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Equivalent circuit models

Modelling the electrical energy supply of electrolysis plant under fault conditions

Workshop „Modeling of electrolysis plants on component and system level“

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Agenda

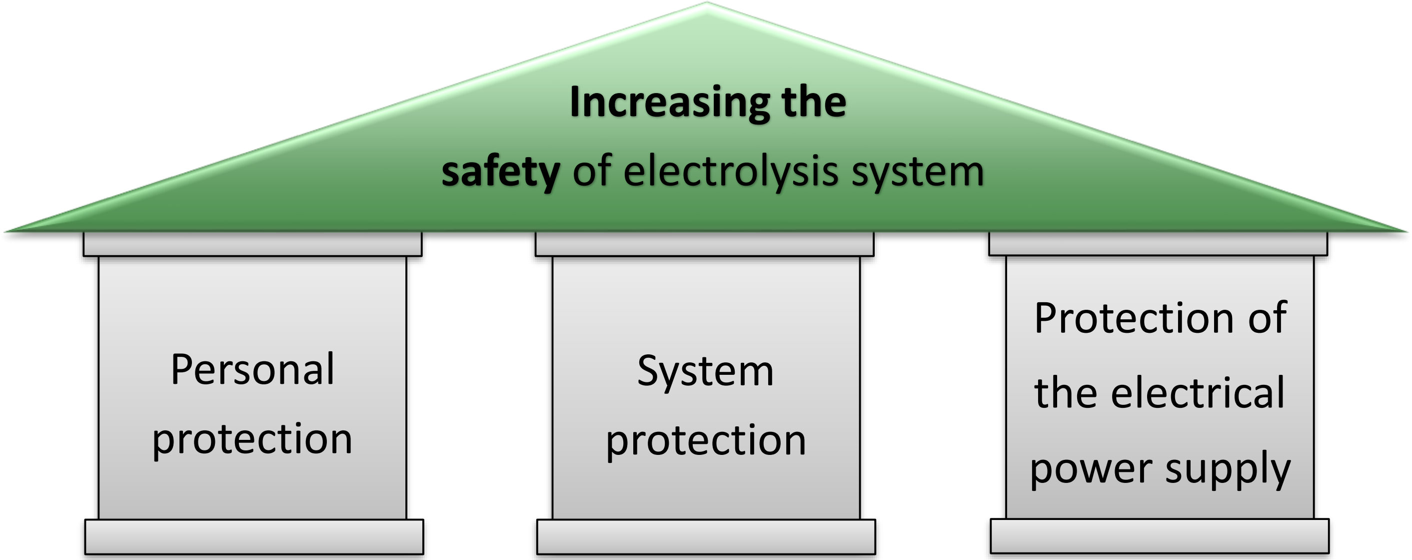
- Motivation and Introduction
- Experimental investigation on 50 kW PEM electrolyser at Forschungszentrum Jülich (FZJ)
- Equivalent circuit model of electrolyser for short circuit

Figure 1: Investigation of high-current fault arc in the Lab at TUD (fault current = 10 kA)

Motivation and Introduction

Motivation

- Overall GOAL:



- Specific GOAL:
  - **Design of an adaptive protection system for electrolysis systems (ELS)**

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Motivation and Introduction

Protection system and protection function

Protection system (PS)

- Electrical power system is divided in several protection zones (PZ)
- Each zone is protected by one protection device (or more)
- PS = Combination of all protection devices

Protection function (PF)

- State estimation of the associated zone based on measurement
- Result: zone is in operating / error status
- Off-Signal to Switch
- Implementation on Protection device (PD)

