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# Aspects of a generic Photovoltaic model examined under the German Grid Code for Medium Voltage

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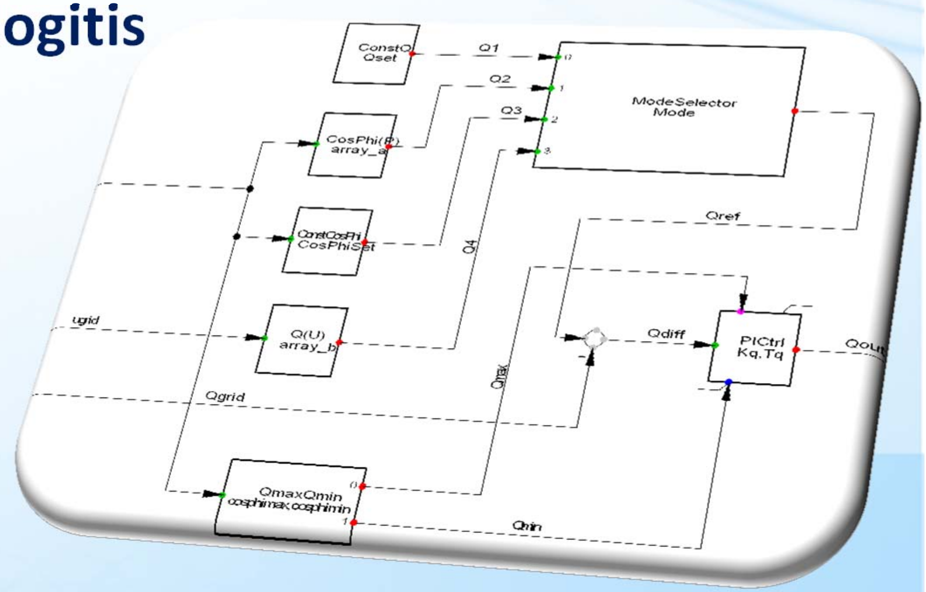

# OUTLINE

1. INTRODUCTION
2. MODEL
3. CONTROL ASPECTS
4. CONCLUSIONS & RECOMMENDATIONS

# Overview

**The driving force:**

- The increasing PV penetration to the power grid (current status + future scenarios)

**Requirements:**

- Detailed Grid Codes to ensure proper operation of the power grid
- Further studies and modeling based on grid codes to end up in more concrete solutions

**Objective:**

- Group together some basic knowledge concerning the requirements that PV systems should fulfill to comply with the German Grid Code for MV

**Approach:**

- Examination and improvement of a generic photovoltaic model built by DIgSILENT

# The German Grid Code

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| Grid Codes | Voltage Band | Fault Ride Through | Reactive Power Supply | Frequency Band | Active Power Derating |
|---|---|---|---|---|---|
| High Voltage (>110 kV) | 0.8 $U_N$ ↔ 1.16 $U_N$ | ✔ | ***Method***<br>U, cosϕ, Q<br>***Limitations***<br>$Q/P_n$ and voltage level (3 different variants) | 47.5 Hz ↔ 51.5 Hz | $\Delta(\frac{P}{P_M}) = 40\frac{\%}{Hz}(50.2Hz - f)$<br>$50.2Hz < f < 51.5Hz$ |
| **Medium Voltage** (<110 kV & >10 kV) | **0.8 $U_N$ ↔ 1.15 $U_N$** | ✔ | ***Method***<br>**Q(U), $\cos\phi_{fix}$, $Q_{fix}$, cosϕ(P)**<br>***Limitations***<br>**$0.95_{underexcited}$ to $0.95_{overexcited}$** | **47.5 Hz ↔ 51.5 Hz** | $\Delta(\frac{P}{P_M}) = 40\frac{\%}{Hz}(50.2Hz - f)$<br>$50.2Hz < f < 51.5Hz$ |
| Low Voltage (<10 KV) | 0.8 $U_N$ ↔ 1.1 $U_N$ | ✘ | ***Method***<br>$\cos\phi_{fix}$, cosϕ(P)<br>***Limitations***<br>$0.90_{un}$ to $0.90_{ov}$ $\sum S_{E_{MAX}} > 13.8kVA$<br>$0.95_{un}$ to $0.95_{ov}$ $\sum S_{E_{MAX}} \leq 13.8kVA$ | 47.5 Hz ↔ 51.5 Hz | $\Delta(\frac{P}{P_M}) = 40\frac{\%}{Hz}(50.2Hz - f)$<br>$50.2Hz < f < 51.5Hz$ |

