Modeling, Simulating and Validating Wind Turbine Behavior During Grid Disturbances

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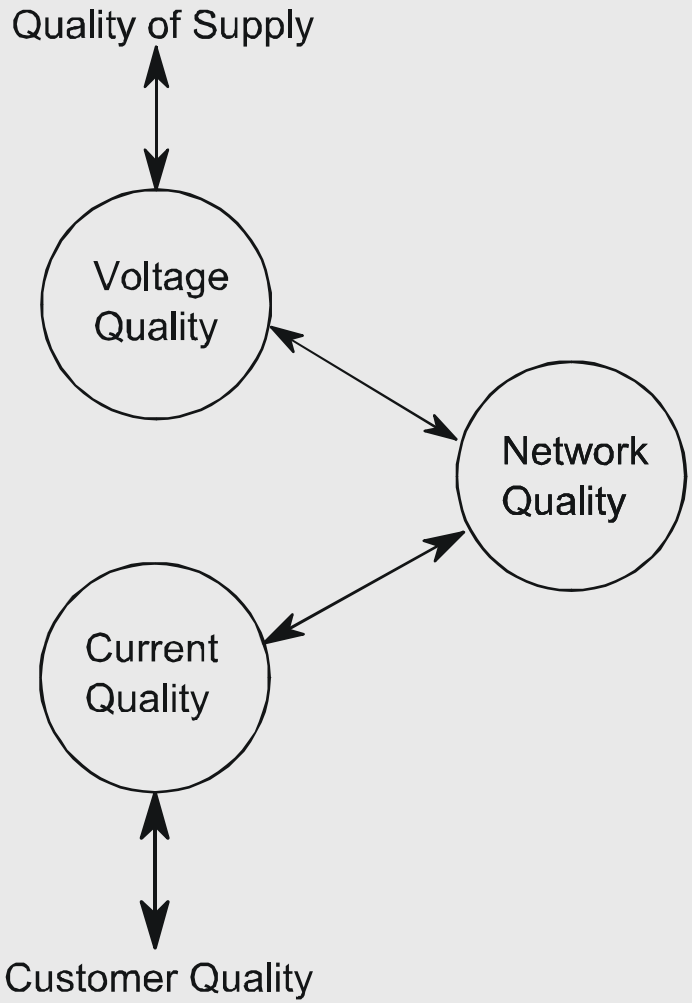
Power Quality Phenomena



- Grid frequency
- Voltage magnitude
- Supply voltage variations
- Flicker
- Harmonics and inter-harmonics
- Unbalance

Power Quality and the Effect of Small Scale Wind Power

- Voltage Dips
- Voltage Fluctuations and Flicker
  - Flicker emission during start-up
  - Flicker emission during continuous operation
- Harmonics

In the Dutch system (15 000 MW load):

