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European cooperation Network on Energy Transition in Electricity

Most promising disruptive technologies on smart grids and technology transfer success stories

The Smart Transformer technology and its impact on the electric grid

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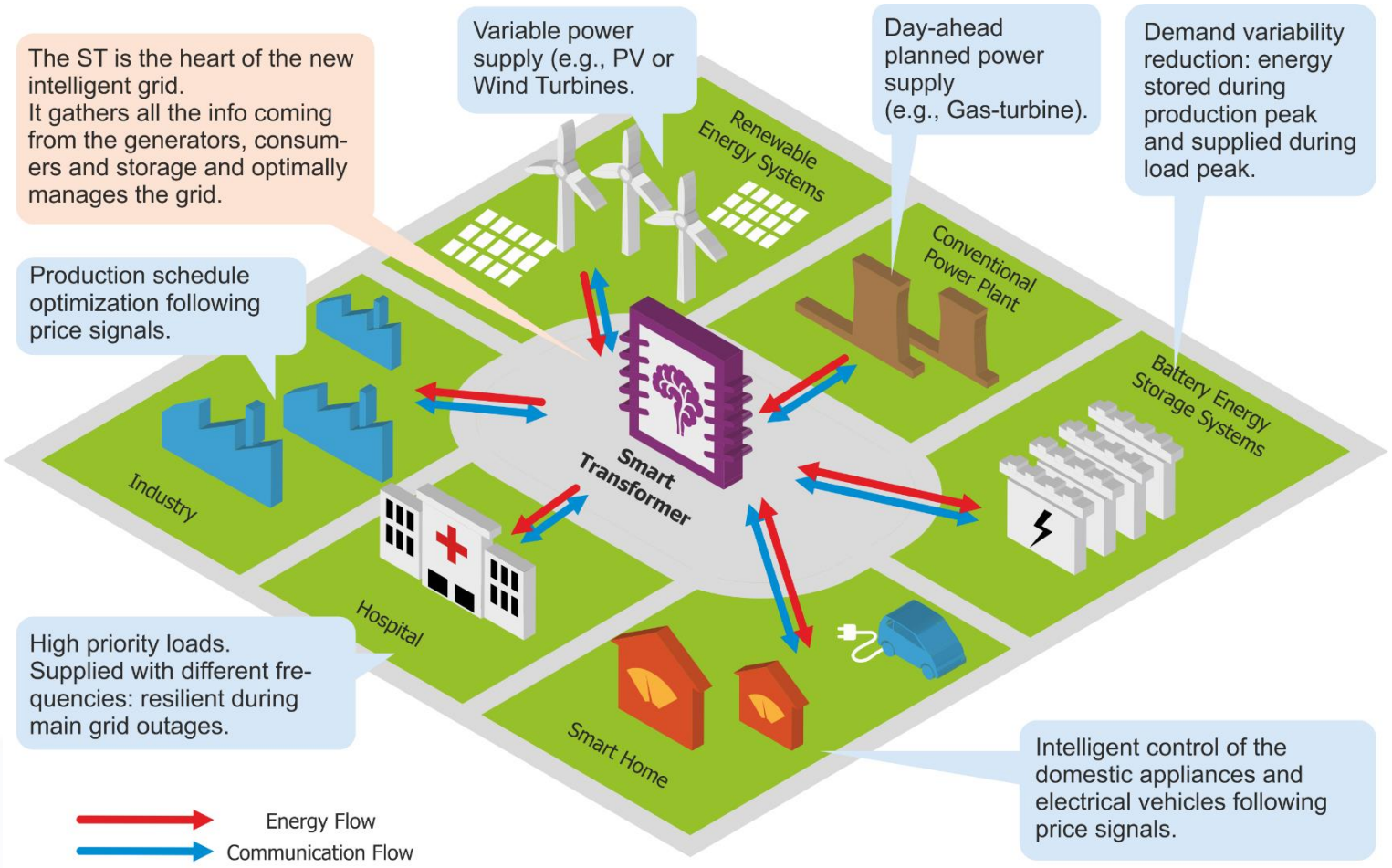
26th October, Madrid

Kiel University
Christian-Albrechts-Universität zu Kiel

Outline

- ✓ The Highly Efficient And Reliable smart Transformer: HEART project facts.
- ✓ The Smart Transformer in the electric grid: identify the LV-grid, control the load/generation, offer services to MV-grid
- ✓ Smart Transformer design: a grid-tailored sizing approach

Highly Efficient And Reliable smart Transformer



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HEART Project facts

ERC Consolidator Grant (European Union Research Funding)

