Dr. Hans-Joachim Herrmann, EM DG PRO LM PR

Open Phase Failure on the HV-Side of Power Plants Requires New Protection Solutions

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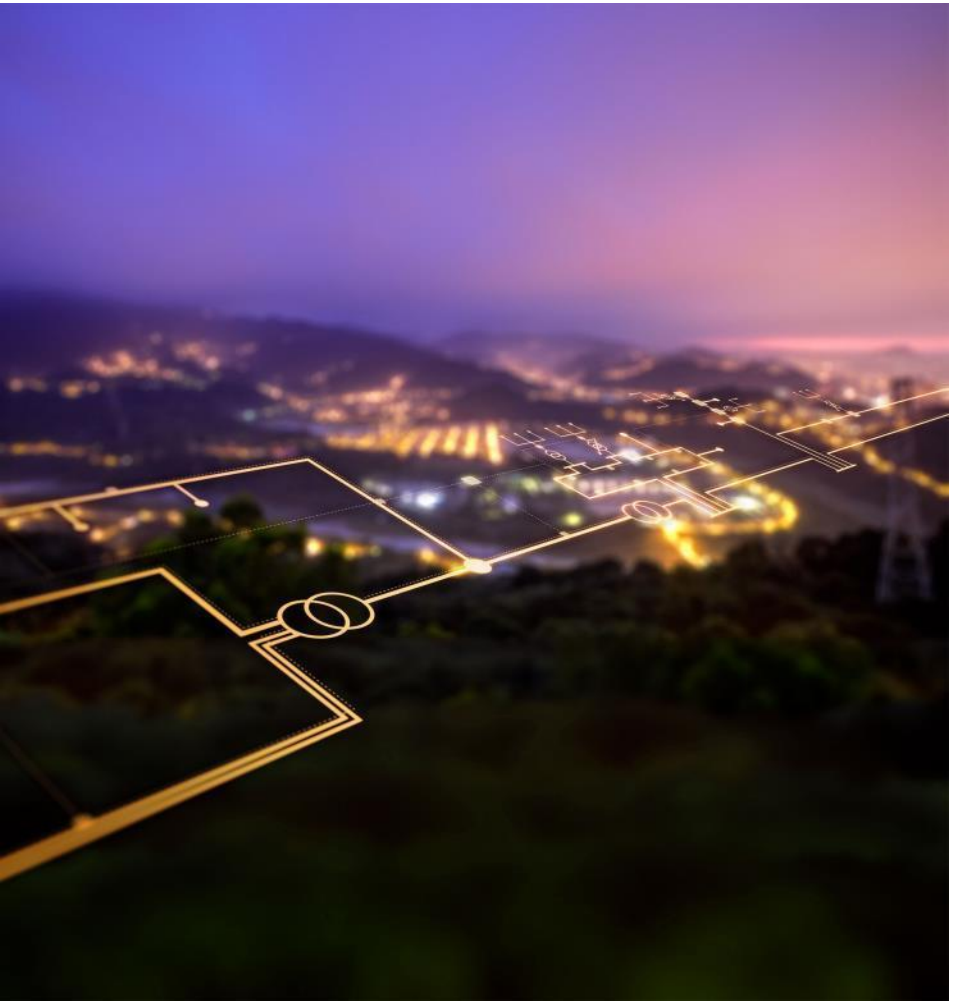
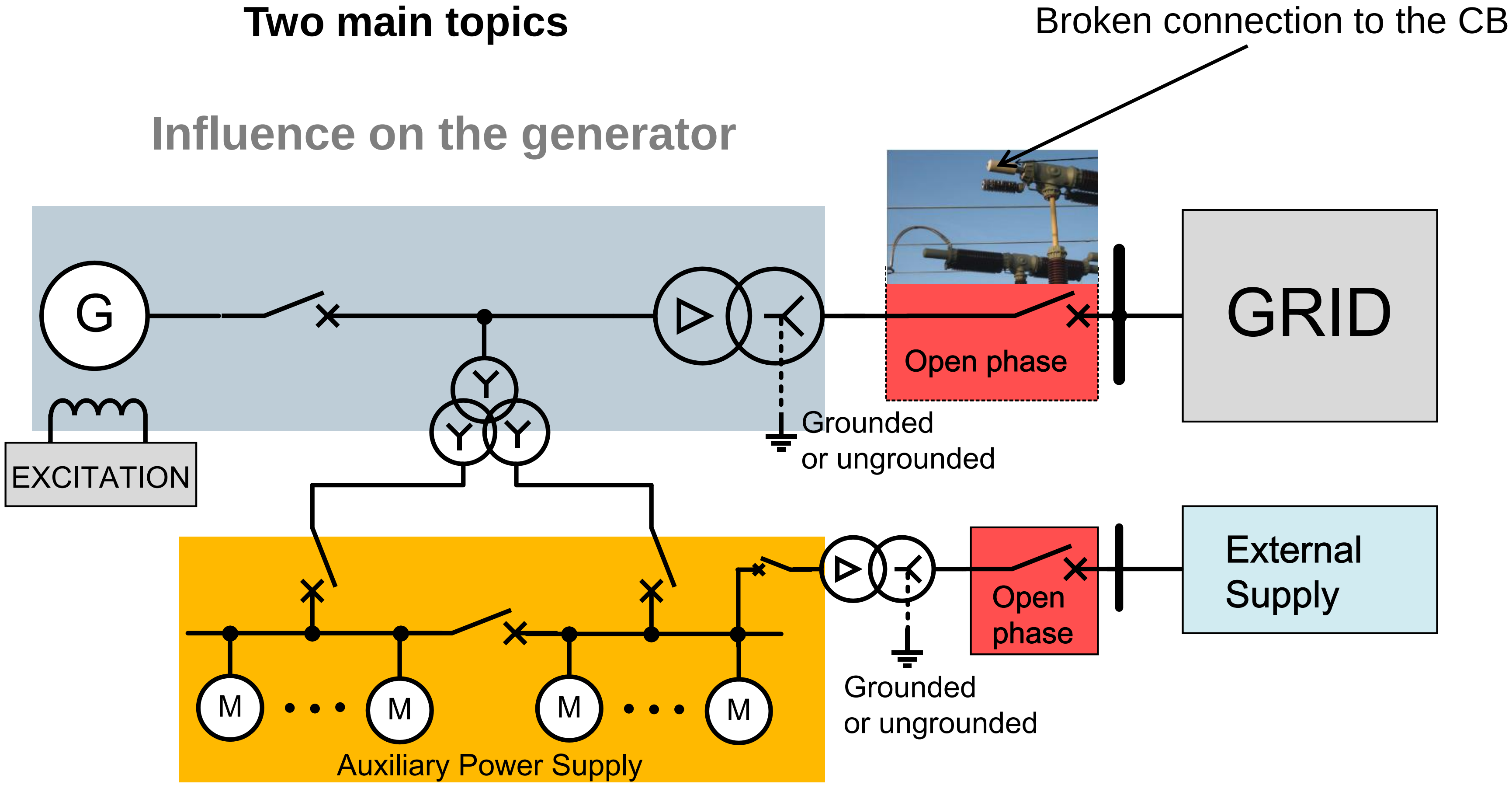