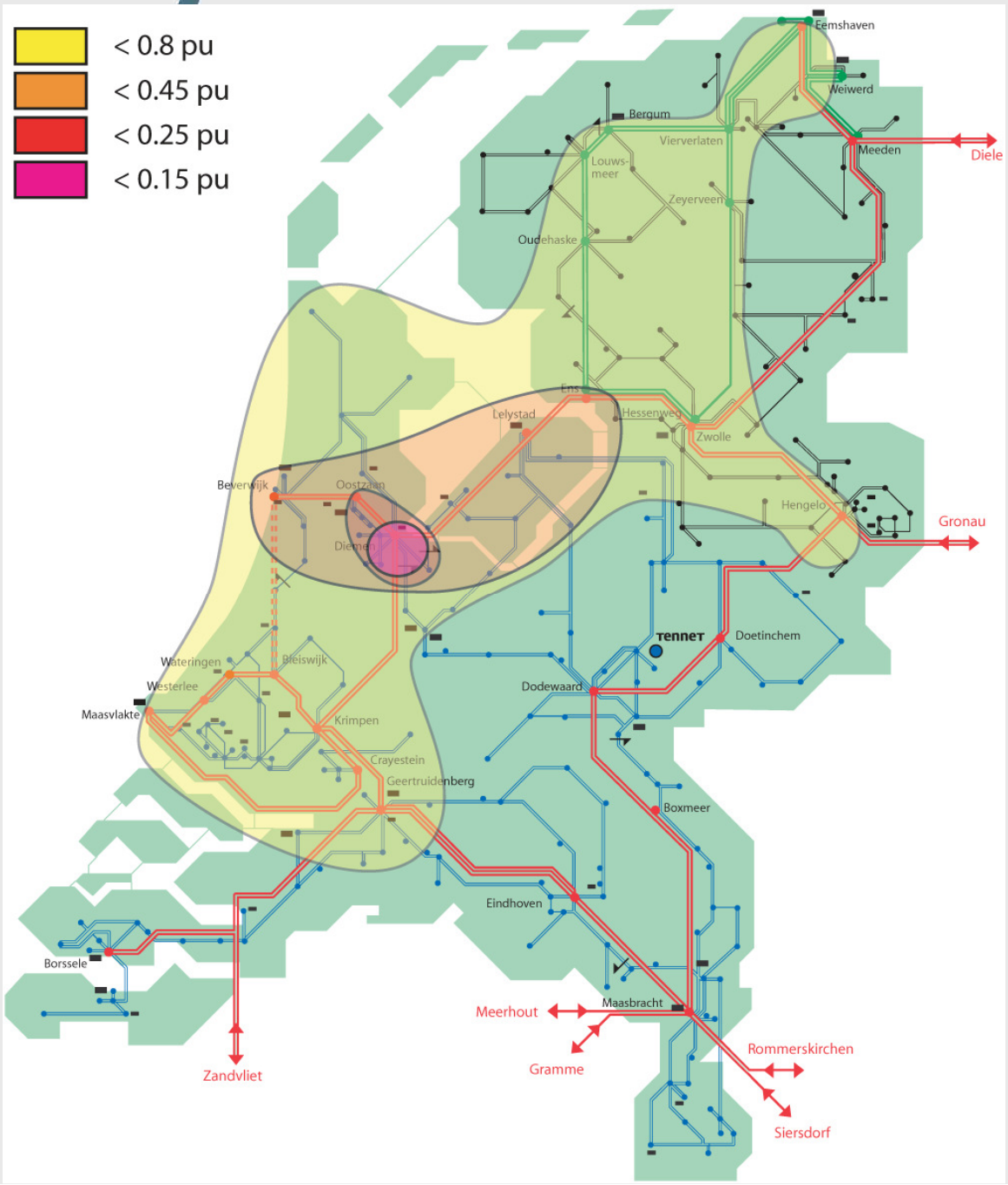
1500 MW wind power connected to the grid (mainly MV).

Average size 750 kW.

This can grow to 3000 MW or 4000 MW.

Voltage Dips and protection – Requirements of National Dutch Grid Code:

- Production means connected to **low voltage** should be disconnected within 0.1 or 0.2 second when the voltage goes under 80% of the nominal voltage (units smaller then 5 kVA) or under 70% (units bigger then 5 kVA)
- Production means connected to the **medium voltage** have no specific rules
- Production means connected to **high voltage** should stay at the grid as long as the critical clearing time permits