- ✓ **One of 43 Consolidators grant in Germany (8% acceptance rate)**
- ✓ **Unique project approved in Power Electronics and Power System field.**
- ✓ **Facts**
  - 1st May starting date
  - 5-years project
  - 2 Mio € funding
  - 1 Post-doc and 4 PhD´s
  - Partnership with Aalborg University (Denmark)
  - A MV Laboratory is under developed to carry out the project

The Smart Transformer

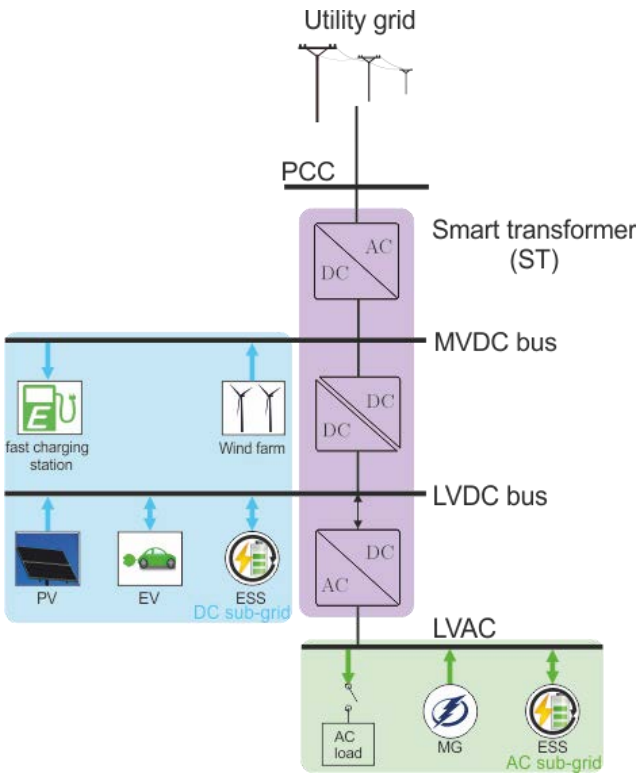
The Smart Transformer features shall be:

✓ LV and MV DC-links available

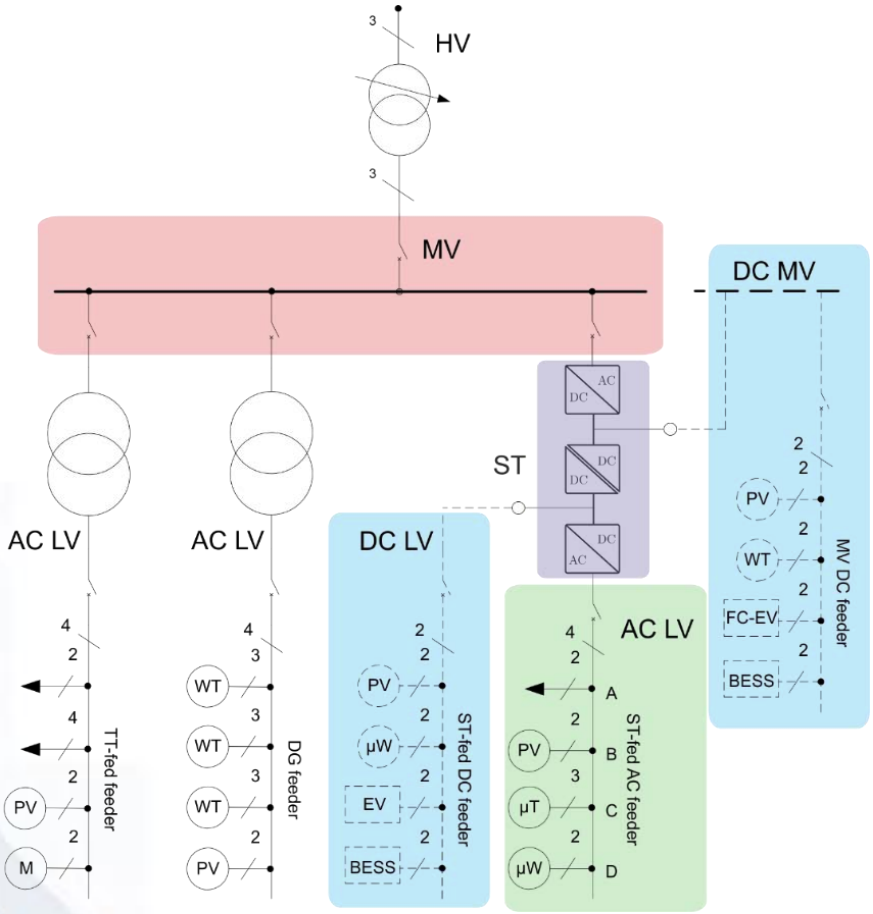
✓ Advanced control of all the three-stages

✓ The system should be able to work even with faulty modules

✓ During partial loading conditions it should be able to fully use its rating for other services



