Optimized parameter settings of reactive power Q(V) control by Photovoltaic inverter – Outcomes and Results of the TIPI-GRID TA Project

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Presentation at ERIGrid Side Event at IRED 2018 at the AIT, Vienna,16 October 2018

See also talk of C. Messner at 35th EU PVSEC, 24 - 28 September 2018, Brussels

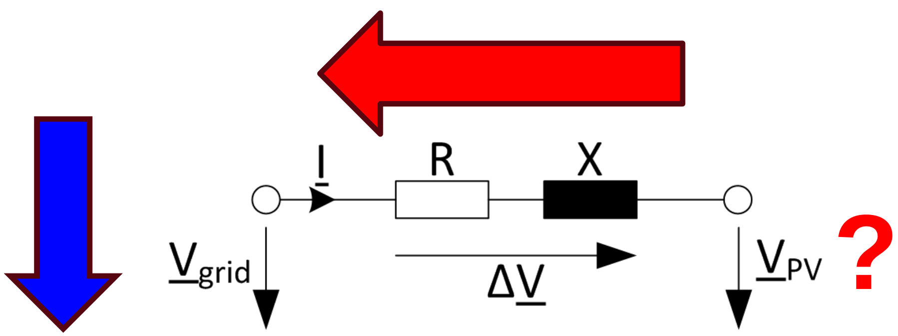
VOLTAGE DEPENDANT ACTIVE AND REACTIVE POWER CONTROL – PQ(V)

Regulations regarding Voltage Rise at PCC:

EN 50160: $\Delta V \leq 10\%$

D-A-CH-CZ Technical Rules: $\boldsymbol{\Delta V \leq 3\%}$

Reduction of ΔV by control of P or Q

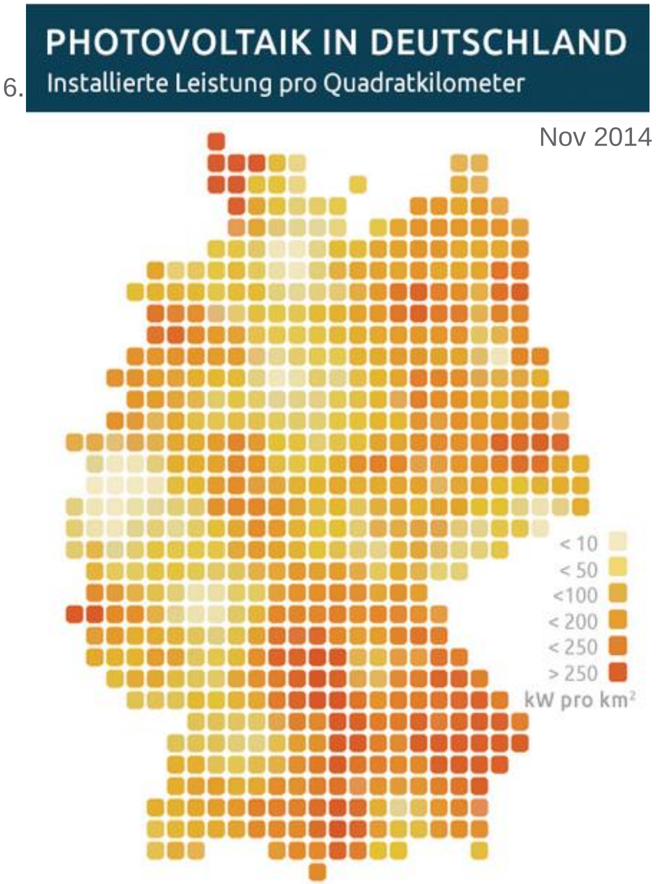


HIGH PV PRODUCTION IN THE GRID STATUS 2014

Markus Niedrist, Fabian Cariget, Franz Baumgartner, Electrosuisse ETG Tagung, Stromnetze, 6.

	Village Germany Dettighofen	Bavaria, Germany	
46%	821 kWp (2014)	11 GWp(2015)	**12%**
	1.55 kWp/Einw.	0.9 kWp/Einw.	

	Germany	Switzerland	
8%	40 GWp (2015e)	1.3 GWp (2015e)	**2%**
	0.5 kWp/Einw.	0.2 kWp/Einw.	

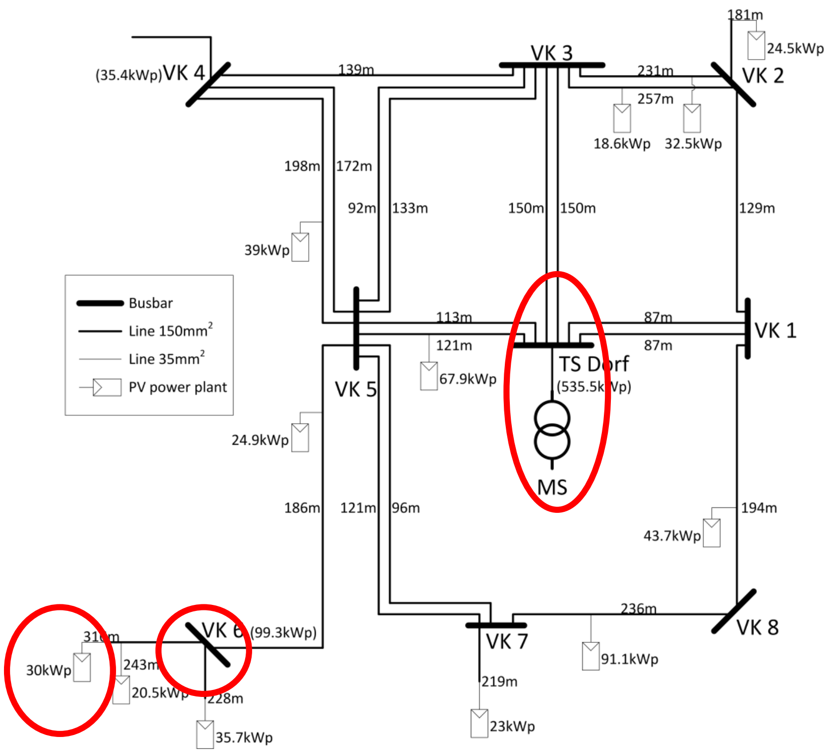


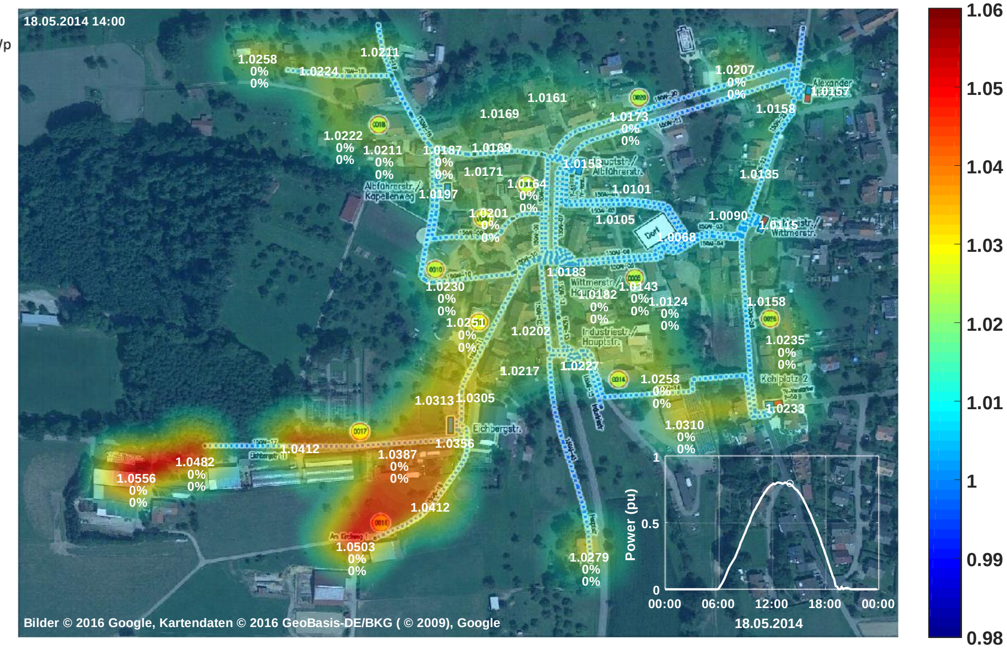
http://strom-report.de/photovoltaik/#photovoltaik-stromerzeugung
Förderung BRD Einspeisung Mar 2017 von8.5bis 12.3 €cent/kWh

Stromnetze mit hohem PV Anteil, Vortrag, Tagung ETG, VDE OEVE, Zürich Nov 2014
Anmerkung: Schweiz 41 300km2 * 300 kW/km2 = 12 GW ca. 20% PV Stromanteil

EXCEEDING VOLTAGE LIMITS DUE TO DECENTRALISED GENERATION

New challenges for Low Voltage Distribution Grids not exceeding voltage limits, require Smart Inverters and Substations.