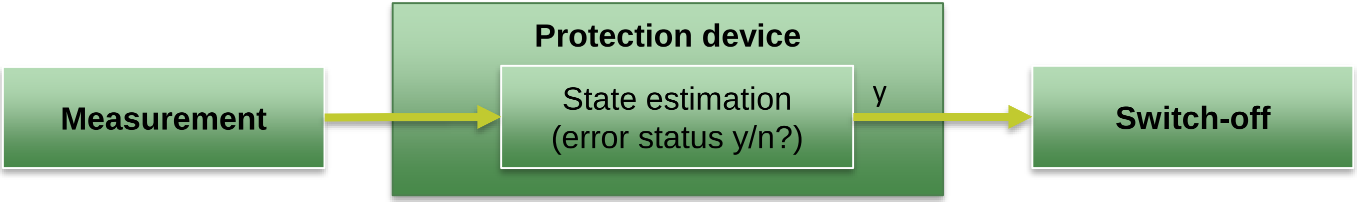


Figure 1: Schematic structure of a protective function with sub-functions

Motivation and Introduction

Protection function: **overcurrent**

- State estimation based on electrical current
- Requirement: rated and fault current ranges must not overlap

Rated currents and fault currents must be known for applicability

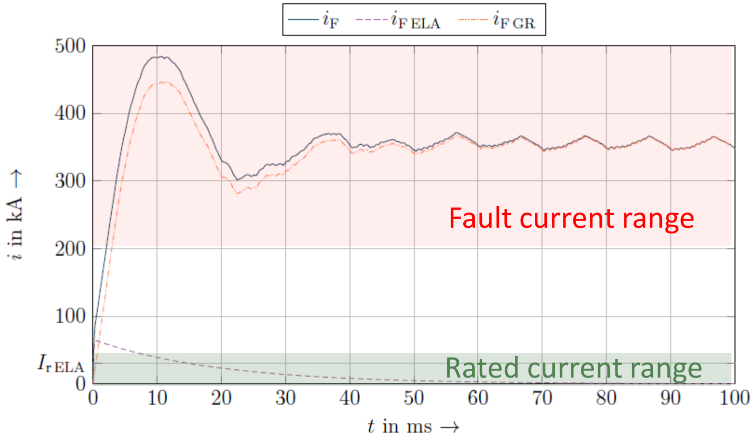
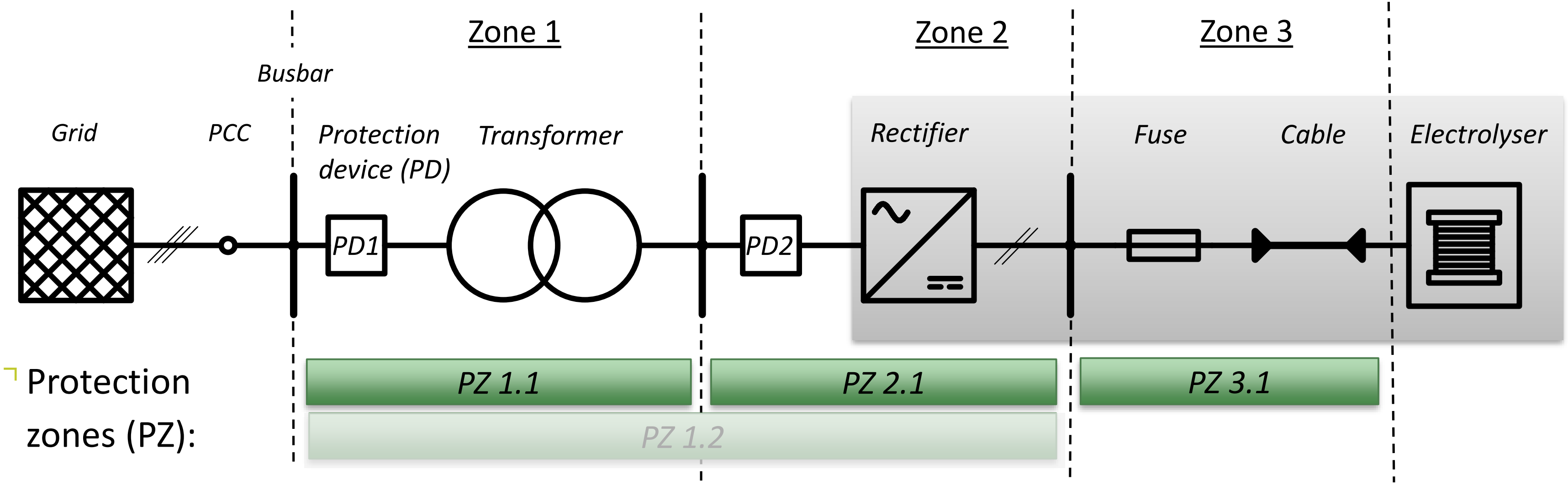