Smart Transformer services for the electric grid



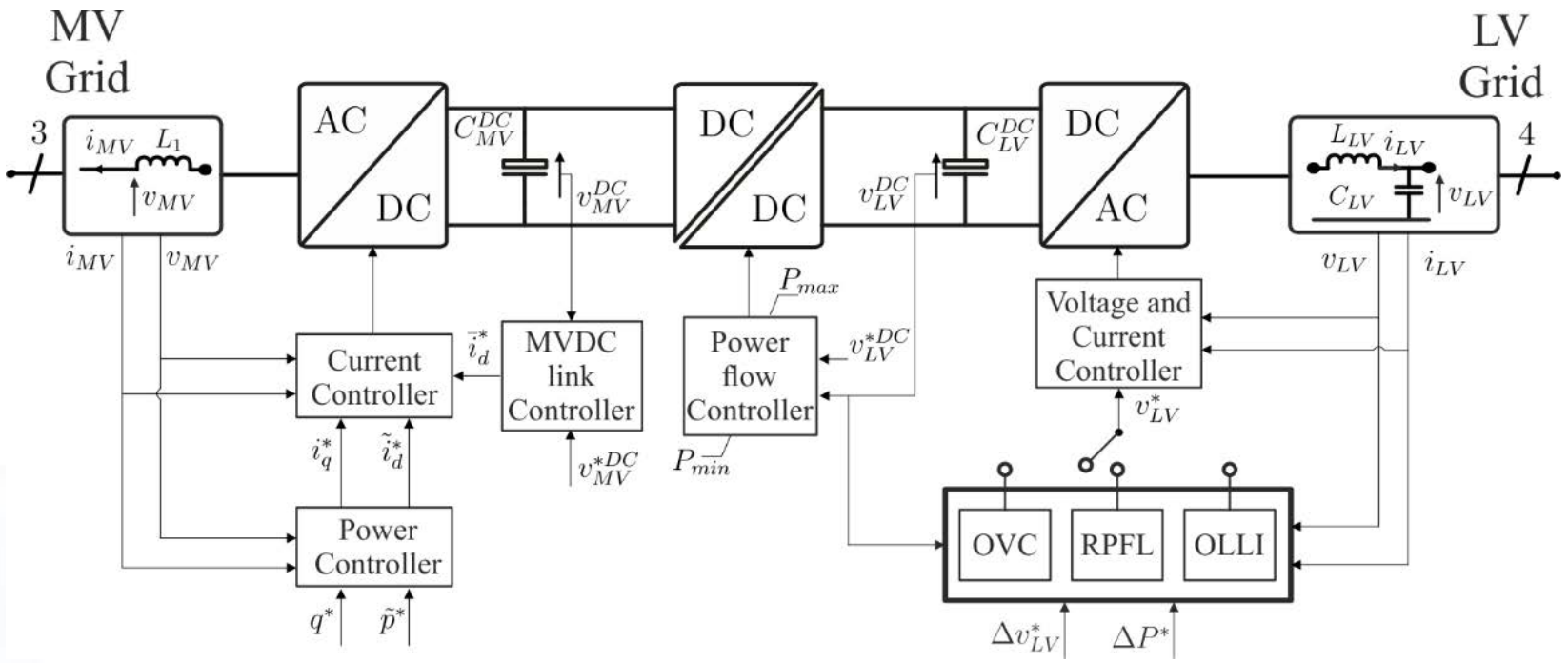
Smart Transformer

- Voltage support (steady state and LVRT)
- Reactive power compensation at HV/MV substation
- Power quality improvements
- Islanding control (high DG in LV)

- Integration of EV-charging stations
- Integration of storage for dispatching
- Reverse Power Flow limitation

- Impedance identification
- Load identification
- Reverse Power Flow limitation
- ST overload control
- Soft-load reduction
- Damping of harmonics and resonances
- LV-side power quality

Control of the Smart Transformer



M. Liserre, G. Buticchi, M. Andresen, G. De Carne, L. F. Costa and Z. X. Zou, "The Smart Transformer: Impact on the Electric Grid and Technology Challenges," in IEEE Industrial Electronics Magazine, vol. 10, no. 2, pp. 46-58, Summer 2016.