Ref: F. Carigiet et al., «Optimisation of the Load Flow Calculation Method in order to perform Techno-Economic Assessments of Low-Voltage Distribution Grids», EUPVSEC 2017

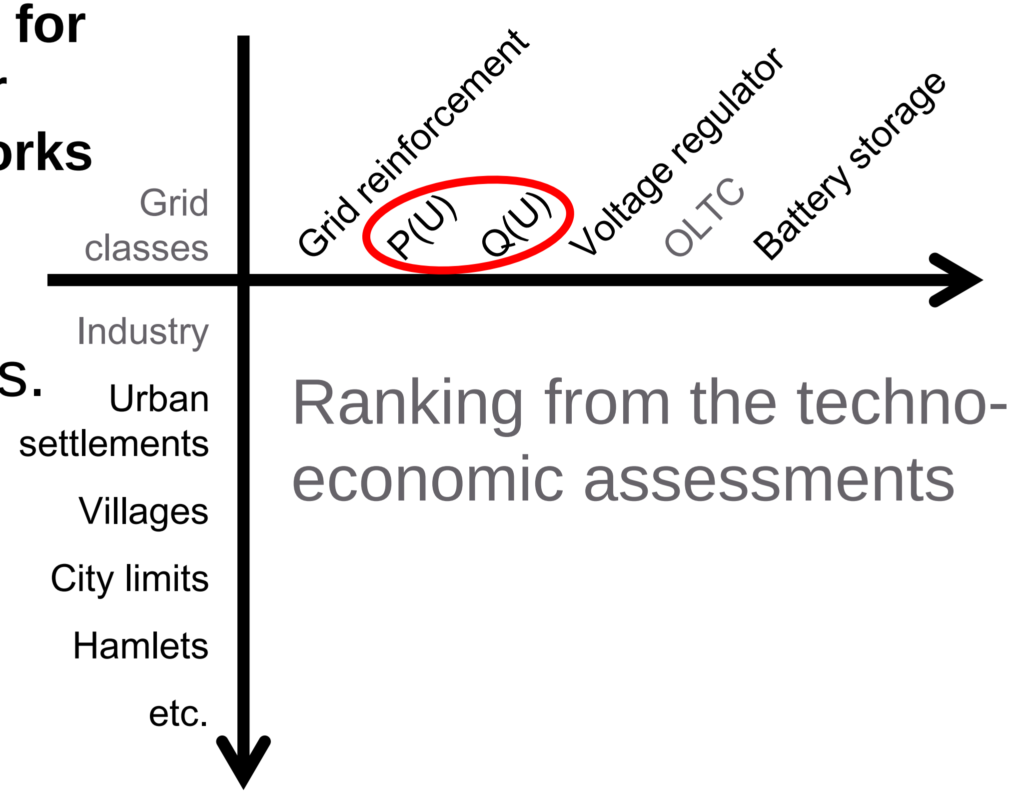
Goal of this work: «Is the PV inverters Q(U) control stable all the time?»

EFFECT OF DECENTRALISED GENERATION THE MOVIE

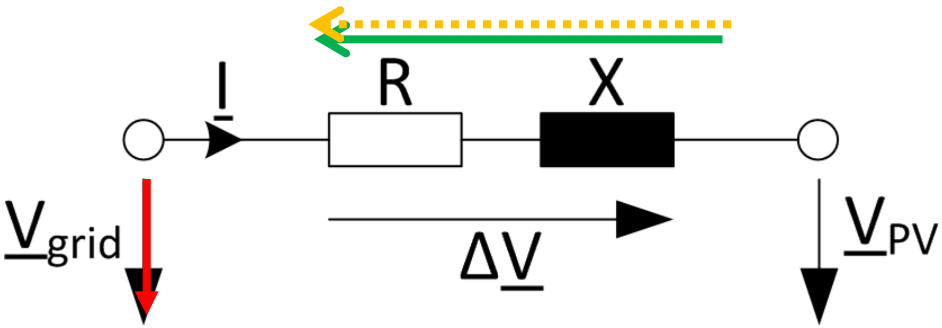
SWISS FEDERARL BUERO OF ENERGY PROJECT GOALS CEVSOL (2016 TO 2019)

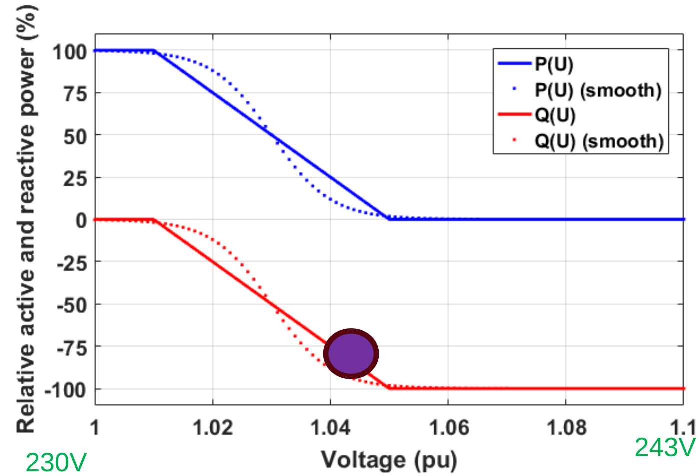
Cost effective smart grid solutions for the integration of renewable power sources into the low-voltage networks

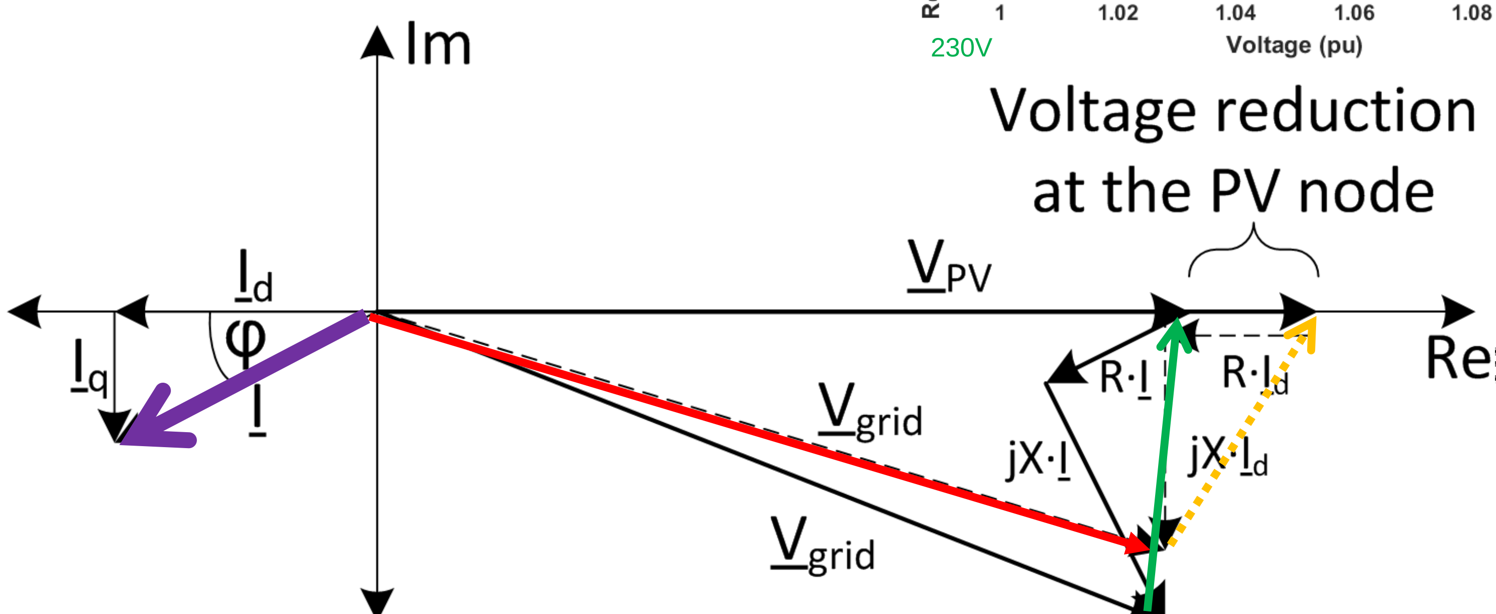
- Most cost-effective solution for individual typical grid class.
- Guideline for distribution system operator (DSO)
- Future cost expectation of the critical grid classes.



