Status
15.09.2011 15:29	CN_BRUNNENFELD_U_Meas	11.122	kV		SPONT
15.09.2011 15:29	CN_BRUNNENFELD_U_Meas	415.677	V		SPONT
15.09.2011 15:29	DG_BRUNNENFELD_P_Meas	222.875	kW		SPONT
15.09.2011 15:29	DG_BRUNNENFELD_Q_Meas	134.344	kVar		SPONT
15.09.2011 15:29	DG_Brunnenfeld_Cosphi_math	0.8564	math.		SPONT