On-Line Load sensitivity Identification

The load can be represented with an exponential model for the voltage and with a linear dependency from the frequency

$$P = P_0 \left(\frac{V}{V_0}\right)^{K_p} \left(1 + K_{fp}\left(\frac{f - f_0}{f_0}\right)\right) \qquad (1a)$$

$$Q = Q_0 \left(\frac{V}{V_0}\right)^{K_q} \left(1 + K_{fq}\left(\frac{f - f_0}{f_0}\right)\right) \qquad (1b)$$

- ***V*** Independent of initial voltage and does not require initialization
- ***V*** Only one parameter is needed for active and one for reactive power.
- ***V*** The exponent is equal to load sensitivity to voltage

$$\frac{dP}{dV} = K_p P_0 \left(\frac{V}{V_0}\right)^{K_p - 1} \frac{1}{V_0}$$

$$\frac{dQ}{dV} = K_q Q_0 \left(\frac{V}{V_0}\right)^{K_q - 1} \frac{1}{V_0} \qquad (2)$$

$$\frac{dP/P_0}{dV/V_0} = K_p$$

$$\frac{dQ/Q_0}{dV/V_0} = K_q \qquad (3)$$

G. De Carne, M. Liserre and C. Vournas, "On-Line Load Sensitivity Identification in LV Distribution Grids," in IEEE Transactions on Power Systems, vol. 32, no. 2, pp. 1570-1571, March 2017.

On-Line Load sensitivity Identification: algorithm implementation

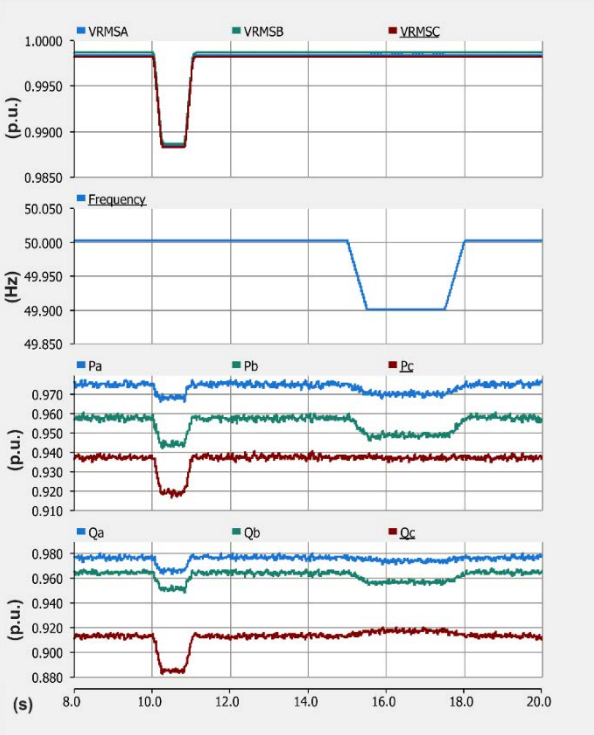
$$K_p = \frac{\frac{P(t_k) - P(t_{k-1})}{P(t_k)}}{\frac{V(t_k) - V(t_{k-1})}{V(t_k)}} \qquad K_q = \frac{\frac{Q(t_k) - Q(t_{k-1})}{Q(t_k)}}{\frac{V(t_k) - V(t_{k-1})}{V(t_k)}} \qquad (4)$$