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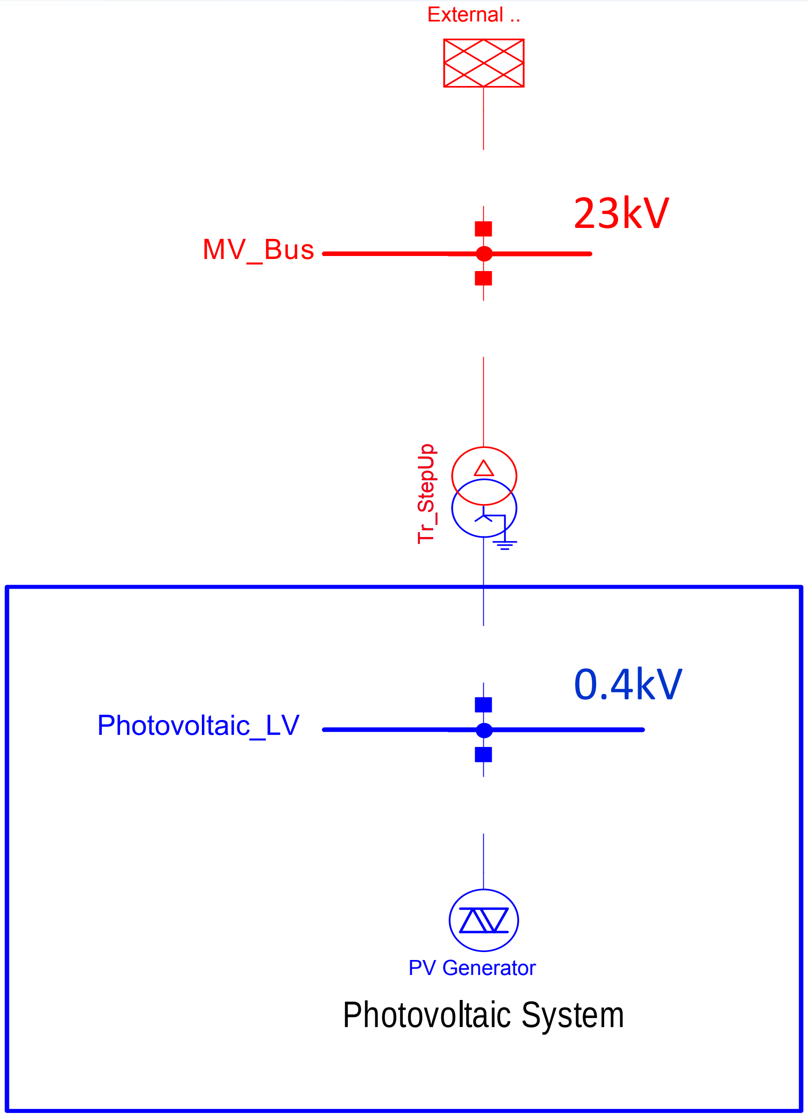
# The model




- PV system is modeled by a static generator
- Nominal capacity: 0.5 MVA
- Designed PF: 0.95
- Active power operational limits: 475 kW