REDUCTION OF THE VOLTAGE AT PV INVERTER



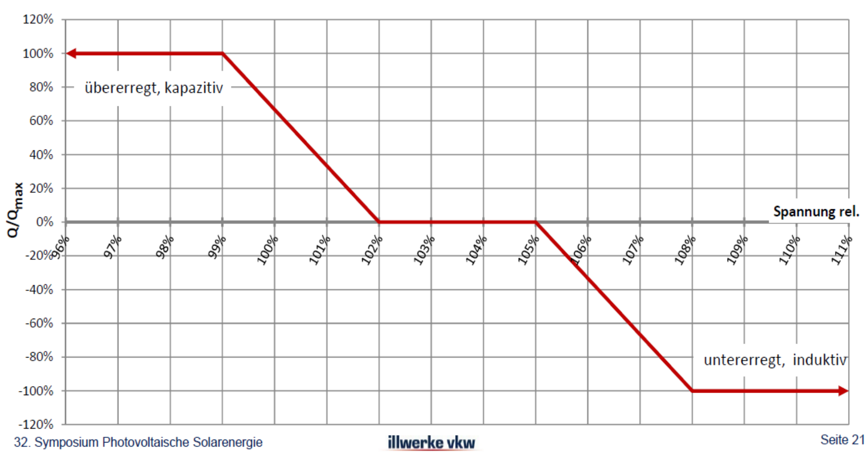




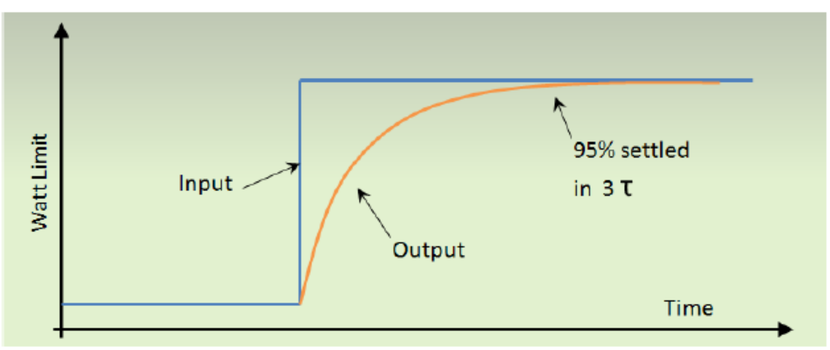
Q(V) CONTROL METHOD

Mitigation of over and under-voltage by the favorized inverters Q(U) control method

- Curve parametrization
  - Given by DSO as static characteristics according to local grid situation
  - Over excited at under-voltage, Under excited at over-voltage
- Timing parameter
  - Time constant of total system response - exponential characteristics, PT1 behavior
    Adjusted time constant usually 3τ or 95% settled of total system response (VDE)
  - Austrian TOR-D4 Standard: adjusted time constant 1τ (63% settled)



Q(U) curve (Elbs; 32. PV Tagung Deutschland, Staffelstein 2017)



Time Constant Definition (IEC 61850-90-7)

Q(V) - PV INVERTER ON THE MARKET

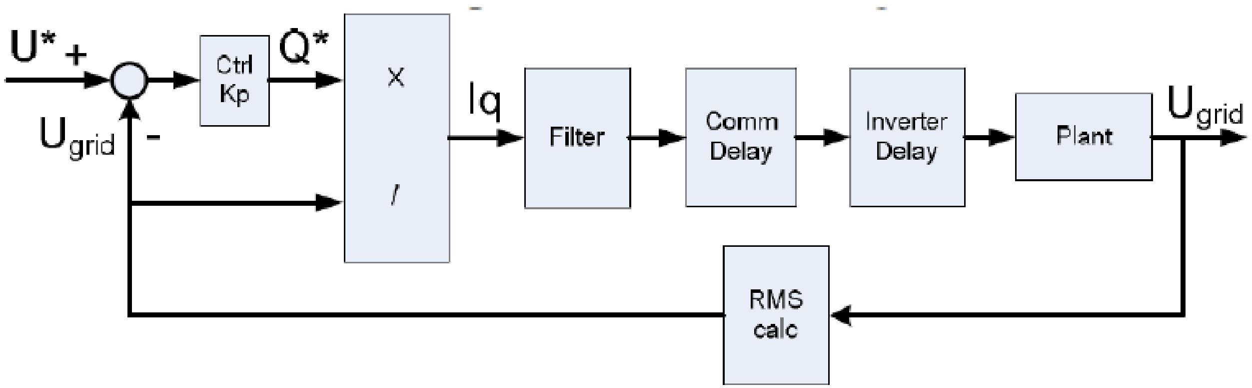
List of Q(V)-enabled inverters from Voralberger Energienetze GmbH (VKW)
https://www.vorarlbergnetz.at/inhalt/at/1524.htm (effective from 01.10.2017)

Manufacturer	Allowed	Not allowed	Not yet investigated
ABB (Power One)			Aurora Trio
AEconversion	Plant size <600W		
Bosch		All	
Delta		All	
Dhiel		Platinum	
Fronius	Galvo, Symo, Eco	IG Plus V-3, IG 15/20/30	
Kaco		Powader	
Kostal		Piko	
Refusol		All	
Samil Power		All	
SMA	Tripower	FLX Pro	
SolarEdge	SE4k to SE17k	All larger types	
Solutronic			Solplus 80-120
Steca		All	
Sungrow		All	
Zeversolar			Evershine TLC

Since 2015, VKW already applied voltage dependent RPC on 2500 PV inverters in Austria

Q(V) CONTROL LOOP

Controller Parameters : k prop. factor, time response τ

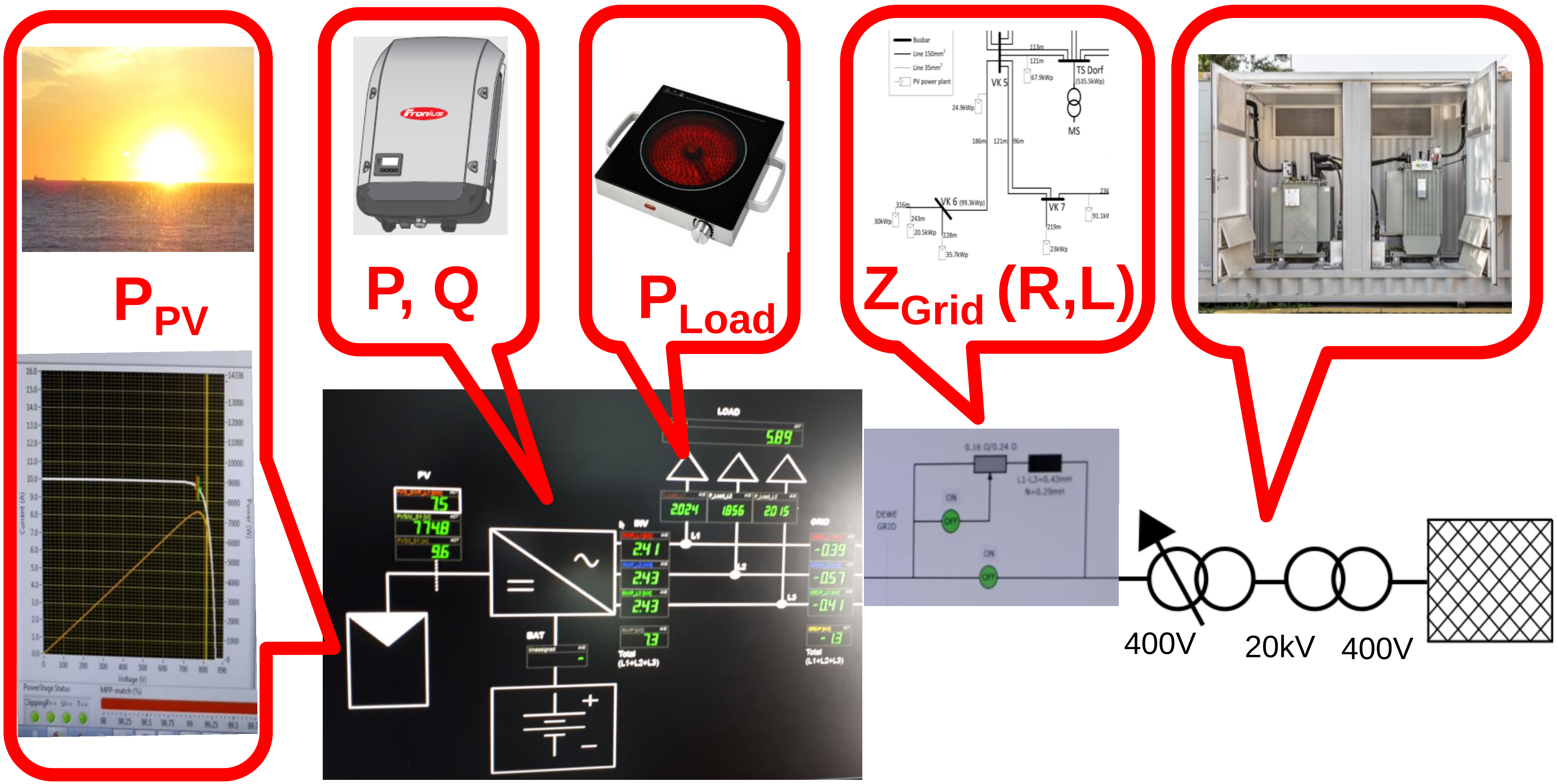


$$Kp = \frac{\Delta Q[pu] \cdot S_N}{\Delta U[pu] \cdot U_N} = m \cdot \frac{S_N}{U_N}$$

$$\frac{T}{\tau} \leq \frac{1}{a_\zeta \cdot \frac{\Delta U_{\mathrm{PV}}}{\Delta U_{\mathrm{droop}}} \cdot \frac{\tan\varphi}{R/X} + b_\zeta}$$