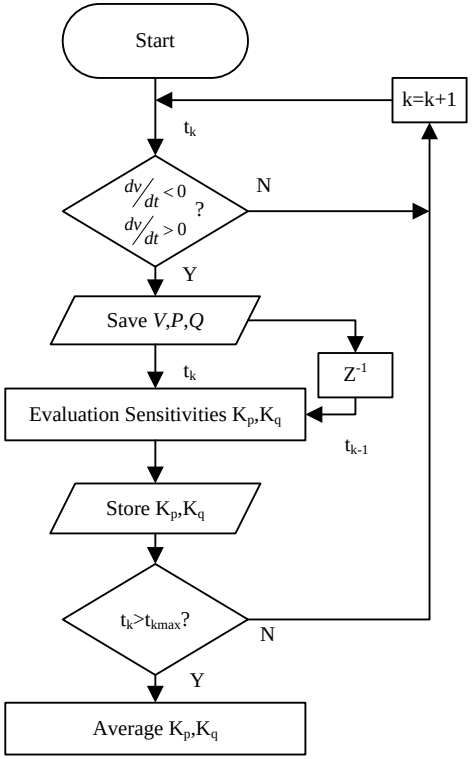
ST Voltage

ST Frequency

ST Active Power

ST Reactive Power





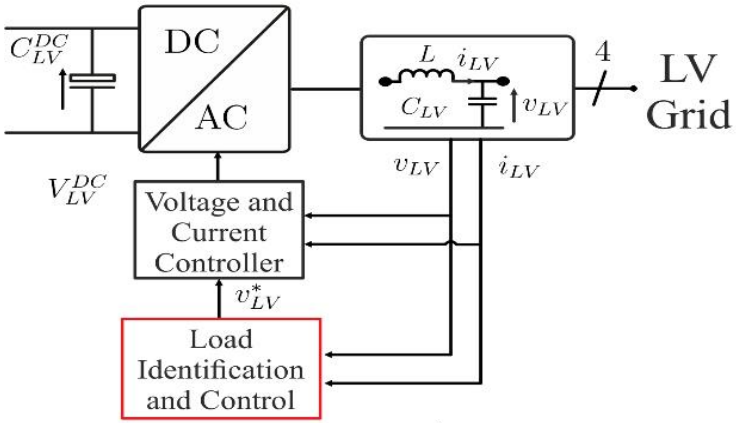
Soft Load Reduction

- ✓ High load consumption can affect the system stability. The generators may not follow the load demand during grid contingencies.
- ✓ In case of perturbations (e.g., faults) or critical conditions (e.g., devices overload), the load shedding represents an effective, although costly, solution.
- ✓ The Smart Transformer can instead reduce the load consumption performing a “soft-load reduction”. Controlling the voltage amplitude in LV grid, the load power consumption can be shaped.

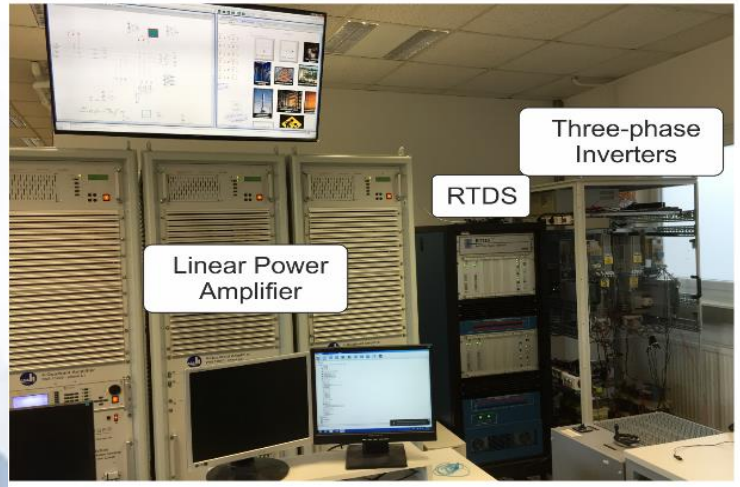
$$\frac{V}{V_0} = 1 + \frac{\Delta P}{P_A K_{pA} + P_B K_{pB} + P_C K_{pC}}$$

G. De Carne, G. Buticchi, M. Liserre, C. Vournas, “Load Control using Sensitivity Identification by means of Smart Transformer” IEEE Transactions on Smart Grid, Early Access.

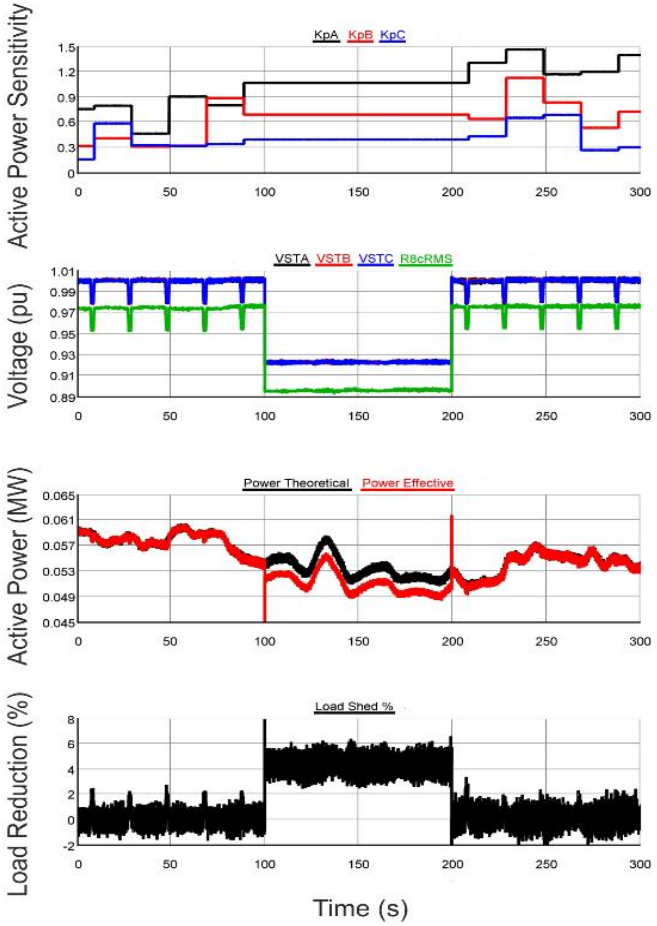
Soft-load reduction



a)