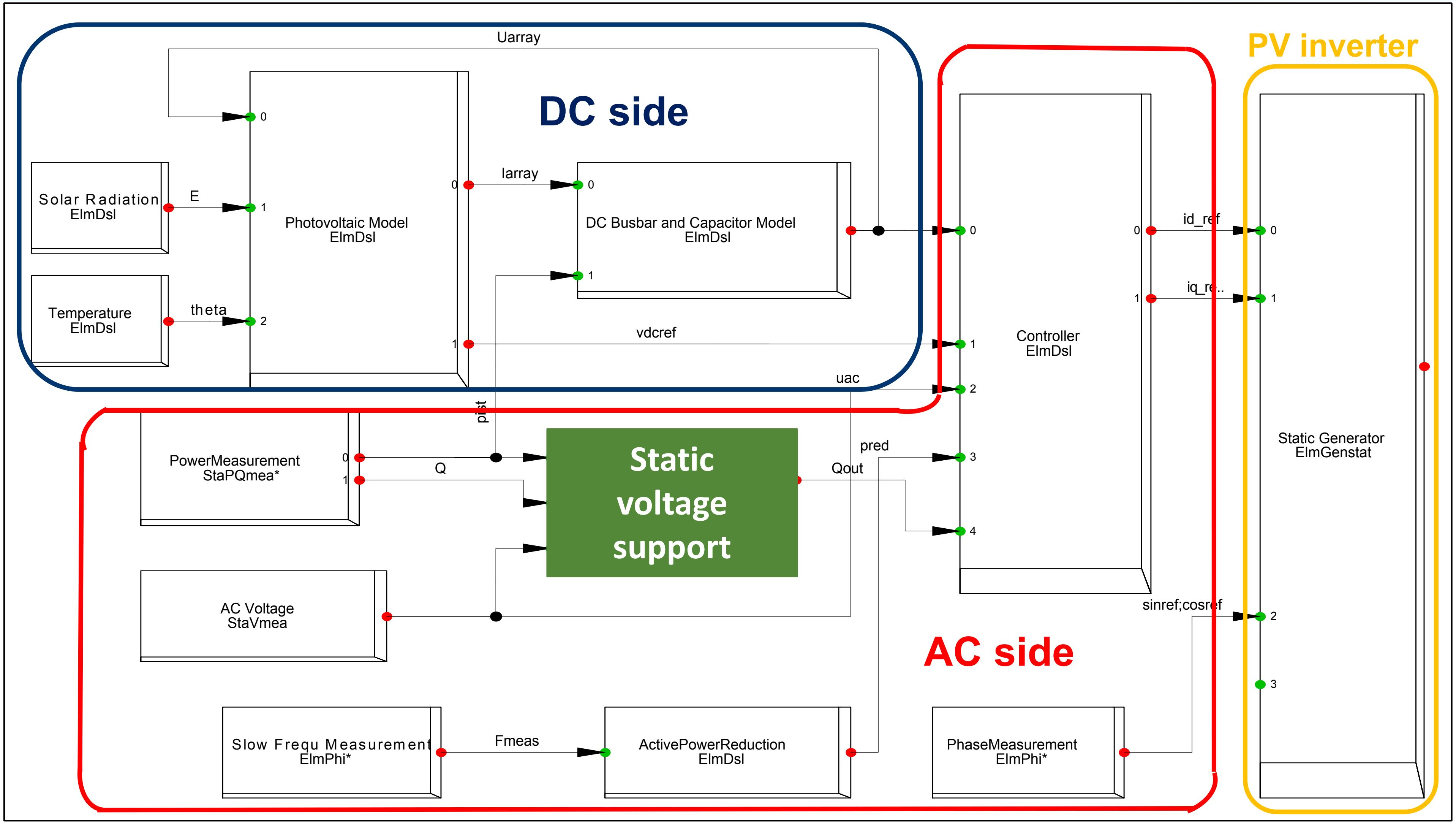
***Steady state operation***

- Active power supply: 450 kW

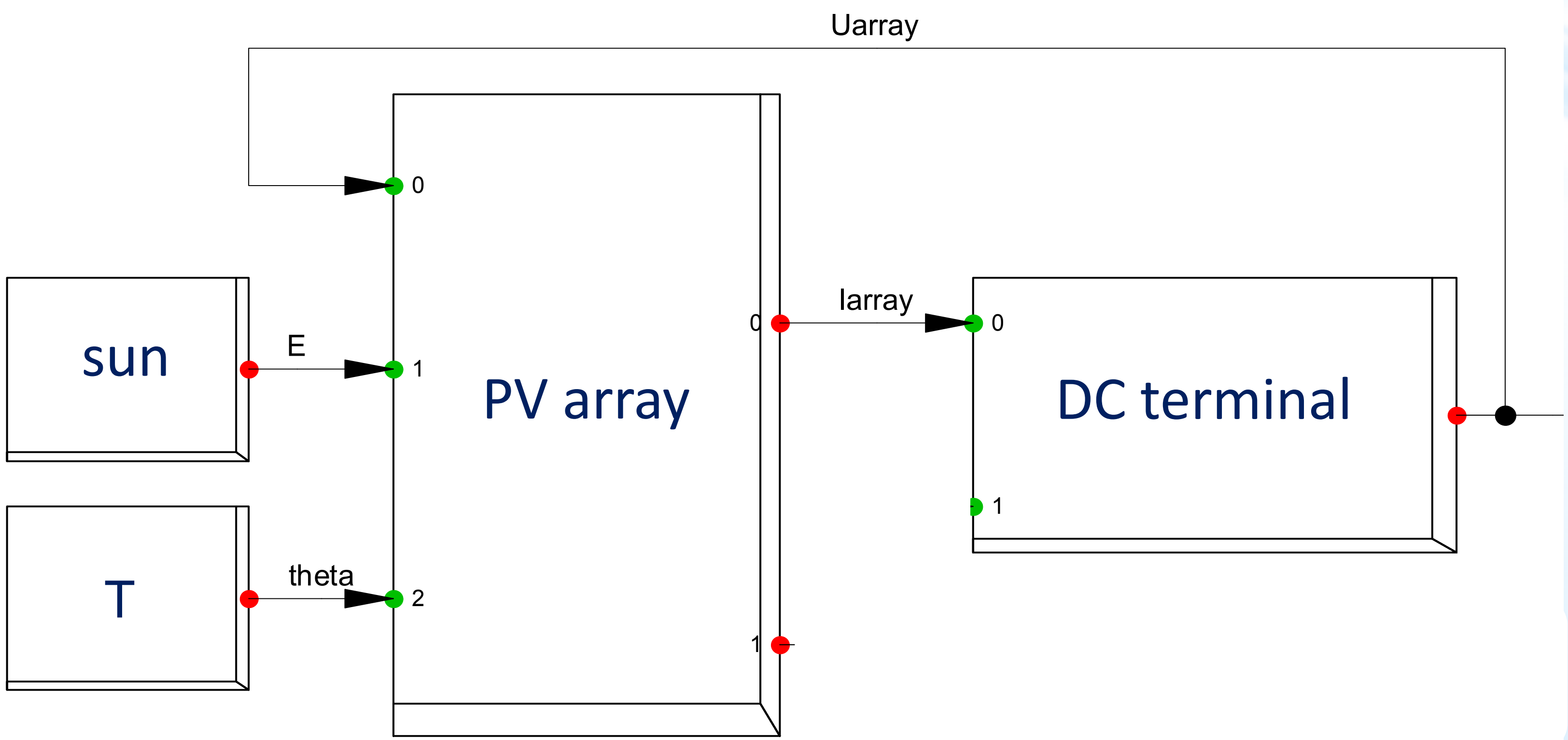
(defined by the configuration of the PV array)

- Reactive power supply: 0 kVar ($\cos\phi = 1$)

# The control frame



# The DC side




- The array outputs are based on the ideal cell model. Temperature corrections and module interconnection
- The voltage input of the inverter is calculated in the DC terminal