Figure 1: Curve of the fault current components $i_{F\,ELA}$ and $i_{F\,GR}$ of fault current i_F with metallic fault [3]

Motivation and Introduction

Protection system design for electrolysis systems (ELS)

- **Electrical power supply of an ELS (simplified equivalent circuit diagram):**

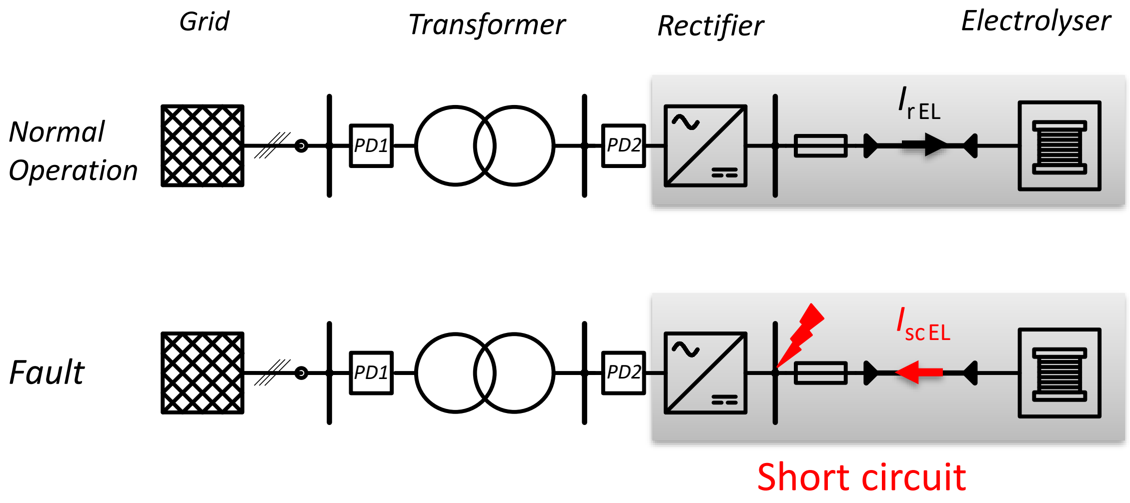


- Protection zones (PZ):

PCC … Point of common coupling

Motivation and Introduction

Behaviour of electrolysers in the event of a short circuit in the ELS



- Under fault conditions:
  - Voltage keeps the same sign
  - Reversal of current direction

No Information about electrical behaviour of electrolyser in literature

Motivation and Introduction

Determination of the Short-circuit current from electrolysers

- **Experimental investigation on 50 kW PEM electrolyser at *FZJ***
  - Experimental setup
  - Characterisation of the short-circuit current
  - Influence of system variables
- **Determination of an equivalent circuit diagram to describe the electrical behaviour of electrolysers in the event of a short circuit**

Equivalent circuit model of electrolyser for short circuit

Experimental investigation on 50 kW PEM electrolyser at *FZJ*

Experimental setup

- State 1 (S1 closed, S2 open): Normal operation
- State 2 (S1 open, S2 closed): Short circuit
- Current measurement: Zero flux current transducers
- Short circuiter (S2): Thyristor