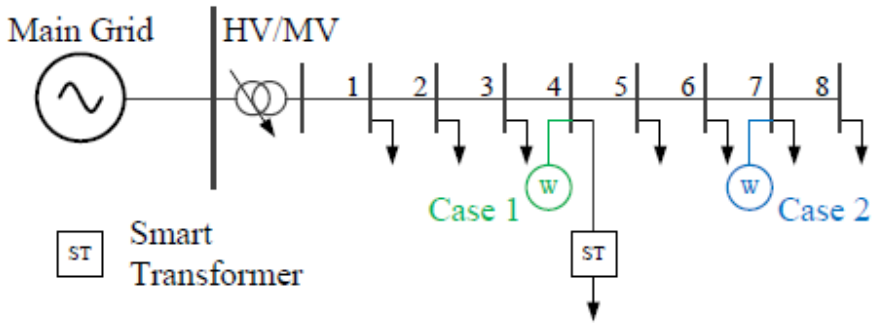
b)



c)

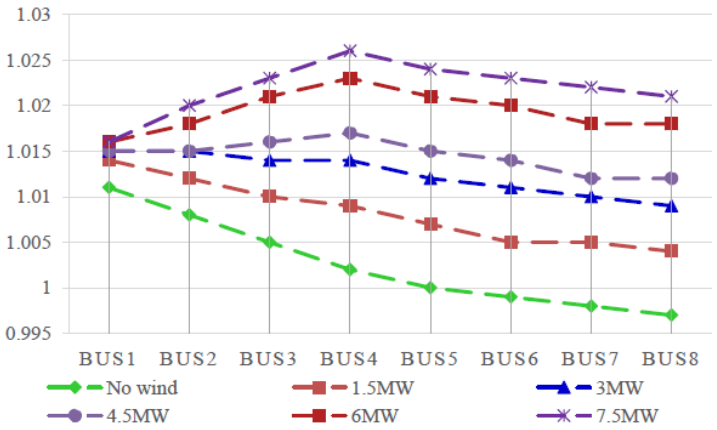
Increasing DG hosting capacity

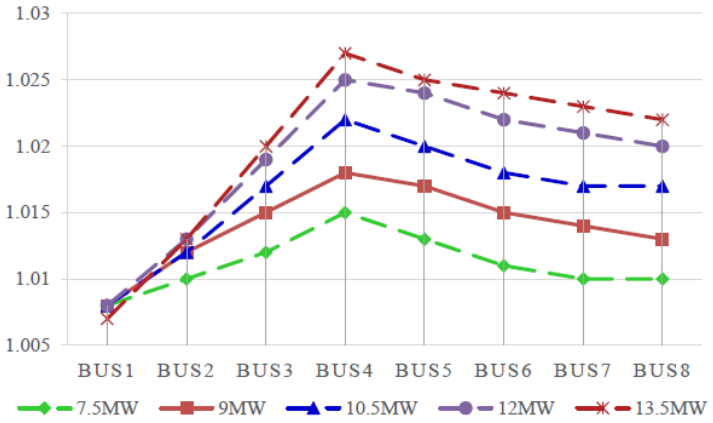
- ✓ Typical DG penetration limits in MV feeders
  - ✓ Voltage rise during light load
  - ✓ Compensation of sudden loss of RES power
- ✓ If at least some MV feeder loads are supplied through STs
  - ✓ ST MV converter can apply voltage control
  - ✓ Either locally or with remote measurement
- ✓ ST can also provide emergency P control
  - ✓ Acting on the LV connected load or DG



Gao, X., G. De Carne, M. Liserre, C. Vournas. "Increasing Integration of Wind Power in Medium Voltage Grid by voltage support of Smart Transformer." EWEA 2016.