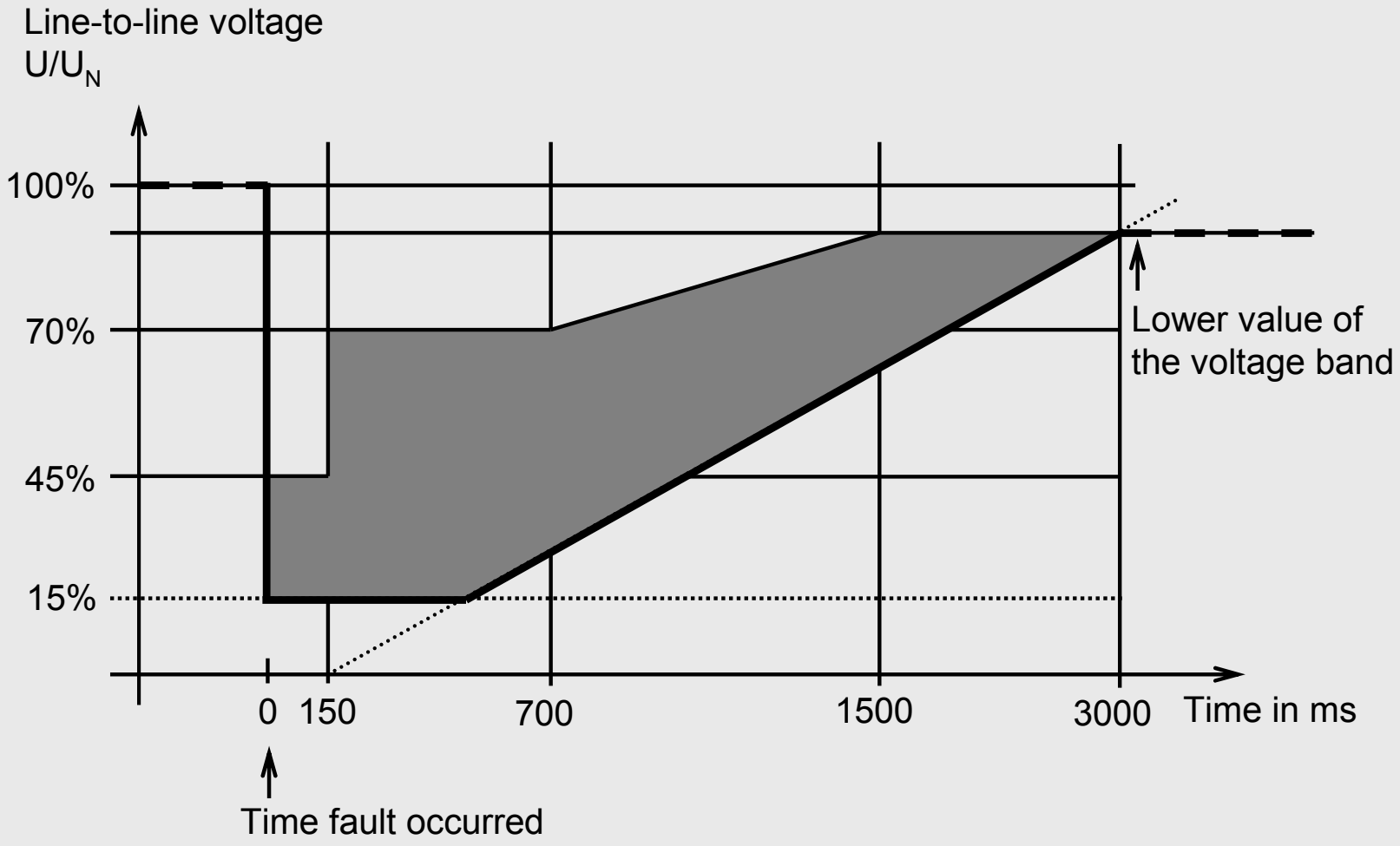


Voltage level during a three-phase fault in Diemen (Amsterdam)

E.On Requirements for Generating Units in Case of Faults:

- **Near-to-generator** three-phase short-circuits must not generally result in generating unit instability or in disconnection from the network. Active power output must resume immediately following fault clearing and be increased with a gradient of at least 20% of rated power per second.
- With **far-from-generator** three-phase short-circuits, disconnection of the generating unit from the network is not permitted even with fault clearing in back-up time of the network protection.