# The AC side

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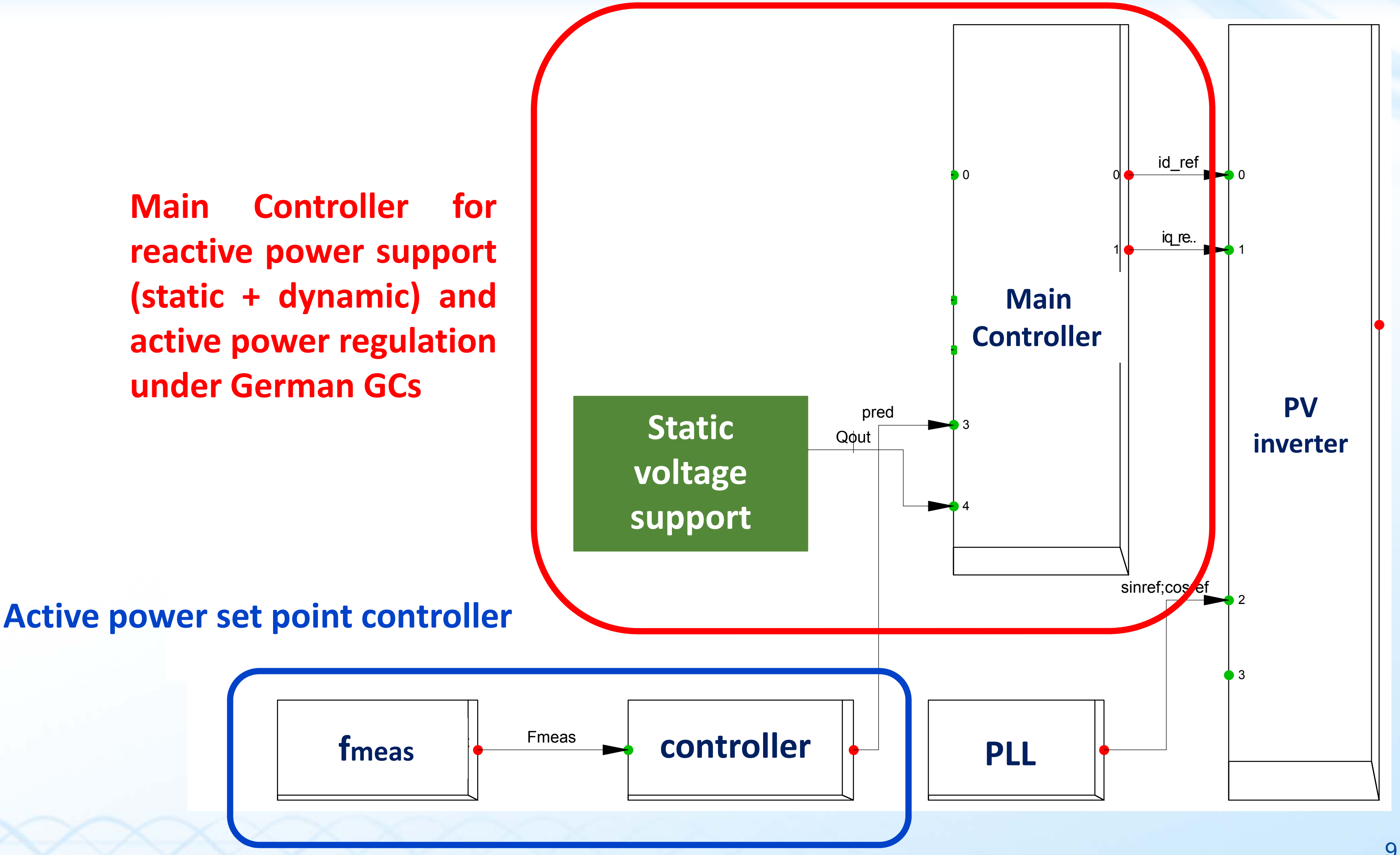

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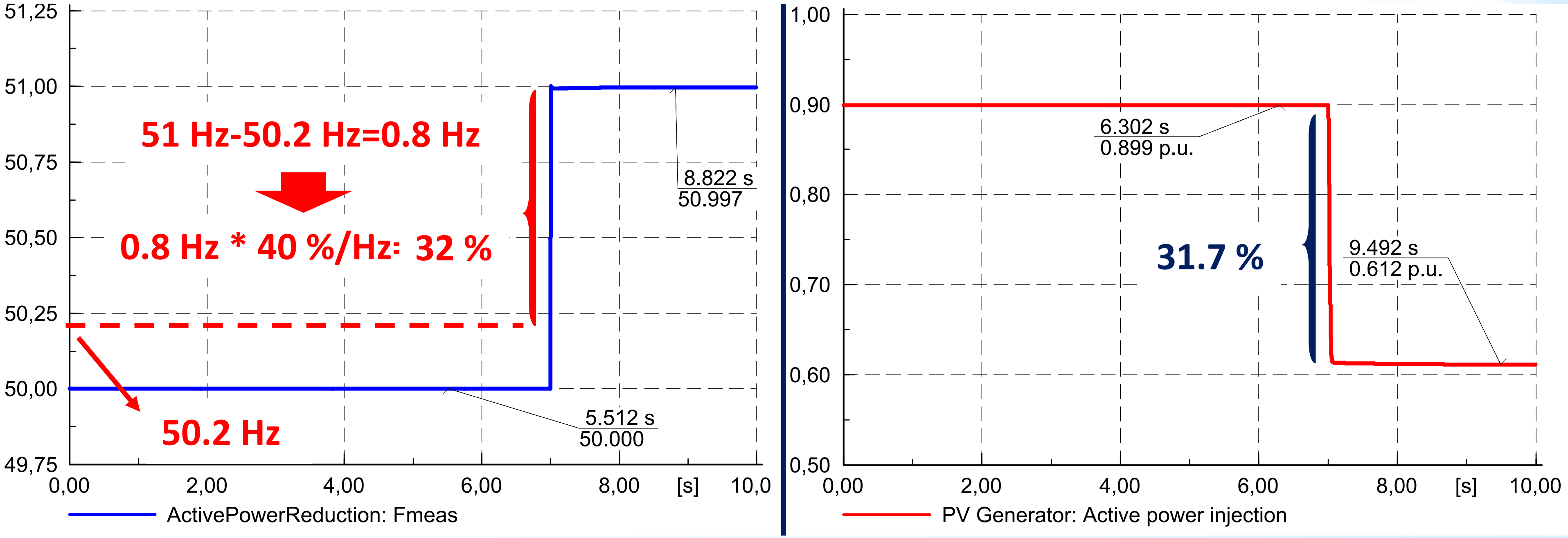
# Active Power Control