- Introduction of open phase failure
- Influence on the generator-transformer unit
  - Proposal for an additional protection
- Influence on the auxiliary power supply
  - Discussion of the problem
  - Proposal for a protection solution

Power system structure and open phase failure situation

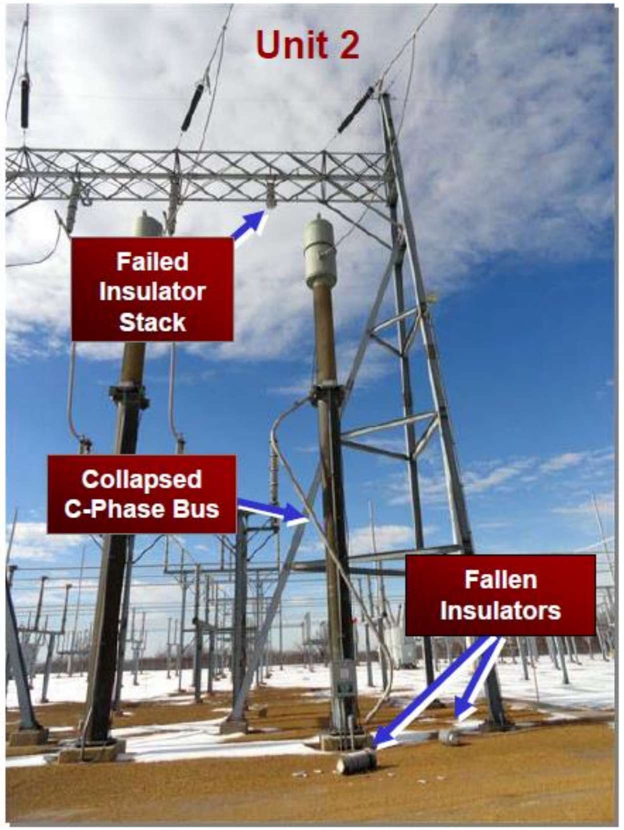
Two main topics

Influence on the generator

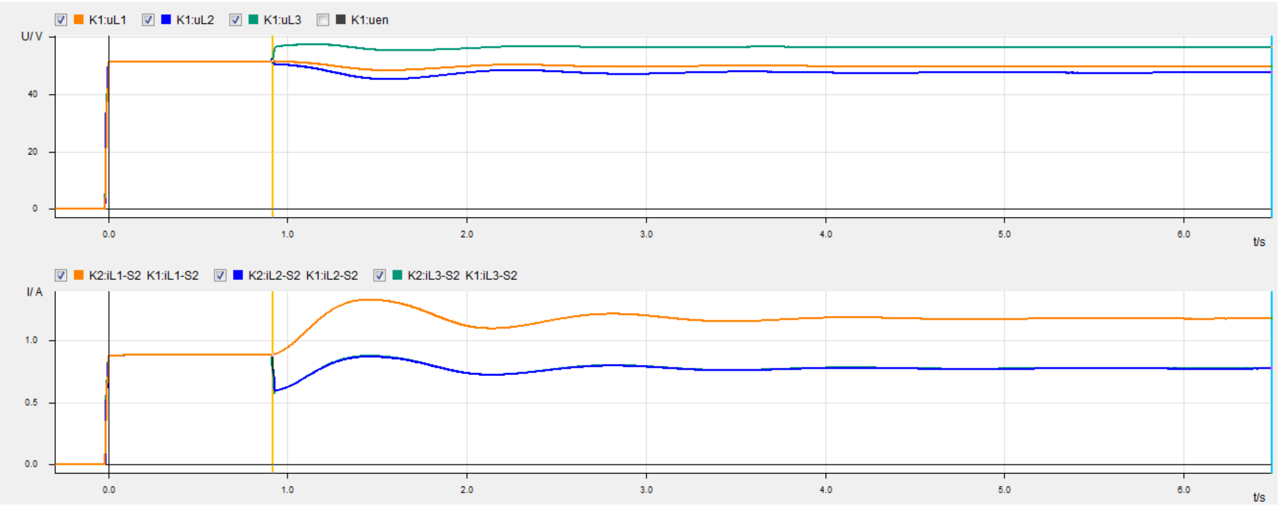