E.On Curve


Line-to-line voltage
U/U_N
100%
70%
45%
15%
0
150
700
1500
3000
Time in ms
Lower value of
the voltage band
Time fault occurred

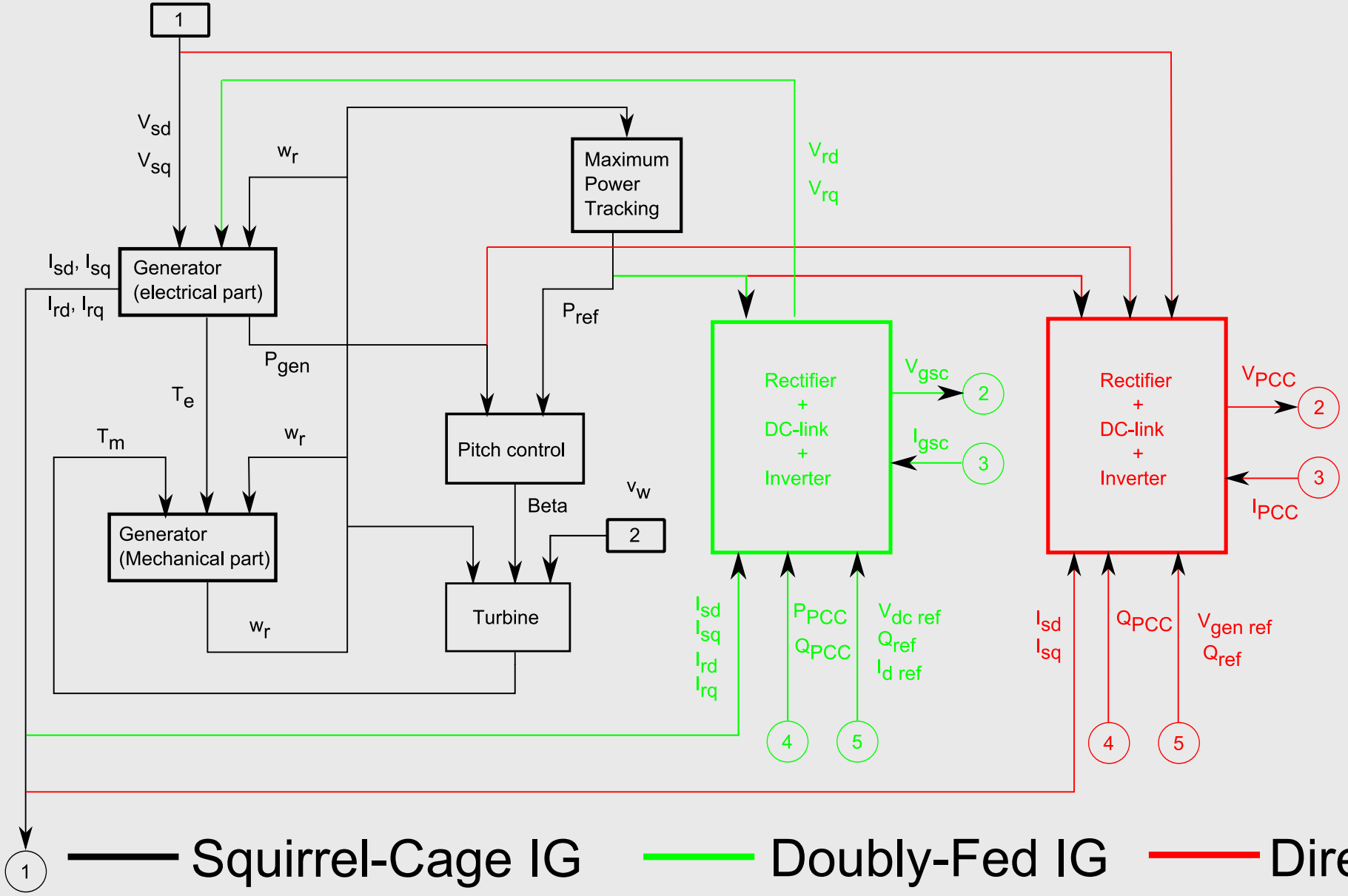
Voltage Fluctuations and Flicker – Requirements of National Dutch Grid Code:

- Voltage variations ≤10% U_{nom}
- Voltage variations ≤3% U_{nom} in situations without loss of production, disconnection of heavy loads or faulted connections
- Long term flicker P_{lt} ≤1 during 99.5% of the time
- Long term flicker P_{lt} ≤5 during 100% of the time