***Test:***

- Create an over-frequency event at 51 Hz




***Results:***

- The active power is being reduced from 0.9 p.u. to 0.61 p.u., meaning a reduction of ≈ **31.7%**
- The controller is effective with a dynamic response around 50 ms

# Dynamic voltage support-FRT

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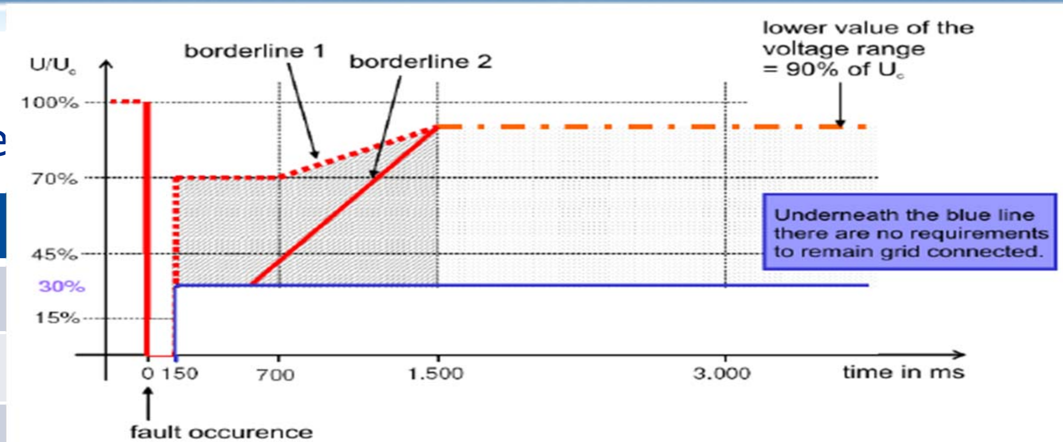
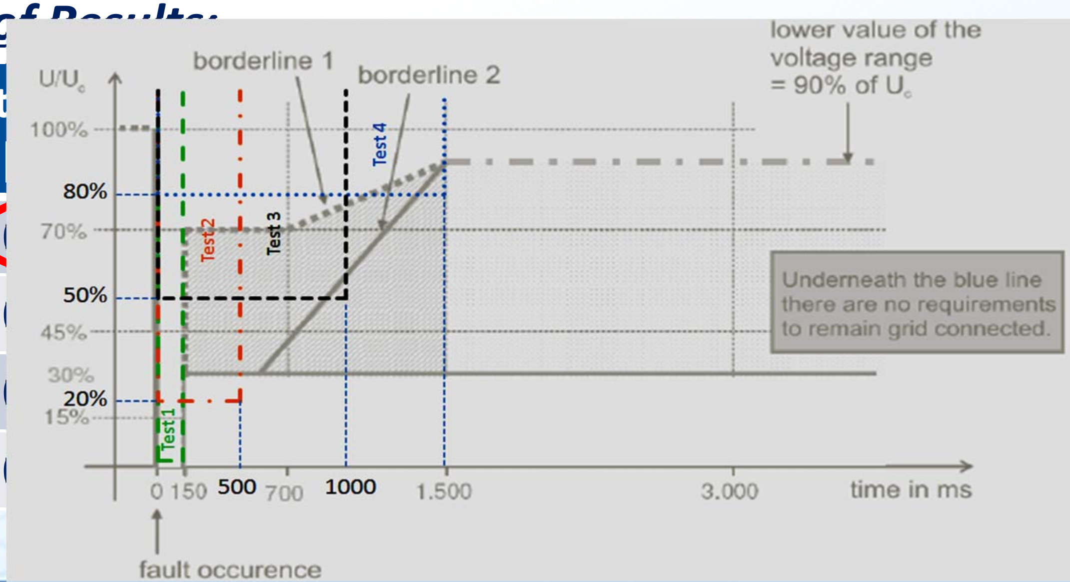
***Test:***

- Create four diffe… guidelines




| Test | | …ion of fault [ms] |
|---|---|---|
| 1 | | 150 |
| 2 | | 550 |
| 3 | 0,5 | 1000 |
| 4 | 0,8 | 1500 |