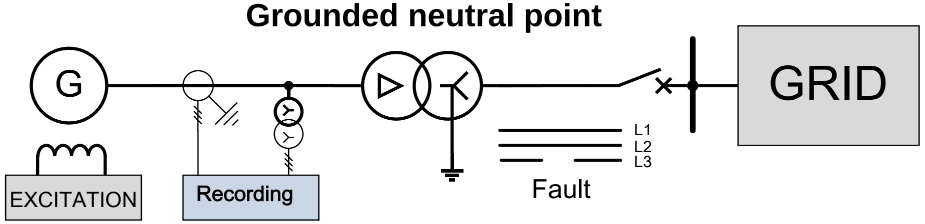
Influence on the auxiliary power supply

Byron Failure

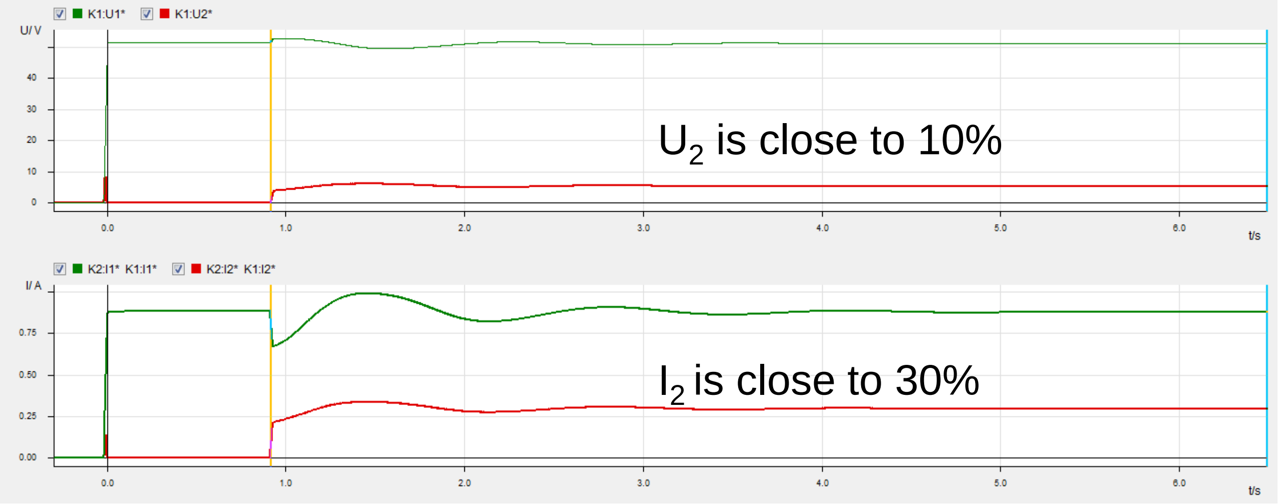


Influence on generator (one open phase failure)
Grounded transformer neutral point





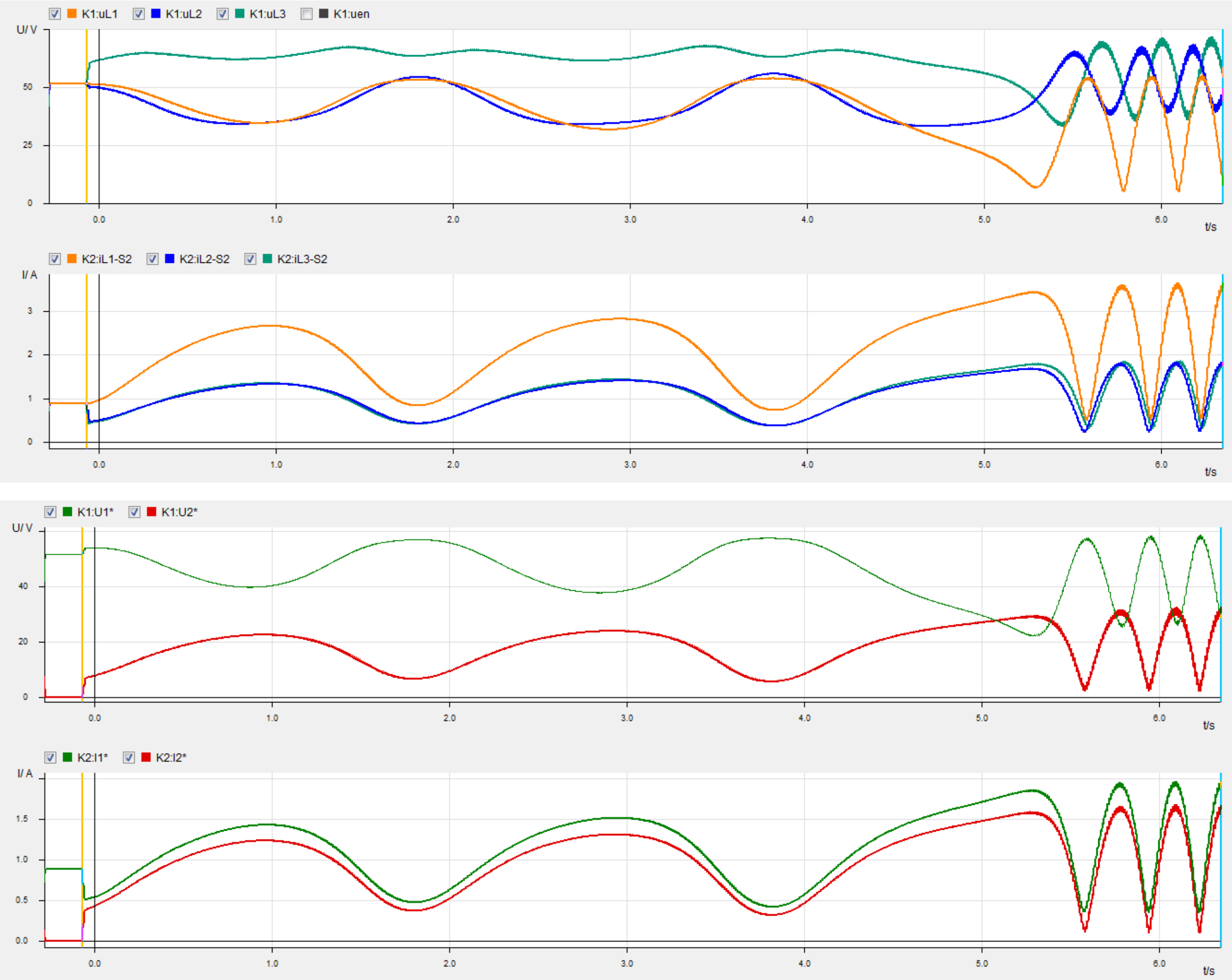
After a short transient period there are stable conditions
(depending on the load and settings overcurrent protection can pickup in one phase)