A. Constantin and R. D. Lazar, “Open loop Q(U) stability investigation in case of PV power plants,” in *Proc. 27th Eur. Photovoltaic Solar Energy, Conf. Exhib.*, Frankfurt, Germany, 2012, pp. 3745–3749

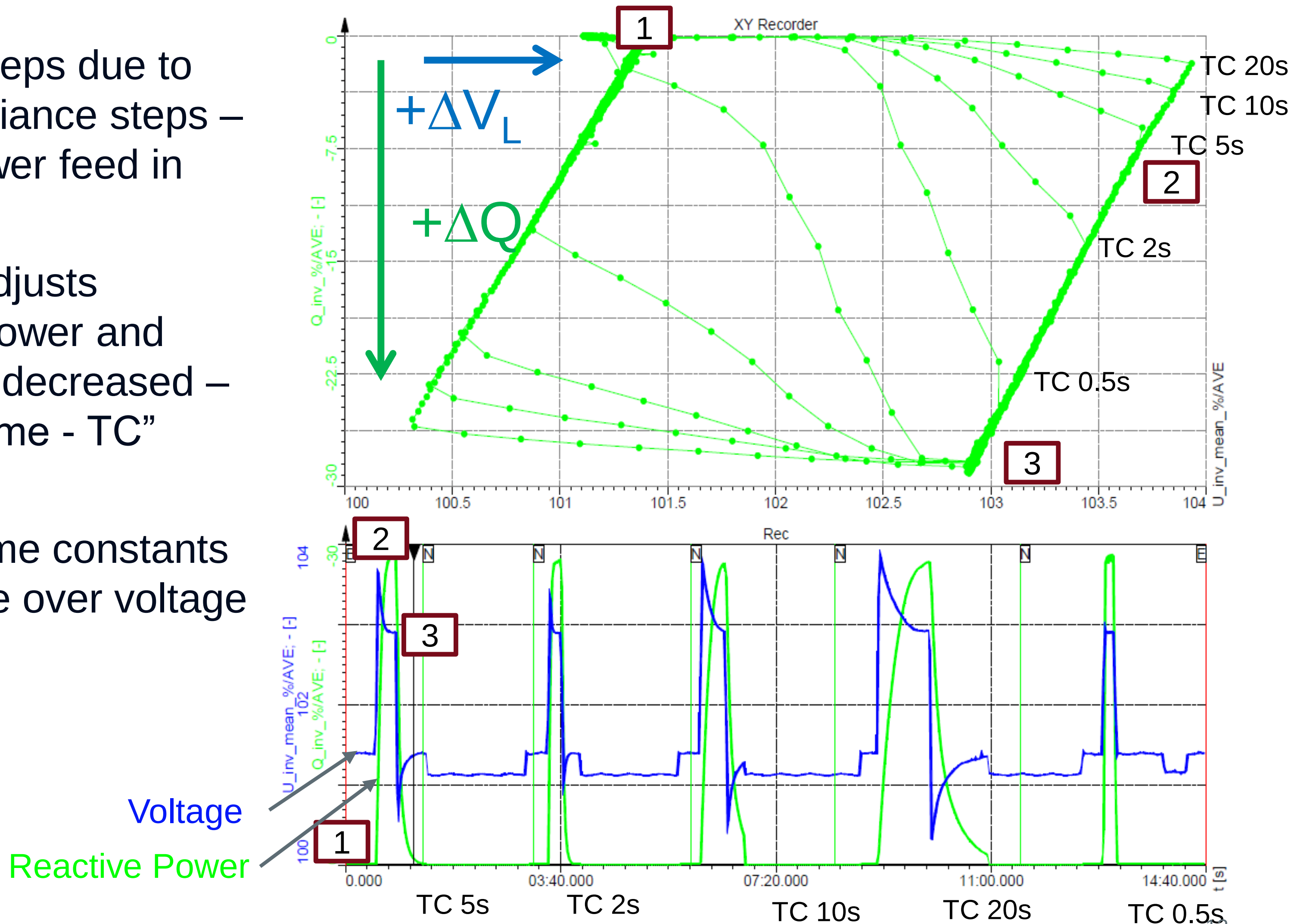
TEST SETUP AT AIT - to apply the stability test



AIT Test Setup – Emulation a real grid in the laboratory

TRANSIENT TEST OF Q(V) TIME CONSTANT SETTINGS FOR STEPS OF SOLAR IRRADIANCE

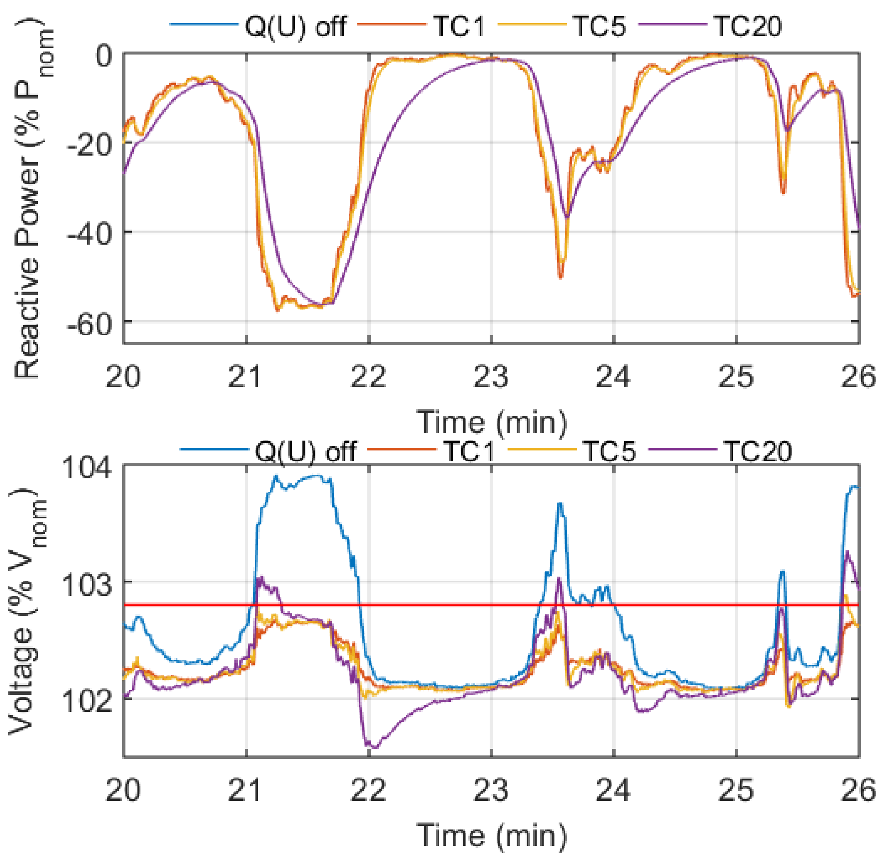
- Voltage steps due to solar irradiance steps – active power feed in
- Inverter adjusts reactive power and voltage is decreased – "it takes time - TC"
- Shorter time constants reduce the over voltage faster.