***Aggregate table of Results:***



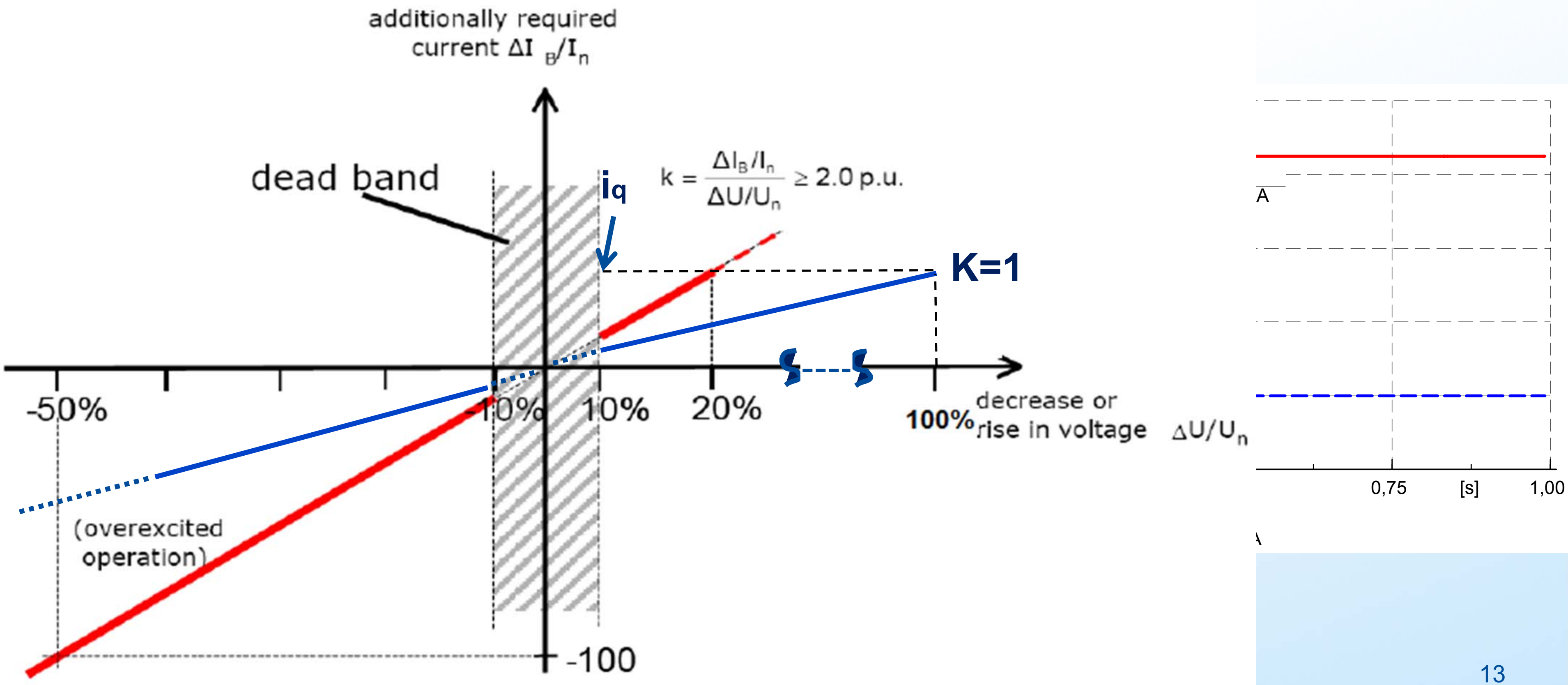

| Voltage dip [%] | Volt… | | Injected reactive current [kA] |
|---|---|---|---|
| 100 | ( | | 0,681 |
| 80 | ( | | 0,542 |
| 50 | ( | | 0,342 |
| 20 | ( | | 0,119 |