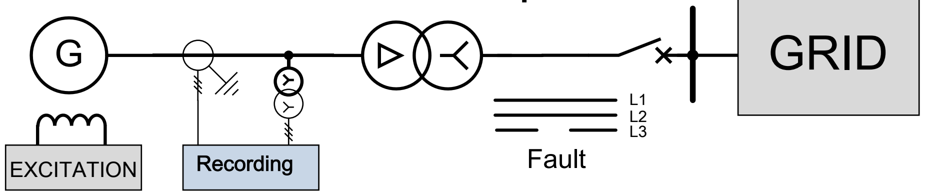
Measurable negative sequence voltage

A higher negative sequence current flows. Thermal negative sequence protection trips after seconds (I_2^2 * t = 5 s →trip after 55,5s)

Influence on generator (one open phase failure)
Isolated transformer neutral point



Isolated neutral point



The generator becomes instable and after few seconds an asynchronous condition occurs

High negative sequence voltage, but the voltage swings (a chattering of a U_2-function is possible)

High negative sequence current; he swings synchronous with the positive sequence current (I_2-protection trips too late)

Influence on generator (one open phase failure)
Isolated transformer neutral point

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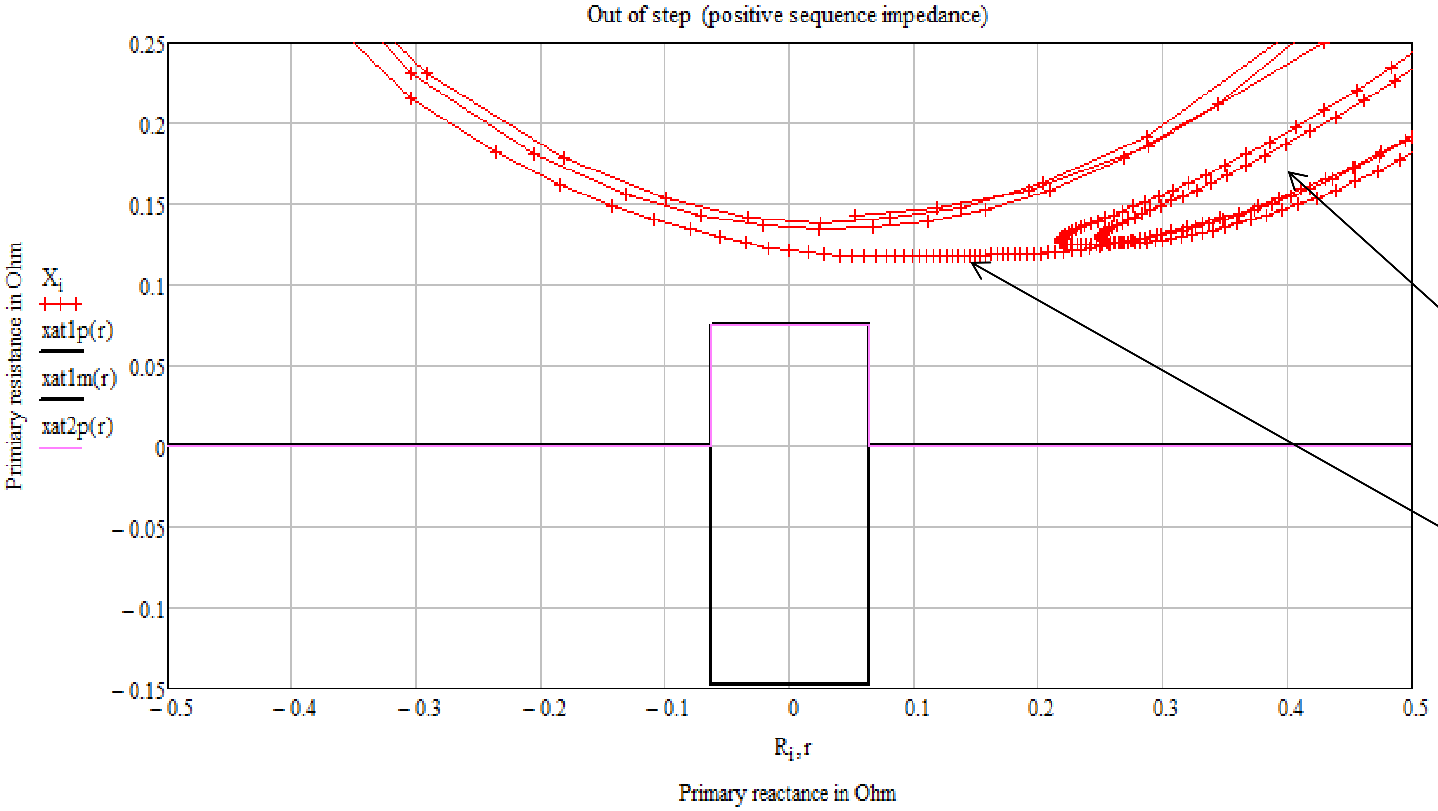
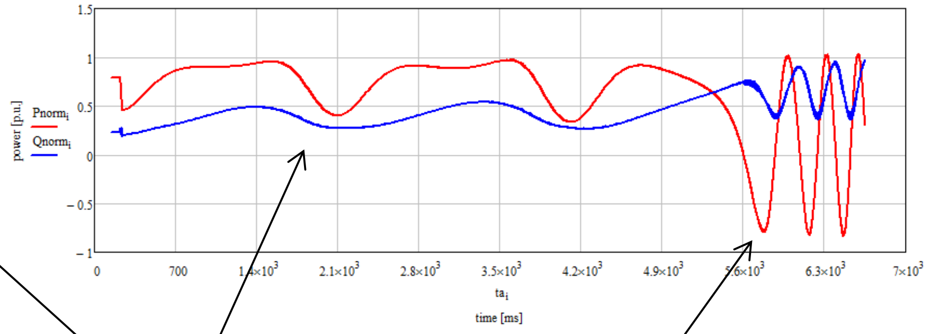
Impedance trajectory