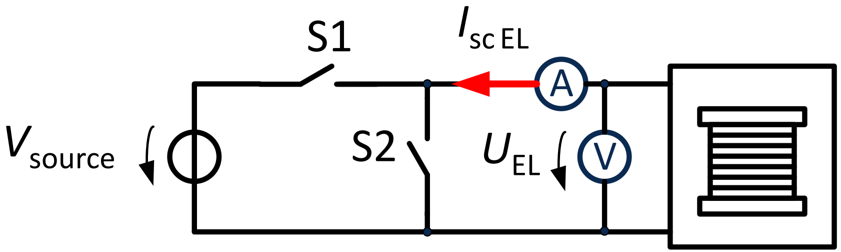


Figure 1: Equivalent circuit diagram of test setup at the FZJ

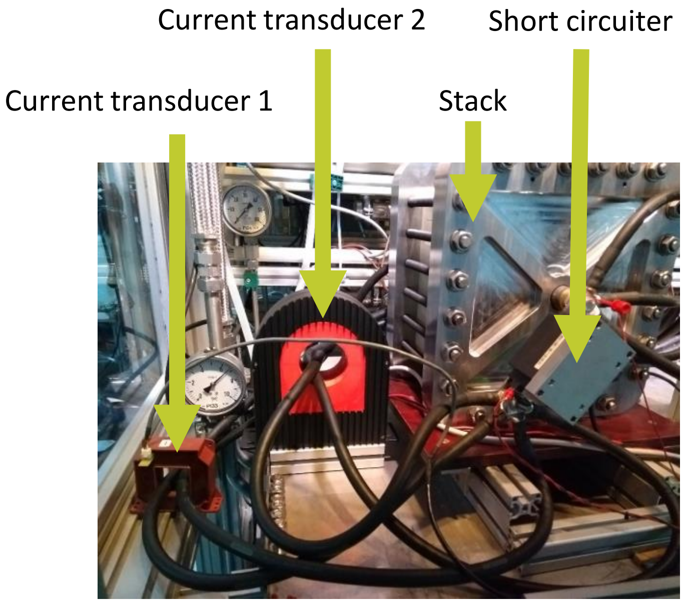


Figure 2: Test setup with 50 kW electrolysis stack at the FZJ [4]

Experimental investigation on 50 kW PEM electrolyser at FZJ

- **Characterisation of the short-circuit current**
  - Steep rise in current after fault occurrence
  - After reaching maximum: exponential drop in short-circuit current (with single time constant)

- **Peak of $I_{sc\ EL}$ is up to five times the rated current $I_{r\ EL}$**
- **No fuel cell operation visible**
- **Short circuit behaviour similar to capacity**

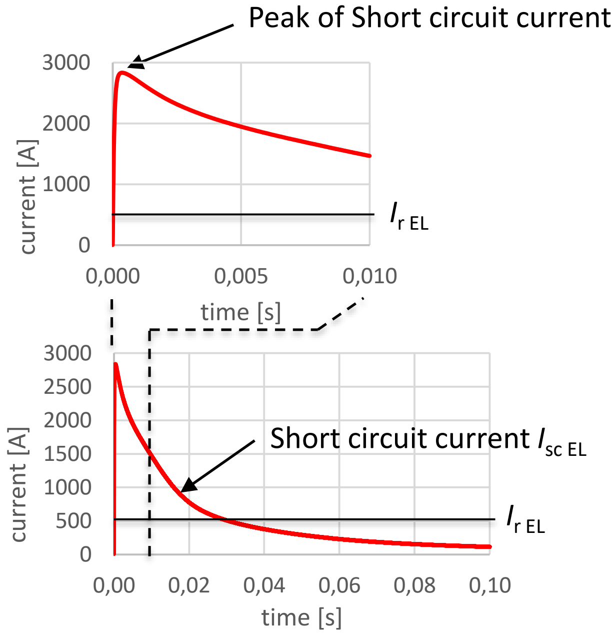


Figure 1: Time curve of the short-circuit current with peak value from a 50 kW electrolysis stack with an external short circuit [4]

Leitprojekt H_2Giga

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Experimental investigation on 50 kW PEM electrolyser at FZJ

Influence of system variables

System variables	*Influence*
Catalytic configuration	High
Membrane thickness	High
Operating current	Medium
Stack temperature	Medium
Gas pressure	Medium