MV feeder Test results

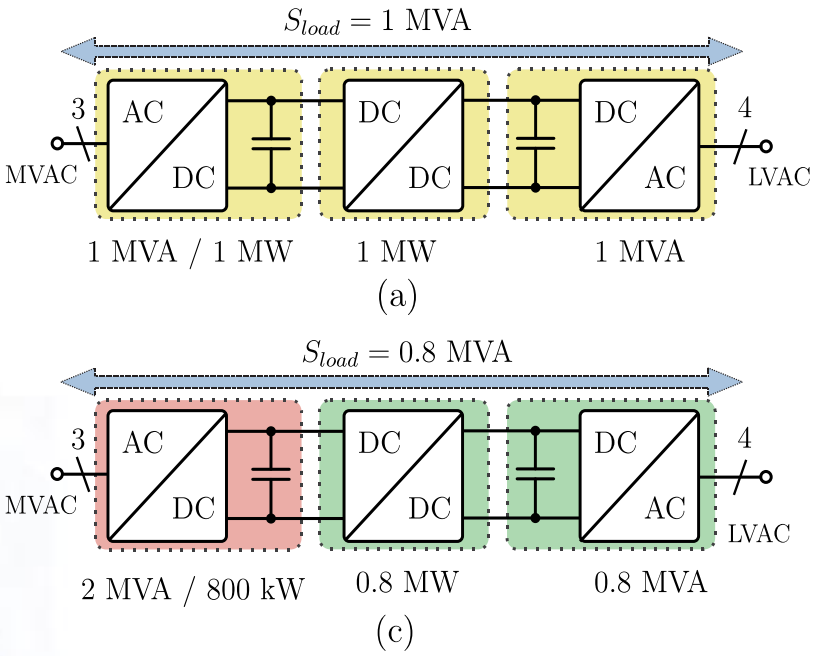




- ✓ Without ST
- ✓ Consider allowed overvoltage ΔV up to 2,5%
- ✓ Max penetration limit 7.5 MW

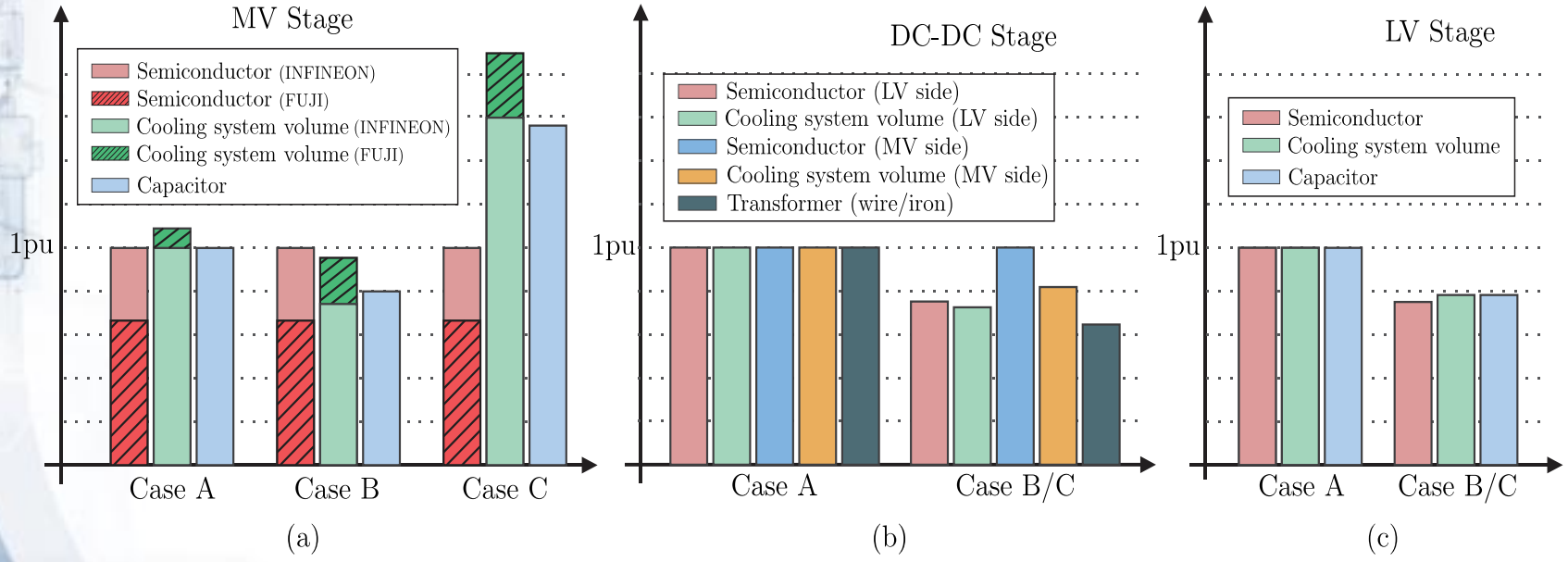
- ✓ With ST
- ✓ ΔV limit +2,5%
- ✓ Max penetration limit 12 MW
- ✓ Increase of 4.5MW (60%)

How to rate the ST ?