Asynchronous power swing

(red = active power P; blue = reactive power Q)

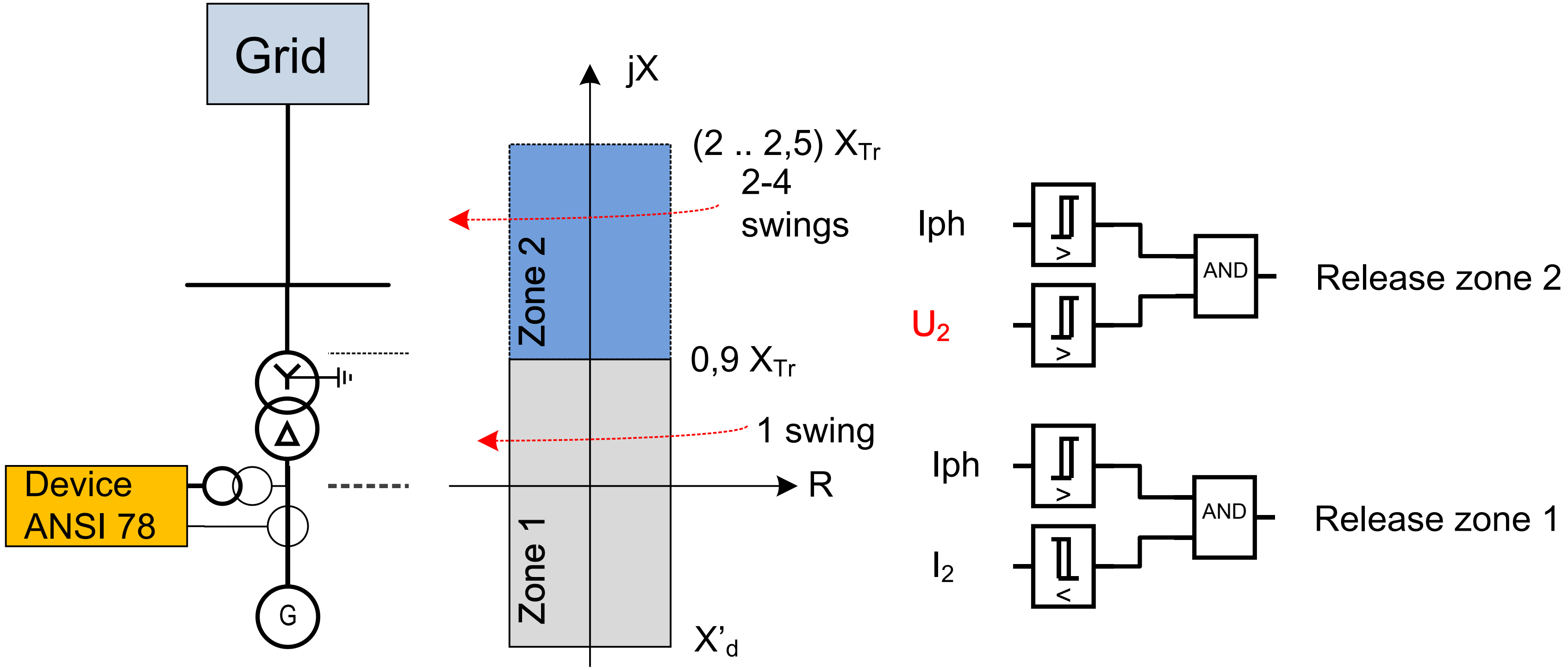


Synchronous swing

Asynchronous swing

The generator falls out of step (out of synchronism) and this event stresses the turbine and generator

Proposed solution
Additional characteristic for the out of step protection (ANSI 78)