- Parameters of stack have higher influence than the operating conditions

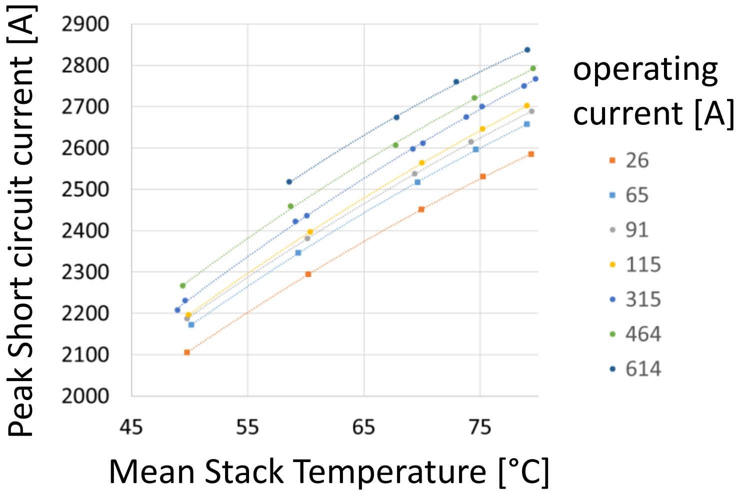


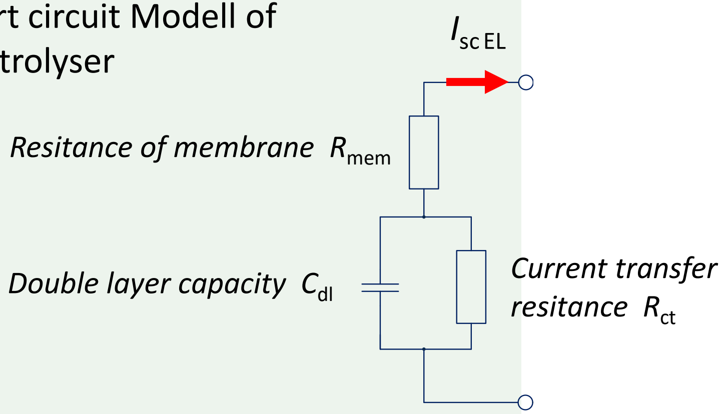
Figure 1: Influence of Stack temperature and operating current on the peak instantaneous value of the short-circuit current (average gas pressure 0.2 barg) [4]

Equivalent circuit model of electrolyser for short circuit

Determination of model parameters

- **Method**: Fitting the elements of equivalent circuit diagram from measurend data
- **Requirement**: Estimation of the parameters of the test circuit

Short circuit Modell of Electrolyser



Equivalent circuit model of electrolyser for short circuit

Outlook

- Analysing electrolysis plants in the MW range: **model must be scalable**
- Research requirement: **Validation of the scaling of the model**

Table 1: Overview about the system parameters of am 50 kW electrolyser and assumptions for MW range [4]

Parameters	Electrolyser FZJ	Electrolyser plant in MW range
Power [kW]	50	1000
Area of the membrane [cm²]	300	1000
Number of cells in series	27	250
Nominal current density [A/cm²]	2,0	2,0
Nominal cell voltage [V]	1,9	2,0

How to scale the model parameters ?

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Thank you for your attention!

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References

[1] Doemeland, O. W.; Götz, K.: *Handbuch Schutztechnik. Grundlagen Schutzsysteme Inbetriebsetzung*. 8. Auflage, HUSS_Medien GmbH, Berlin, 2007.

[2] Clemens, H.; Rothe, K.: *Schutztechnik in Elektroenergiesystemen*. 3. Auflage, Berlin: Verl. Technik, 1991.

[3] Leide, J.: *Aufbau eines dynamischen Modells der elektrischen Energieversorgung einer Elektrolyseanlage zur Untersuchung des Systemverhaltens*. TU Dresden, Dresden, 2023.

[4] Institute of Energy and Climate Research, Electrochemical Process Engineering (IEK-14), Forschungszentrum Jülich within a project cooperation with SMA Solar Technology AG.