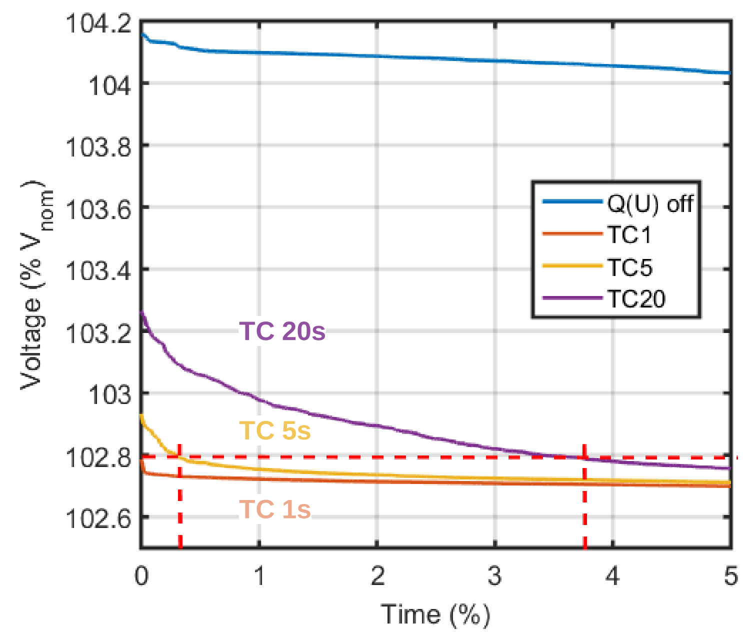
Q(V) and Time Domain - Time constant: 20s,10s,5s,3s,0.5s (for 1τ)

Q(V) TIME CONSTANT COMPARISON FOR A REAL SOLAR PROFILE

- Photovoltaic profile of 30 minutes with high changes of solar irradiation
- Different Q(V) time constant settings for validation



Voltage changes and reactive power adjustment of the inverter



Voltage > 120.8% of total time	
No Q(U) control	45%
Time Constant 20s (1τ)	3.4%
Time Constant 5s (1τ)	0.3%
Time Constant 1s (1τ)	Never

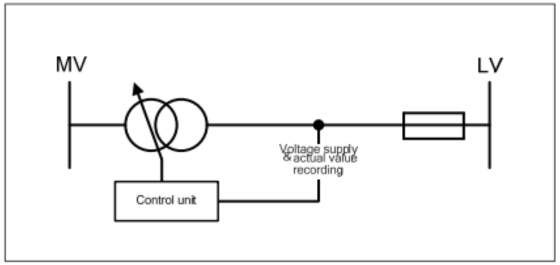
ON-LOAD VOLTAGE REGULATION DISTRIBUTION TRANSFORMER (VRDT) - TAP CHANGER

Effective method to keep voltage within a specific bandwidth

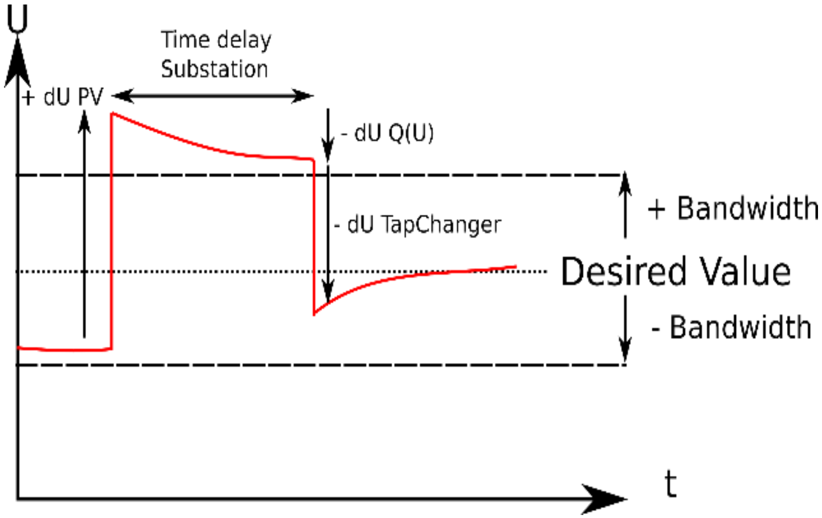
- Dynamically switching of the tap windings of distribution transformer

- Parametrization
    - Bandwidth in which no switching event is required – no switching
    - Time delay the voltage is allowed to stay outside the bandwidth
      typ. Larger 10 seconds

- Stability criteria: Bandwidth >> step voltage (factor of 1.6 recommended by VDE



VRDT at AIT, Voltage supply of control unit used for control (Source: FNN Recommendation Voltage Regulating Distribution Transformer (VRDT) – Use in Grid Planning and Operation)



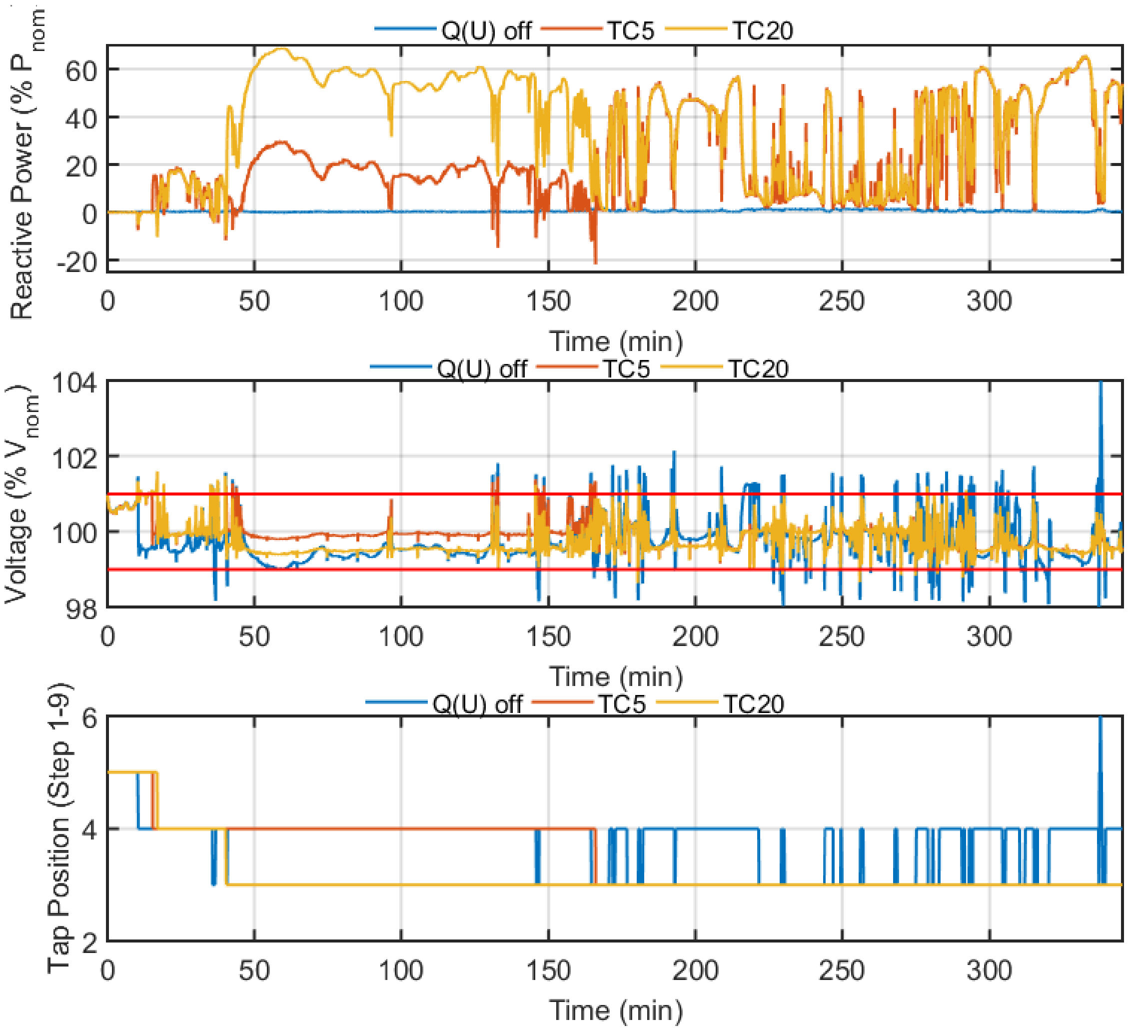
Control Principle VRDT (Source: AIT)

Q(V) TIME CONSTANT COMPARISON FOR A REAL SOLAR PROFILE WITH SUBSTATION

- Combination of Q(V) control and VRDT very effective keeping voltage within narrow limits