Possible device: **7UM85**

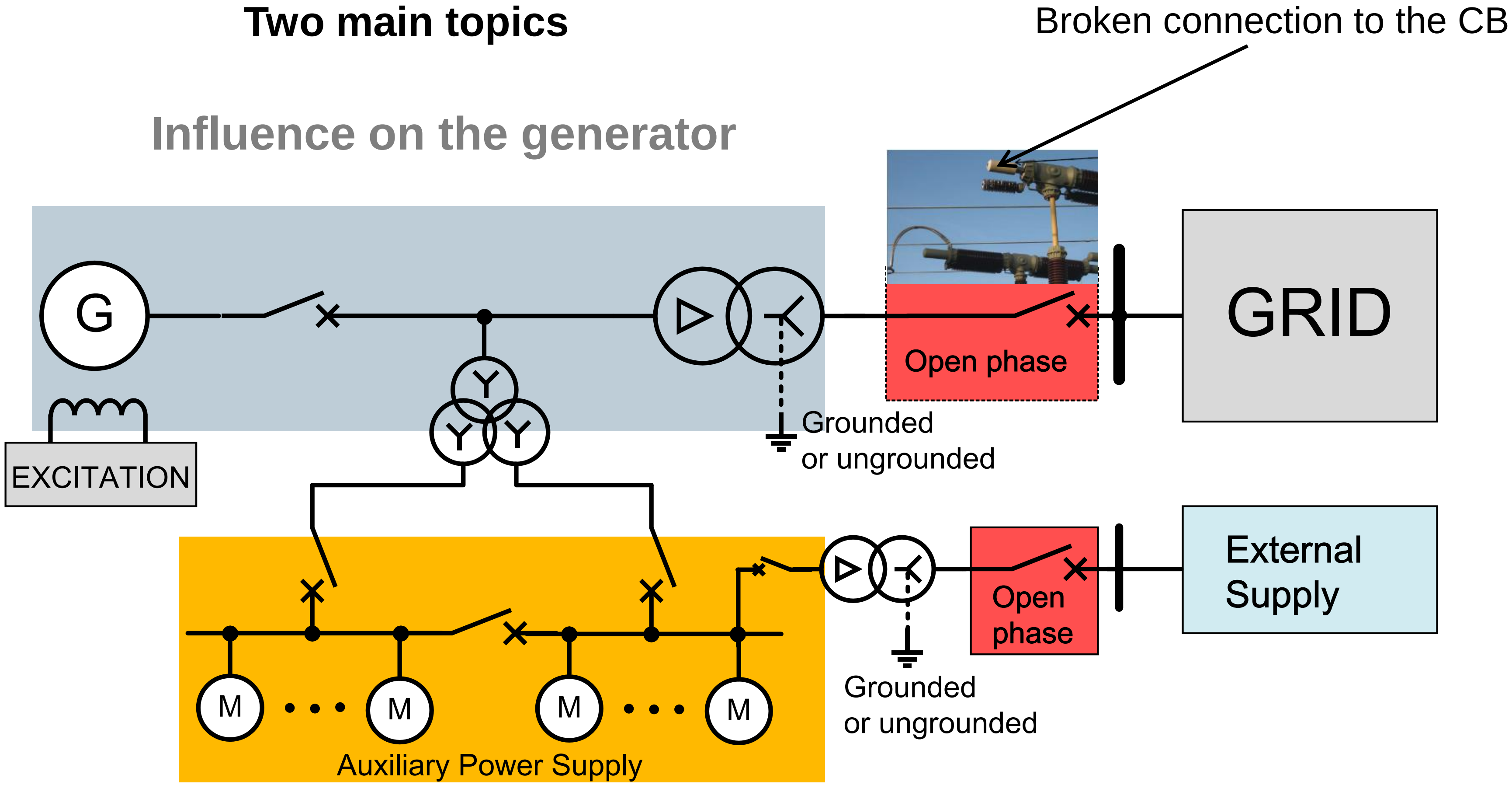
- More zones are possible (U_2 release via CFC)
- Sensitive and accurate measurement of a low negative sequence voltages (U_2)
- Additional U_2 alarm is possible or U_2 protection function

Power system structure and open phase failure situation

Influence on the auxiliary power supply

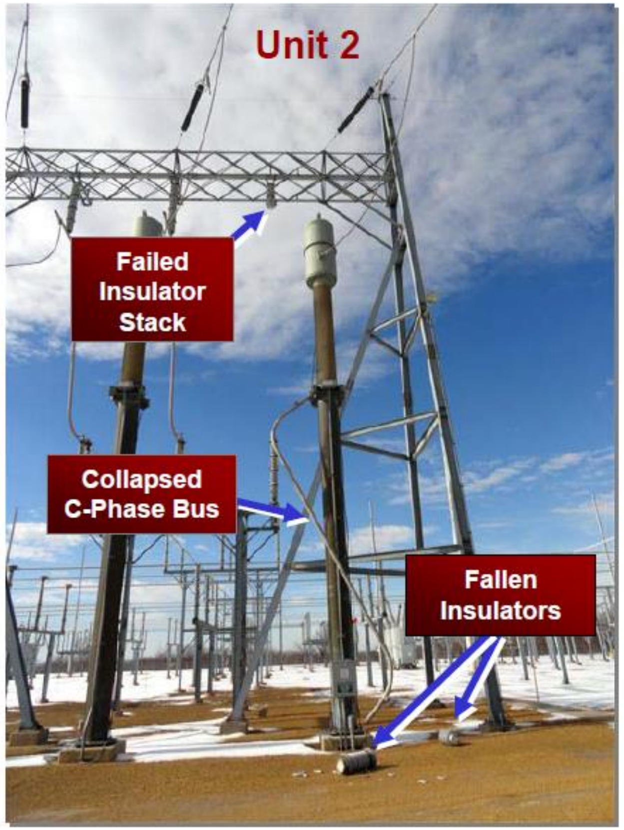
Two main topics

Influence on the generator



Influence on the auxiliary power supply

Byron Failure



Thermal limits of induction (asynchronous) motors

In the technical data of the induction motor no limits for the negative sequence currents are given. Therefore some tests on motors are done and they showed the robustness of motors.

Results from a test in the Lab:

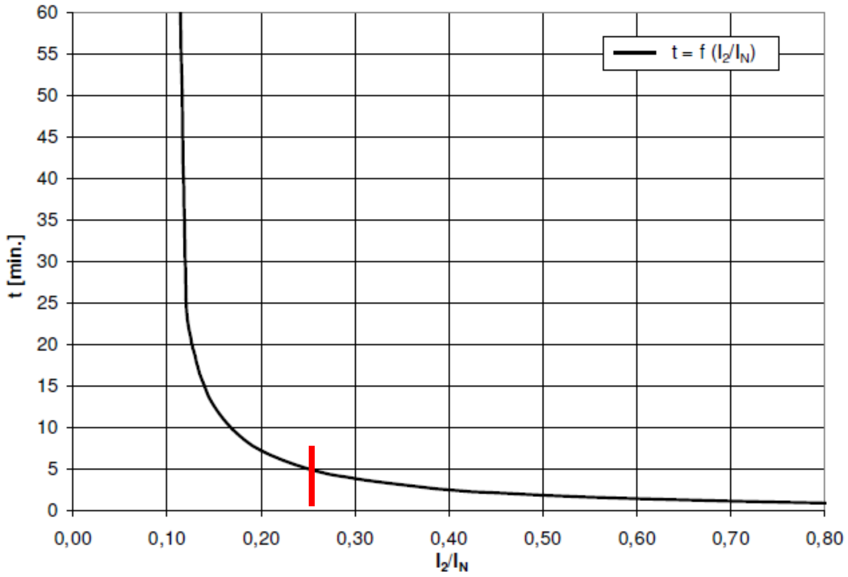
- 5% U_2/U_1 (app. 25%I_2)
- Motor operation 130min
- Winding temperature increased by12 K