# Example of 100% voltage dip

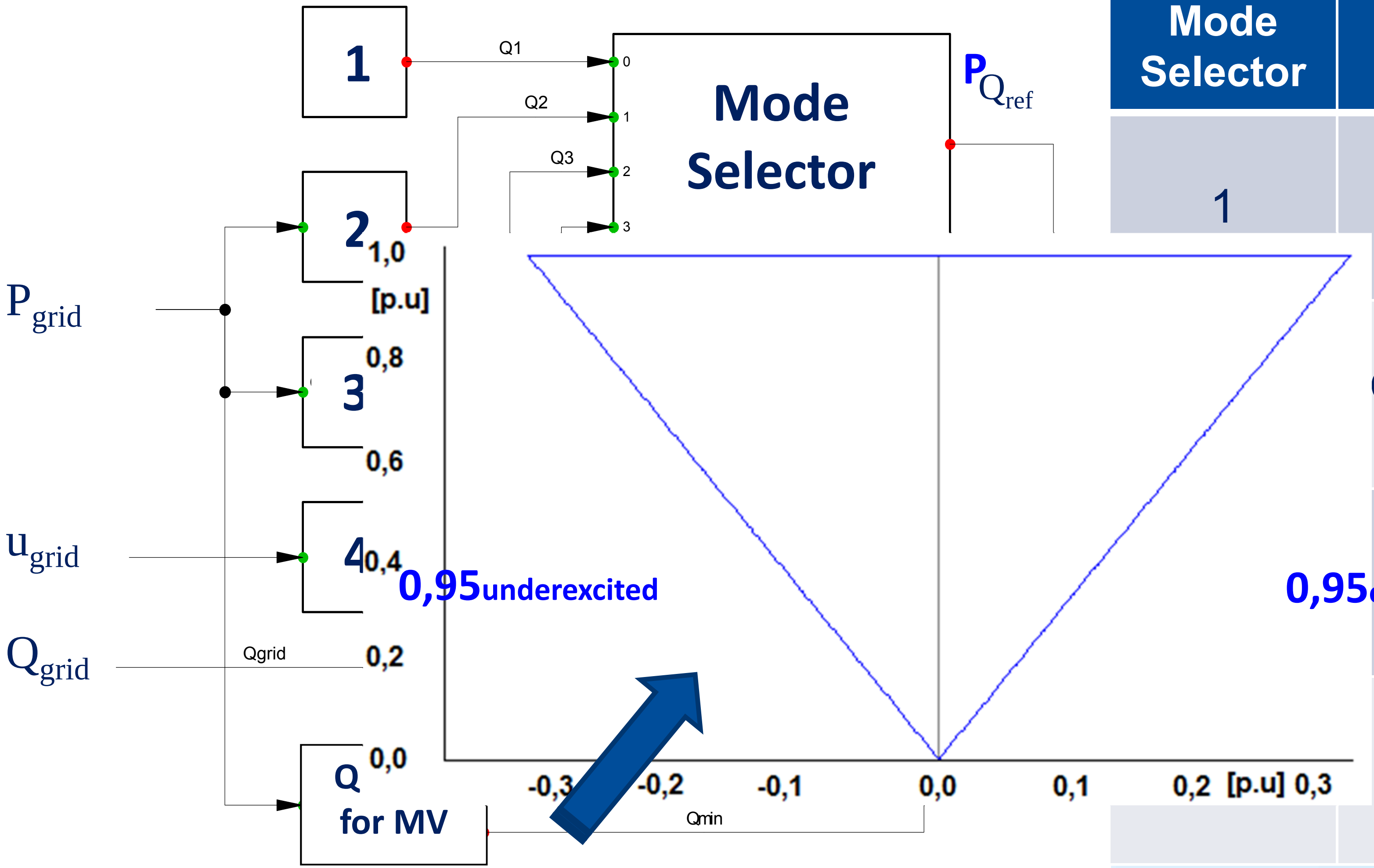
- The reactive current injection:

$$i_q = K\left|du_{ac}\right|$$

where, $du_{ac} = u_{ac\ \text{before fault}} - u_{ac\ \text{during the fault}}$ and K=1



# Static voltage support/Controller




| Mode Selector | Method of Q supply |
| --- | --- |
| 1 | Constant Q |
| | Constant cosφ |
| | Function cosφ(P) |
| | Function Q(U) |

Q

# Static voltage support/Results (1)

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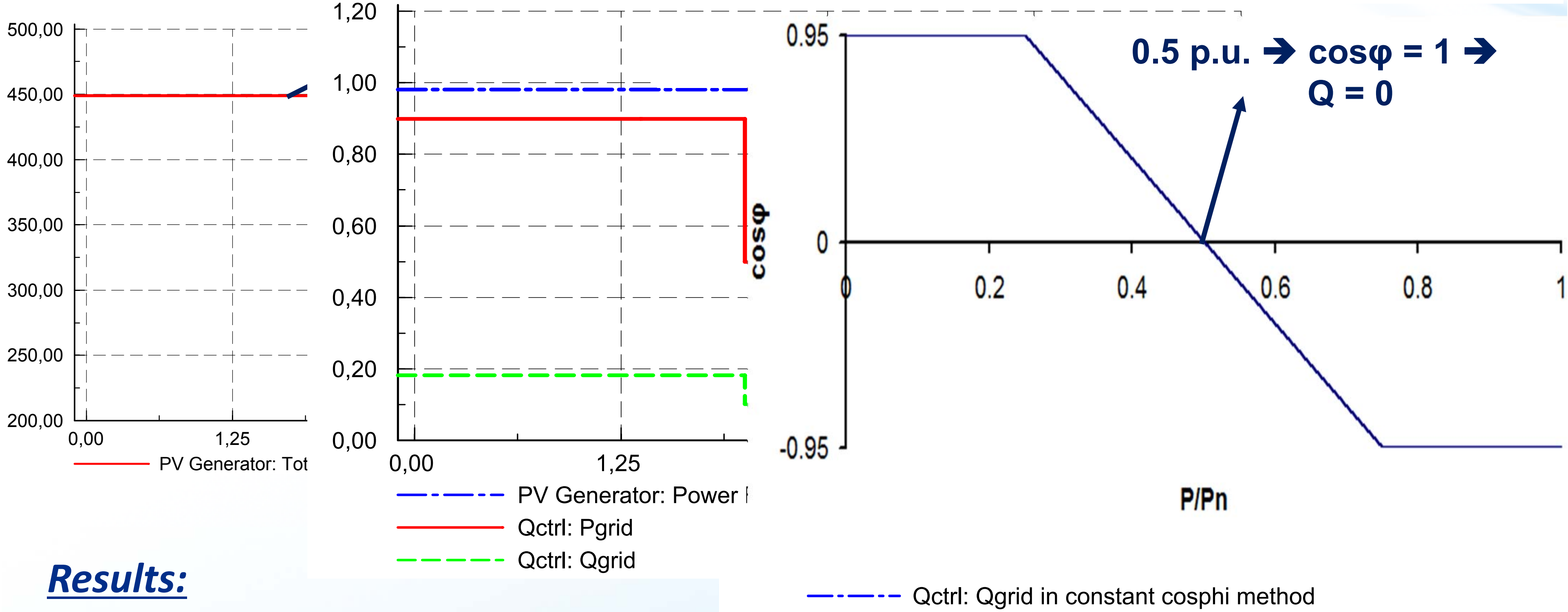
***Test:***