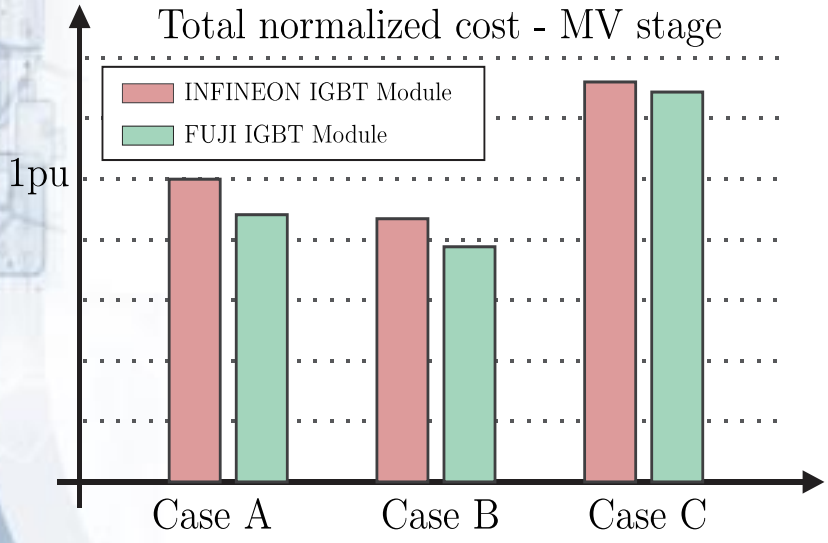


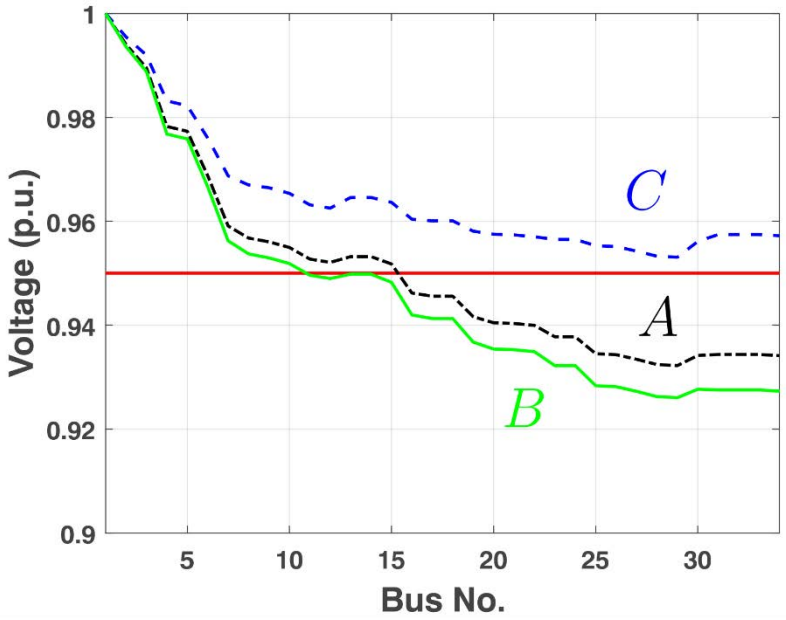
L. Ferreira Costa, G. De Carne, G. Buticchi and M. Liserre, "The Smart Transformer: A solid-state transformer tailored to provide ancillary services to the distribution grid," in IEEE Power Electronics Magazine, vol. 4, no. 2, pp. 56-67, June 2017.

How to rate the ST ?



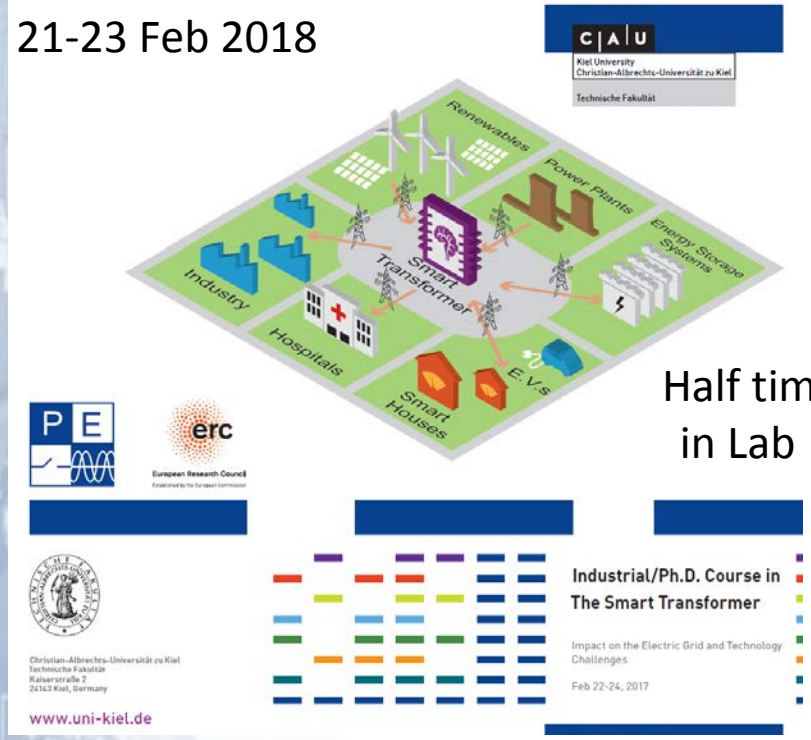
How to rate the ST ?





Join the PhD Course

21-23 Feb 2018



Half time in Lab !

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