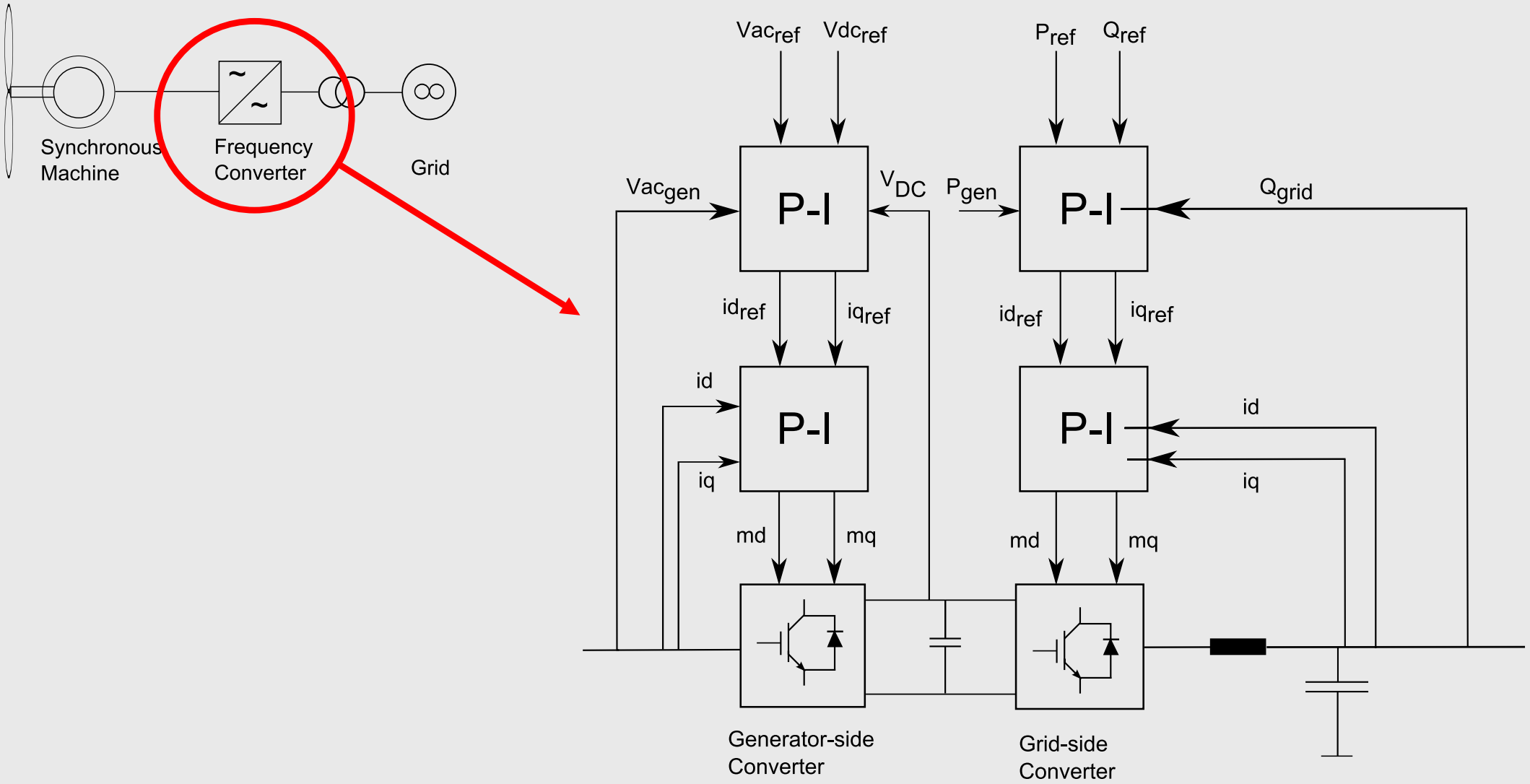
Harmonic Current Emission Limits (IEC 61000-3-12):