- 50 %U_2/U_1 (app. 150%I_2)
- Motor operation 60 sec
- Winding temperature increased by120 K

Conclusion

The limits coming more from the protection due to the selected settings

Given curve from an induction motor:
U_N = 10 kV, I_N = 108 A; Thermal class: F/B



Max. permitted continuous asymmetrical current: $I_2/I_N = 0.12$

25 % I_2/I_N → allowed time 5 min (300s)

One open phase failure on the HV-side of the unit transformer
Summarization of the test results

Simulation cases	Negative sequence voltage (U_2)	Positive sequence voltage (U_1)
Grounded unit transformer neutral point; generator in operation	**3% to 14% U_2** (higher value at higher generator load) Synchronous power swing at high load possible	95% to 100% U_1
Grounded unit transformer neutral point; generator not in operation	1% to 3% U_2 (higher value at higher transformer load) → values are close to the operation conditions	approx. 100% U_1
Ungrounded unit transformer neutral point; generator in operation	**High values of U2** (and I2), see Figure 11 and 5) Asynchronous operation of the generator is possible	U1 value fluctuates (see Figure 11)
Ungrounded unit transformer neutral point; generator not in operation	**15% to 25% U_2** (normal to high motor load) **8% to 15% U_2** (weak motor load)	80% to 95% U_1

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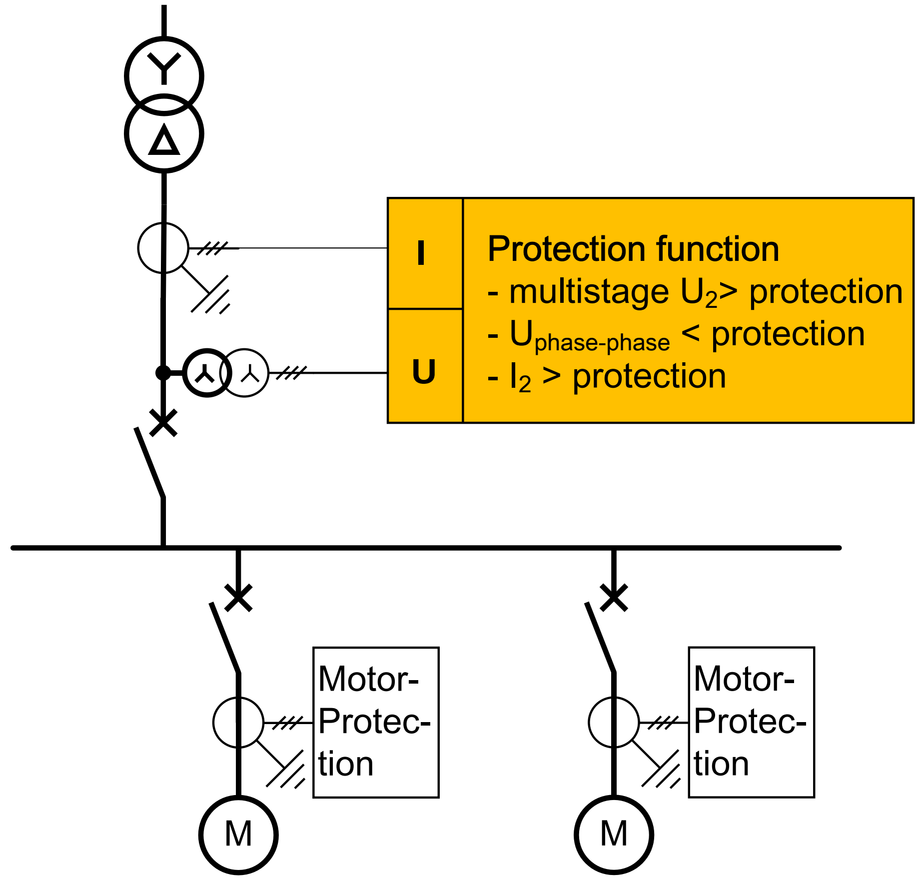
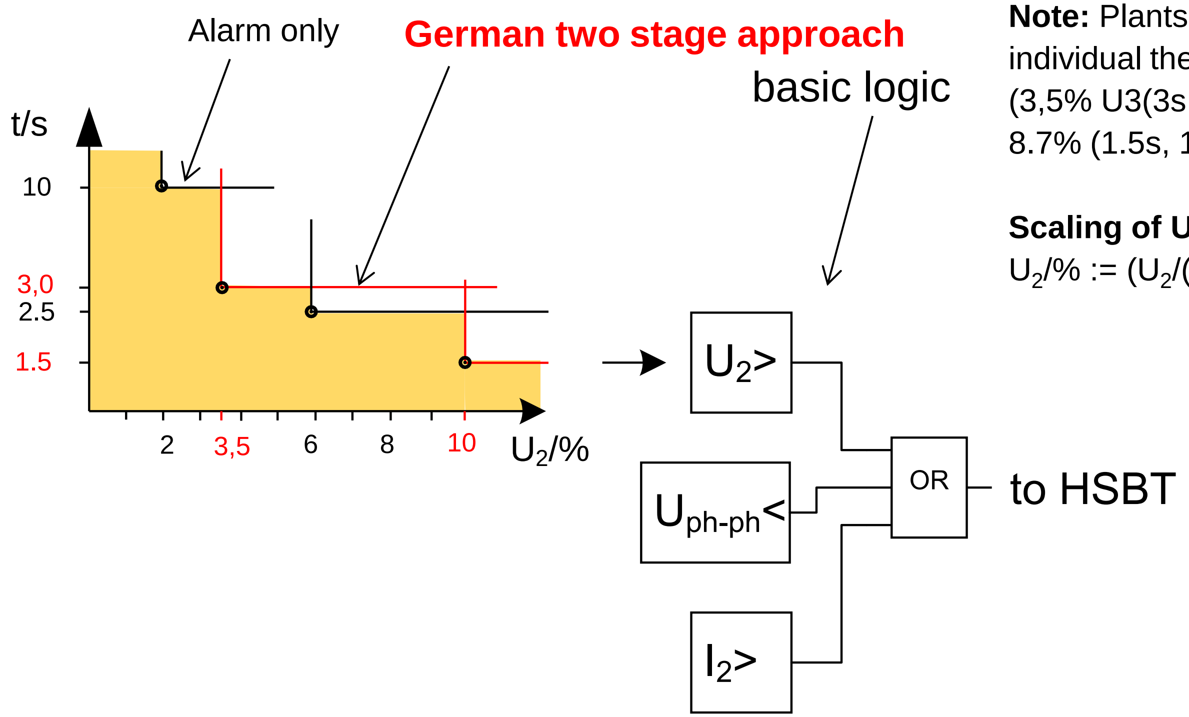
One open phase failure on the HV-side of the external supply transformer
Summarization of the test results