- Reduced tap switching due to Q(V) control

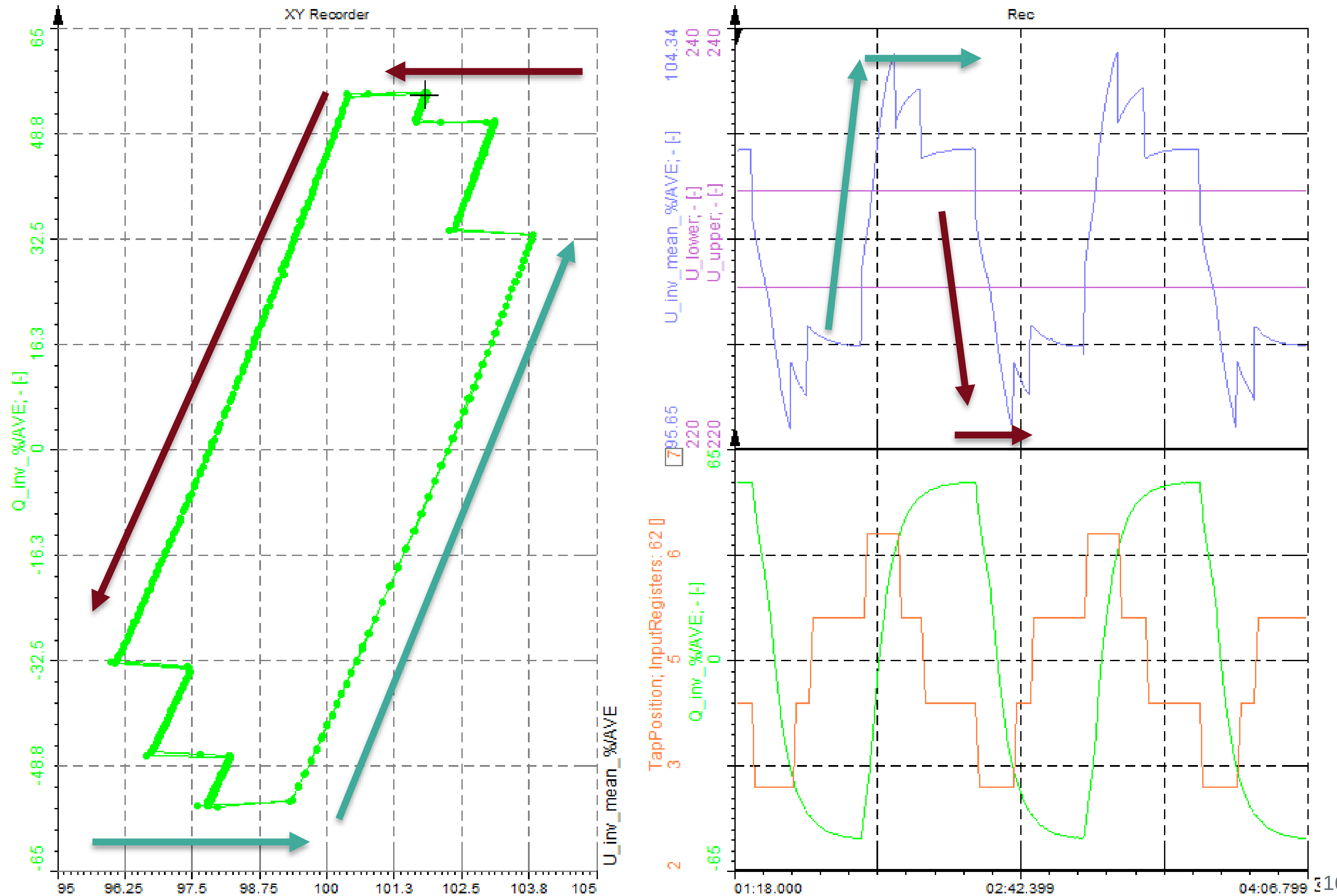
	V > 101%	V < 99%
No Q(U)	4.8%	2.6%
TC. 5s (1τ)	1.5%	0%
TC 25s (1τ)	1.4%	0.2%



Voltage changes and reactive power adjustment of the inverter, including VRDT (Time delay VRDT 15s, Bandwith 1%)

Q(V) – INCORRECT CURVE PARAMETRIZATION

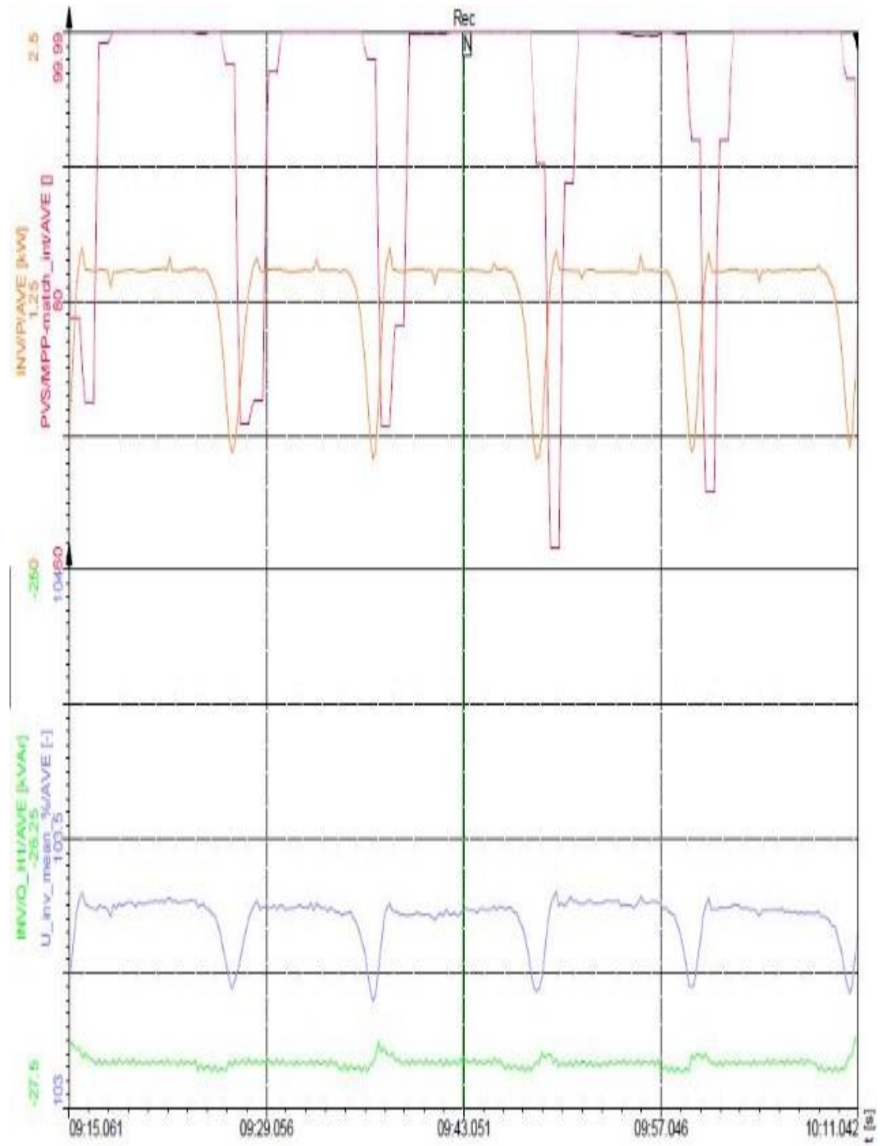
Instability for wrong Q(V) curve +- parametrization (installer “mixed” it up)



Wrong Q(V) sign parametrization (Time constant 5s, VRDT Time delay 15s, Bandwith 1%)