- Create a reduction in the active power injection (examine $Q_{fix}$ $\cos\phi_{fix}$, $\cos\phi$ (P) modes)




***Results:***

- Q supply based on a given set-point
- Q supply by keeping the power factor constant in active power changes
- Q supply based on a characteristic

# Static voltage support/Results (2)

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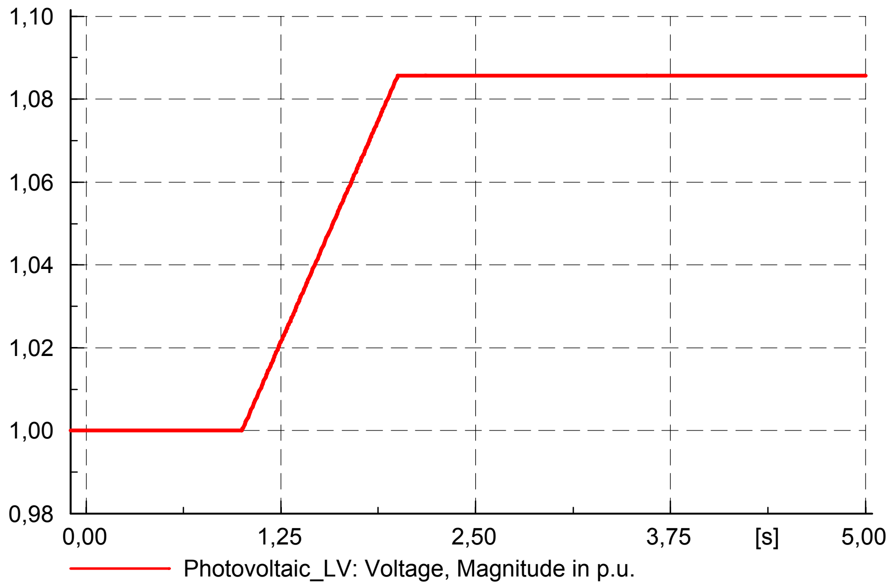
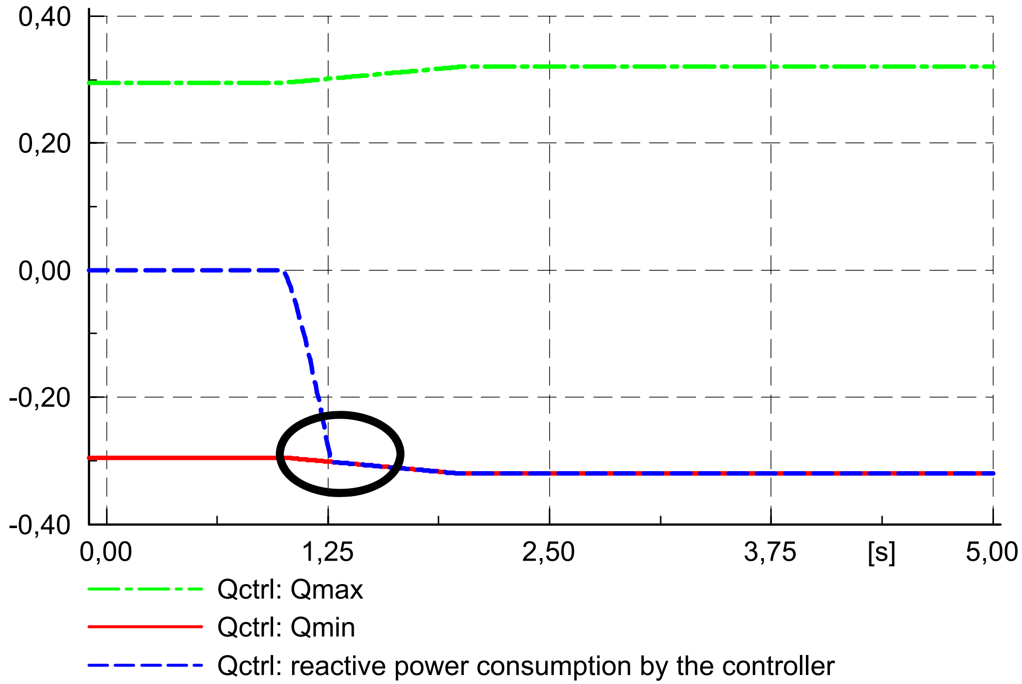
## Test:

- Create an overvoltage within normal limits




## Results:

- The inverter consumes reactive power due to the overvoltage based on a droop
- The controller reaches and operates in the reactive power limitations

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# Conclusions - Recommendations

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**Conclusions:**

The model is capable of:

- Active power control requirement
- LVRT requirement-Dynamic voltage support
- Static voltage support (four-mode controller)

**Recommendations:**

Further studies:

- Testing the PV model and control scheme under different Grid Codes (UK, Denmark, Spain, France etc)
- Enhance the model and perform more detail and sensitive protection studies (e.g. over/under - voltage studies, over/under - frequency studies)

# Thank you for your attention

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Mange tak ...

Vielen Dank ...

Ευχαριστώ ...

*Darmstadt, Germany : http://www.study-in.de/en/leben/staedte-info--11793*