Simulation cases	Negative sequence voltage (U_2)	Positive sequence voltage (U_1)
Grounded external supply transformer neutral point; motor load	**1% to 6% U_2** (higher value at higher load)	95% to 100% U_1
Grounded external supply transformer neutral point; no load	< 1% U2 (not measureable)	Approx. 100% U_1
Ungrounded external supply transformer neutral point; motor load	**15% to 25% U_2** (normal to high motor load) 8% to 15% U_2 (weak motor load)	80% to 95% U_1
Ungrounded external supply transformer neutral point; no load	**30% to 70% U_2** (determined via the coupling, winding capacitances) additional the phase to phase voltages becomes asymmetrical (lower)	40% to 60% U_1

Proposed solution
Supervision of negative sequence voltage



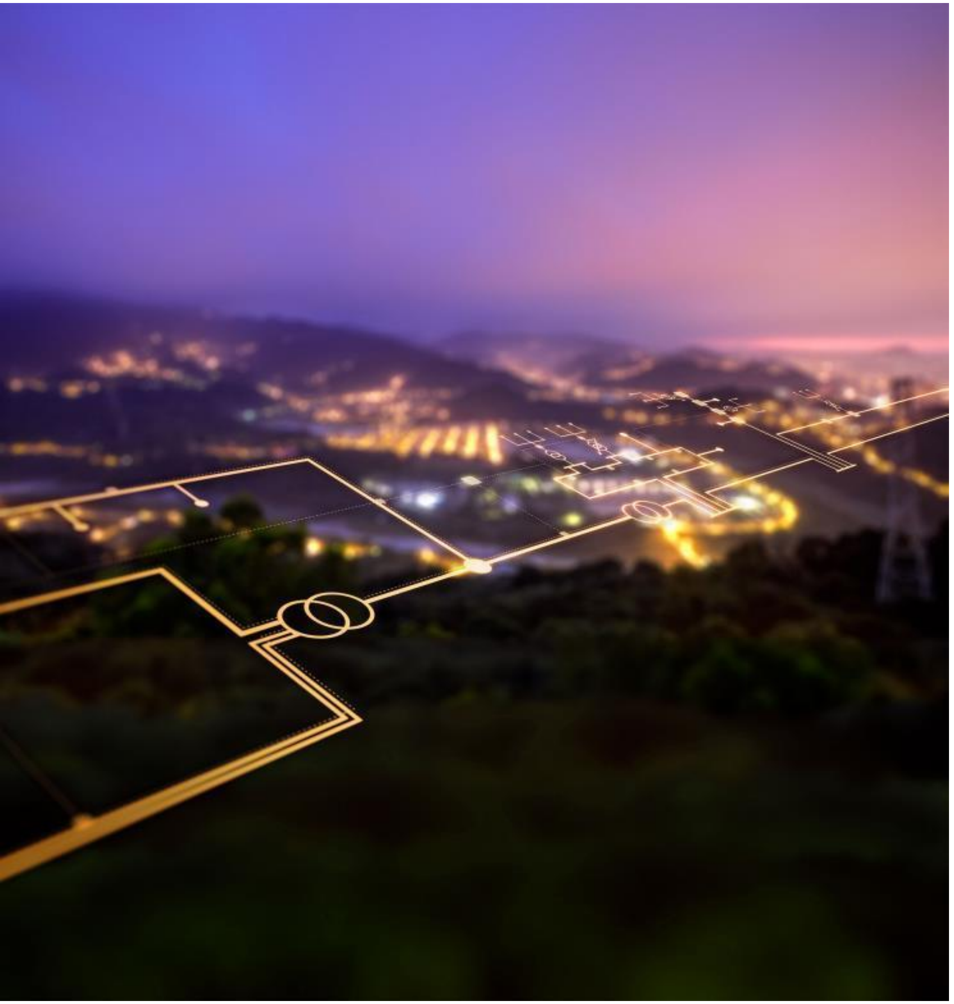


Note: Plants select individual the settings (3,5% U3(3s, 4s) and 8.7% (1.5s, 1.7s)

Scaling of U_2:
$U_2/\% := (U_2/(U_N/\sqrt{3}))\ 100\%$

- Additional safety criterion is the supervision of the phase to phase undervoltage (setting must be lower then the reduced voltage during motor start; time grading according max. U_2-time (3s))
- At high motor load I_2> stage can be used additional (short time grading, lowest U_2 time)

Contact



Dr. Hans-Joachim Herrmann
Principal Key Expert Protection (Product Management)
EM DG PRO LM PR

Humboldt Street 59
91459 Nuremberg

Phone: +49 (911) 433 8266
Fax: +49 (911) 433 8301
Mobile: +49 (172) 3265902

E-mail:
hans-joachim.herrmann@siemens.com

siemens.com/answers