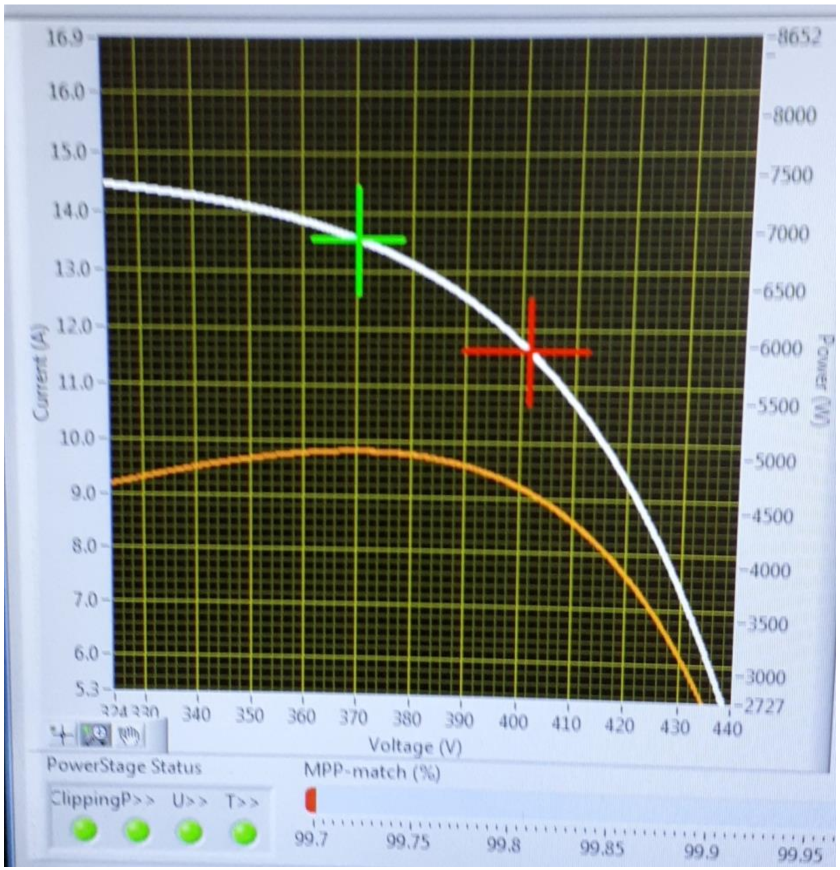
VOLTAGE OSCILLATION

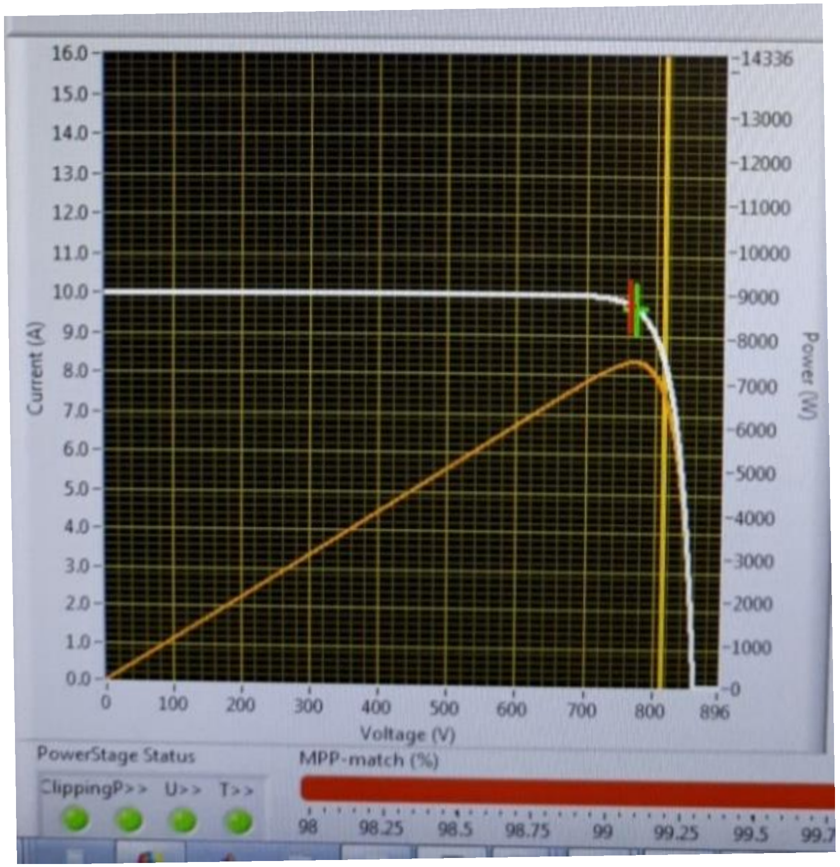
Small line voltage oscillations at a period of about 15 seconds at maximum reactive power and low active power and at the apparent power limit of the inverter performed by increasing the DC voltage to reduce the **m**aximum **p**ower **t**racing efficiency of the PV generator current voltage characteristics



S APPARENT POWER LIMIT AND MPP MISMATCH

Interference of Q(V) controller at the current limit of apparent power may cause
small Q oscillations in sec range coupled with the PV maximum power tracker Voc.

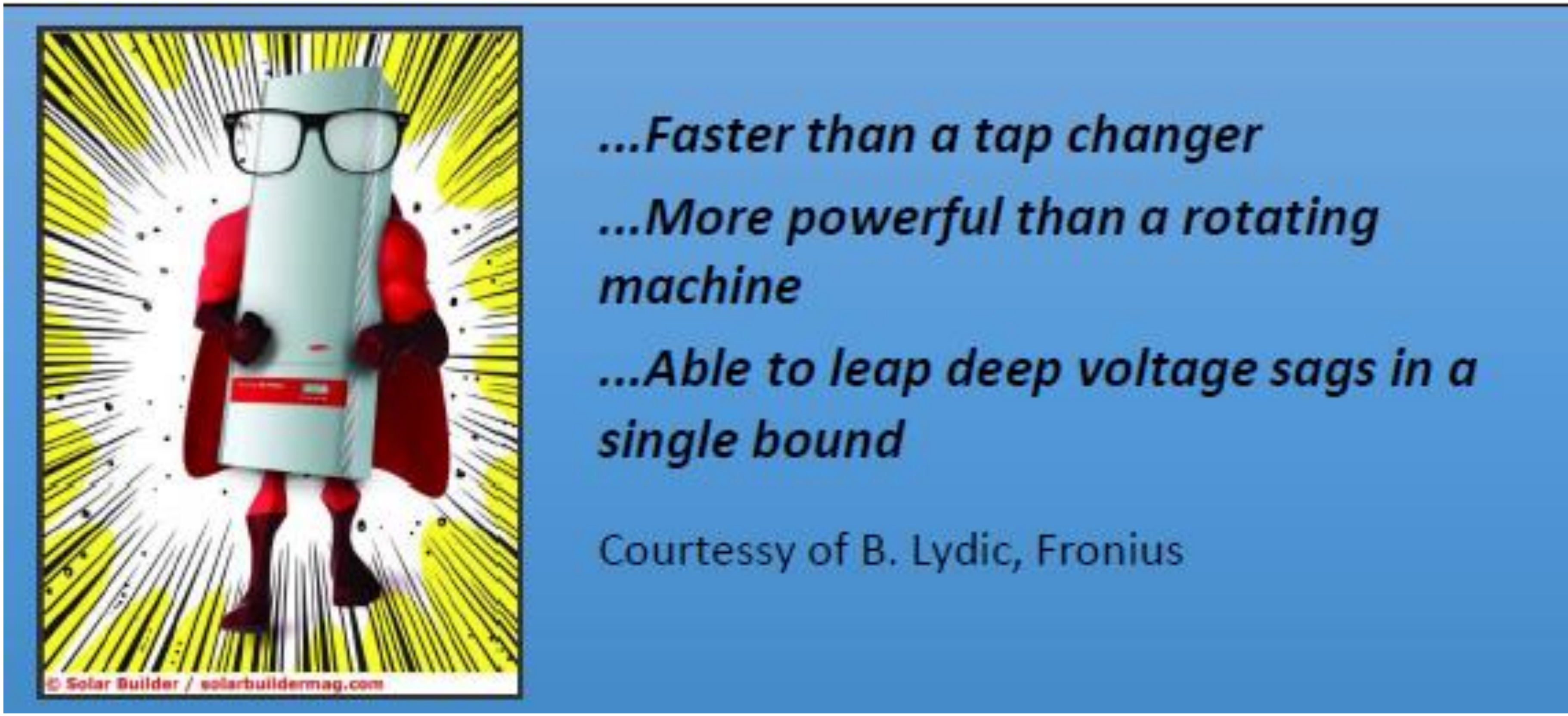




SUMMARY AND CONCLUSION

- No stability problems for time constants between 1s and 5s observed
- Time constants well below 5s reduce over-voltage occurrence dramatically observed during transient compensation of Q(U) inverter control
- Instability in combination with active components as the Voltage Regulation Distribution Transformer (VRDT) was not observed for regular settings due to delay time and much faster TC of Q(U)
- VRDT an Q(U) stability could arise if the installer mixed ab the sign of the static parameter settings of the inverter during the installation process
- Paying attention at different definitions of the adjustable Q(V) time constant in different grid codes (PT1, 1Tau, 3 Tau, Ramp Rates)

PV INVERTERS ARE PART OF THE SOLUTION



Jay Johnson, Sandia Labs, USA
India Smart Grid Week, March 7-10, 2017
Manekshaw Center, New Delhi, India.

AUSTRIAN INSTITUTE OF TECHNOLOGY

IEA ISGAN PAPER 2015

Table I: Review of Grid Codes for the Volt / VAR function

Country/ Grid Code	Data Requirements	Specified Curve	Default Values
US (California)/ UL 1741 SA: 2015	AC and DC current and voltage. The minimum measurement accuracy shall be 1% or less of rated EUT nominal output voltage and 1% or less of rated EUT output current.	• Q_1 = maximum capacitive reactive power setting • Q_2 = reactive power setting at the left edge of the deadband • Q_3 = reactive power setting at the right edge of the deadband • Q_4 = maximum inductive reactive power setting • V_1 = voltage at Q_1 • V_2 = voltage at Q_2 • V_3 = voltage at Q_3 • V_4 = voltage at Q_4	$V_1 = V_2 - Q_1/KVAR_{max}$, $Q_1 = Q_{max,cap}$ $V_2 = V_n$ - $Deadband_{min}/2$, $Q_2 = 0$ $V_3 = V_n + Deadband_{min}/2$, $Q_3 = 0$ $V_4 = Q_4/KVAR_{max} + V_3$, $Q_4 = Q_{max,ind}$
Germany/ FGW - TR3 Rev23 (optional test)	Displacement factor, P, Q, and V useing a 0.2s (min) sliding average. The settling time shall be determined on the basis of ±5% rated active power.	Aditional tests are carried out for PGUs with reactive power control with Q(U) caricteristic curve. The voltage steps start at the lowest voltage to the highest voltage and vice vcersa.	none
Austria ÖVE/ÖNORM EN50438 (optional - in accordance with DSO, e.g. function used by local DSO - -Vorarlberg Netz)	Displacement factor, P, Q, and V using a 0.2s (min) sliding average. The settling time shall be determined on the basis of ±5% rated active power.	V_{1i}= under voltage at the left edge of the deadband V_{2i}= under voltage at max capacitive reactive power V_{1s}= over voltage at the right edge of the deadband V_{2s}= over voltage at max inductive reactive power Q_{1i}=reactive power at V_{1i} Q_{2i}=reactive power at V_{2i} Q_{1s}=reactive power at V_{1s} Q_{2s}=reactive power at V_{2s} $Q_{max,cap}$ and $Q_{max,ind}$ from capability curve	For grid operator (Vorarlberg Netz) $V_{1i} = 1.02\ V_n$, $Q_{1i} = 0$ $V_{2i} = 0.99\ V_n$, $Q_{2i} = Q_{max,cap}$ $V_{1s} = 1.05\ V_n$, $Q_{1s} = 0$ $V_{2s} = 1.08\ V_n$, $Q_{2s} = Q_{max,ind}$
International / IEC 61850-90-7 VV11	Monitor and record electrical output of EUT. • Voltage • Active power	Pointwise definition with (V_1, Q_1) through (V_x, Q_x) points. • Q_x = Desired reactive power setting at V_x • V_x = Voltage setting at Q_x.	No default. Example settings are: $V_1 = 0.97\ V_n$, Q_1 = 50% $Q_{max,overexcited}$ $V_2 = 0.99\ V_n$, $Q_2 = 0$

EU PVSEC 2015 — European PV Solar Energy Conference and Exhibition — Conference 14 – 18 Sep 2015, Exhibition 15 – 17 Sep 2015 — CCH Congress Centre Hamburg • Hamburg • Germany

INTERNATIONAL DEVELOPMENT OF ENERGY STORAGE INTEROPERABILITY TEST PROTOCOLS FOR PHOTOVOLTAIC INTEGRATION

David Rosewater, Jay Johnson, Maurizio Verga, Riccardo Lazzari, Christian Messner, Roland Bründlinger, Kathan Johannes, Jun Hashimoto, Kenji Otani

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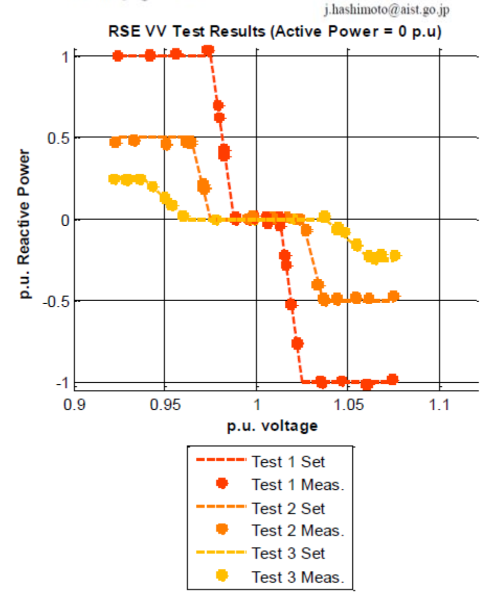

Figure 12: RSE test results for VV function (three test cases with no active power)

JOINT PUBLICATION ISGRAN
WORLD PV CONFERENCE 2018, JUNE, HAWAI, USA

International Development of a Distributed Energy Resource Test Platform for Electrical and Interoperability Certification

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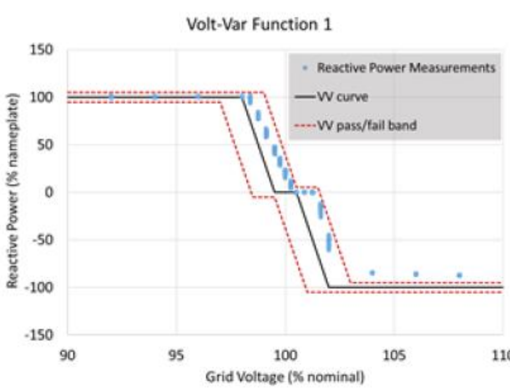
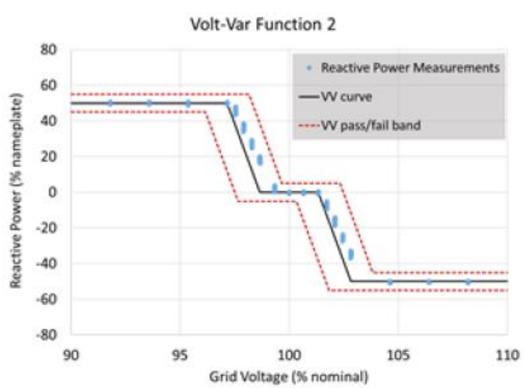


(A) 34.5 kW ASGC Solar Inverter, Reactive Power Priority, Sandia



(B) 34.5 kW ASGC Solar Inverter, Reactive Power Priority, Sandia

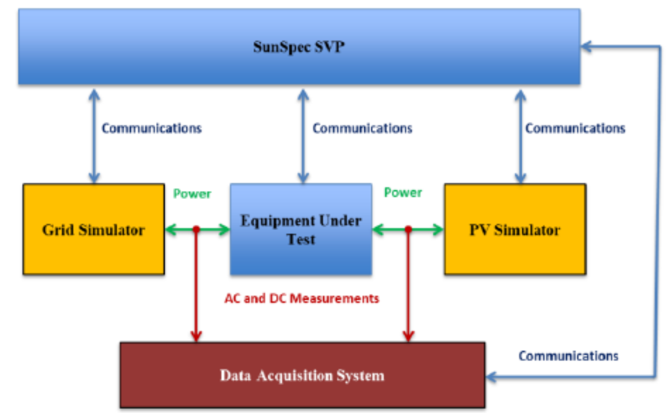


Fig. 1. SVP interaction with laboratory equipment.

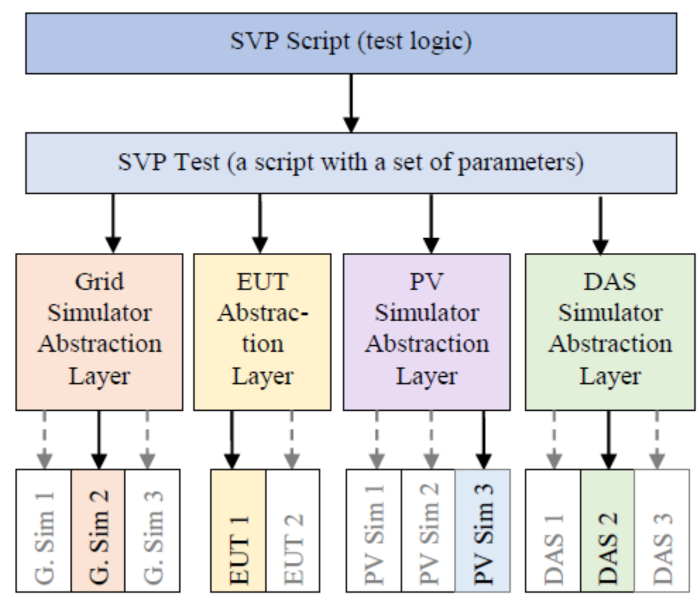


Fig. 2. SVP code structure.

THANK YOU!

To the co-authors and the funding agencies

Franz Baumgartner & Christian Messner, 28.09.2018

ACKNOWLEDGEMENTS

*The authors would like to thank the AIT Austrian Institute of Technology, Vienna for hosting the Transnational Access project "TIPI-GRID" and providing laboratory infrastructure. This research work is partially supported with the European Union's Horizon 2020 grant **654113 (ERIGrid) under the Transnational Access programme.***

PV INVERTER TEST LAB AT AIT

https://www.ait.ac.at/en/about-the-ait/center/center-for-energy/

TWO LINE VOLTAGE STEPS – FAST T=1SEC

Events producing ΔVL step: 1) step change in load 2) substation tap changer