Minimum R_{sce}	Admissible individual harmonic current I_h/I_1 (%)				Admissible harmonic current distortion factors (%)	
	I_5	I_7	I_{11}	I_{13}	THD_i	$PWHD_i$
33	10.7	7.2	3.1	2	13	22
66	14	9	5	3	16	25
120	19	12	7	4	22	28
250	31	20	12	7	37	38
≥350	40	25	15	10	48	46
The relative values of even harmonics up to order 12 shall not exceed 16/h %. Even harmonics above order 12 are taken into account in THD_i and $PWHD_i$ in the same way as odd order harmonics						

Generic Model of Wind Turbines



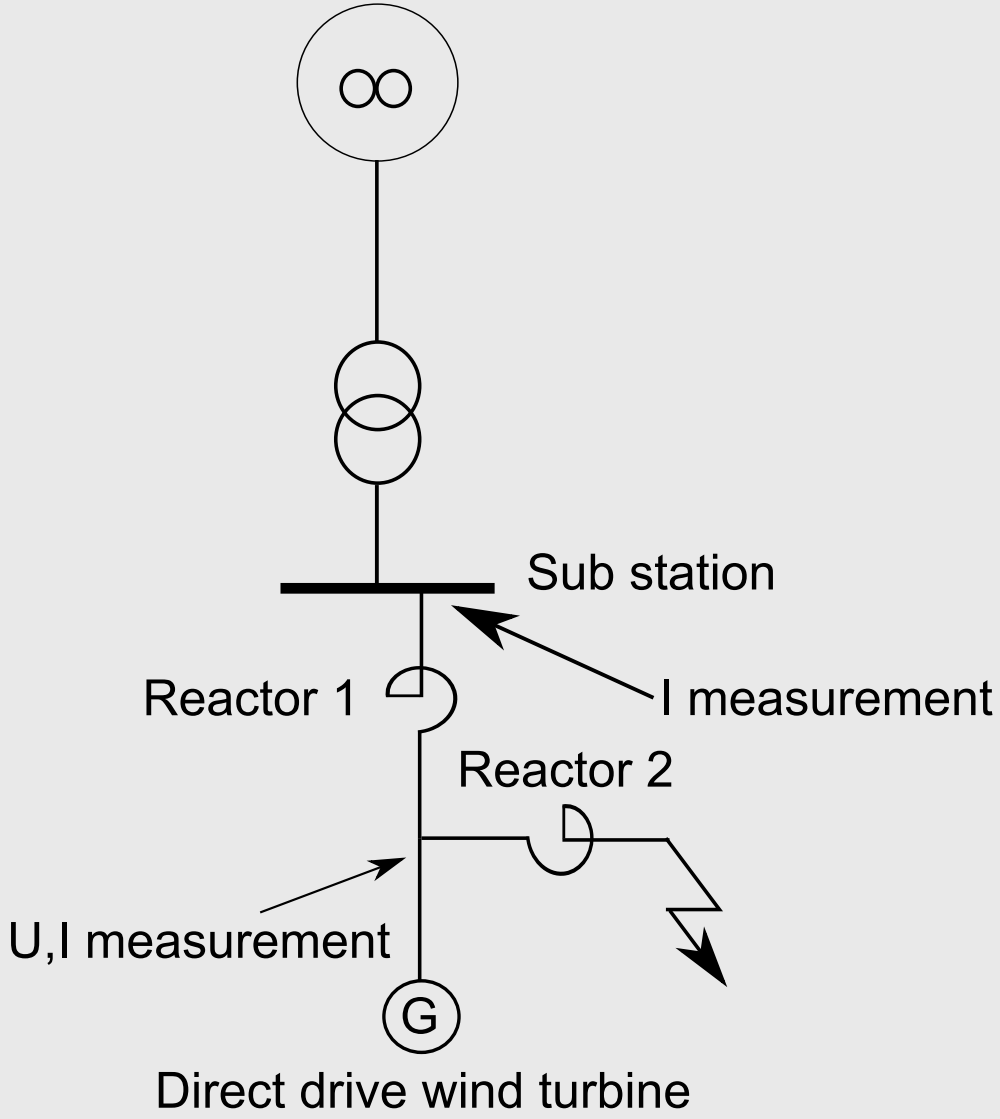
Model of the Direct Drive Wind Turbine



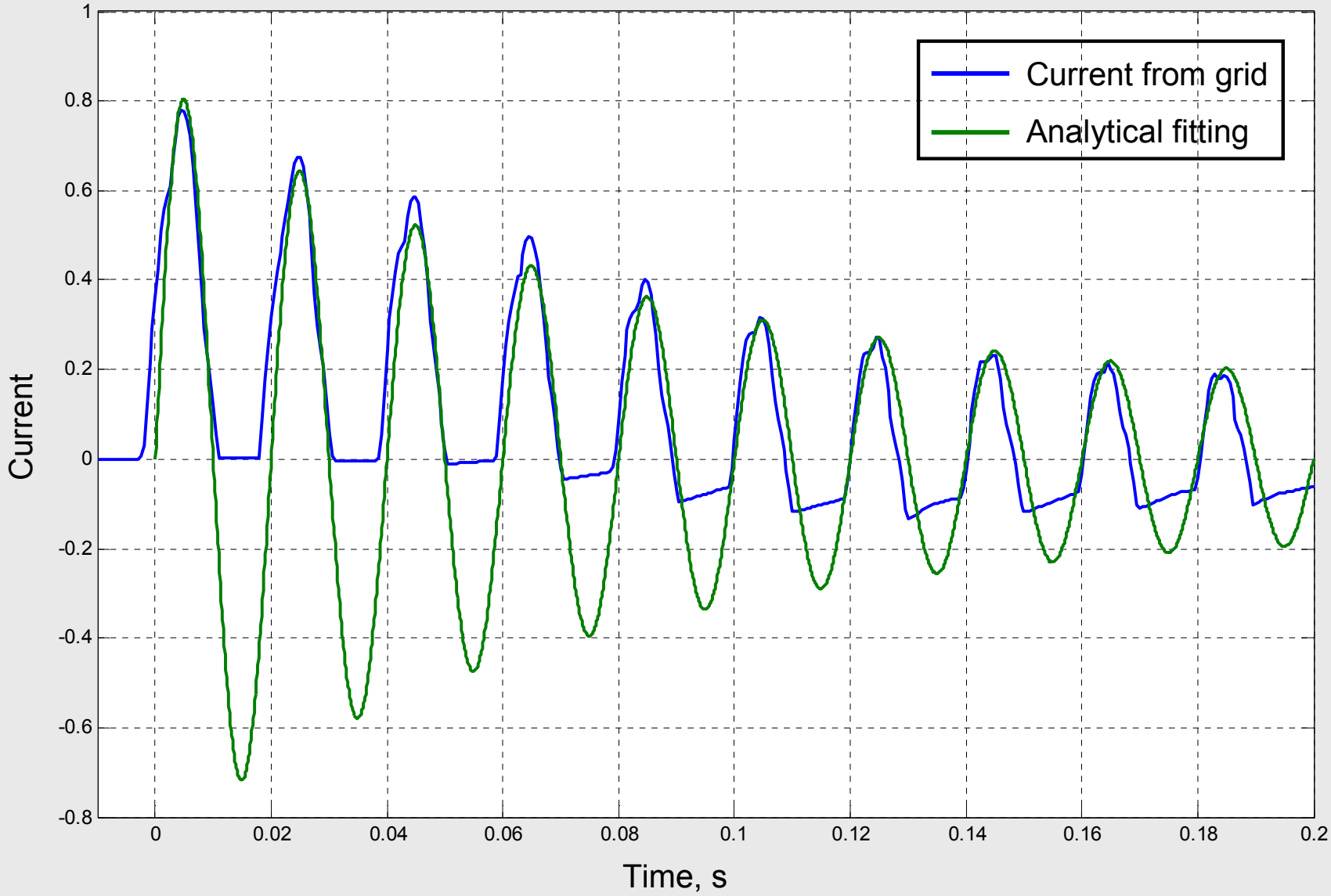
Aim of the Measurements

- Check wind turbine performance during grid disturbance
- Check compatibility with E.on curve
- If necessary adjust parameters of controllers
- Challenge: perform measurement with minimal distortion of other connected customers

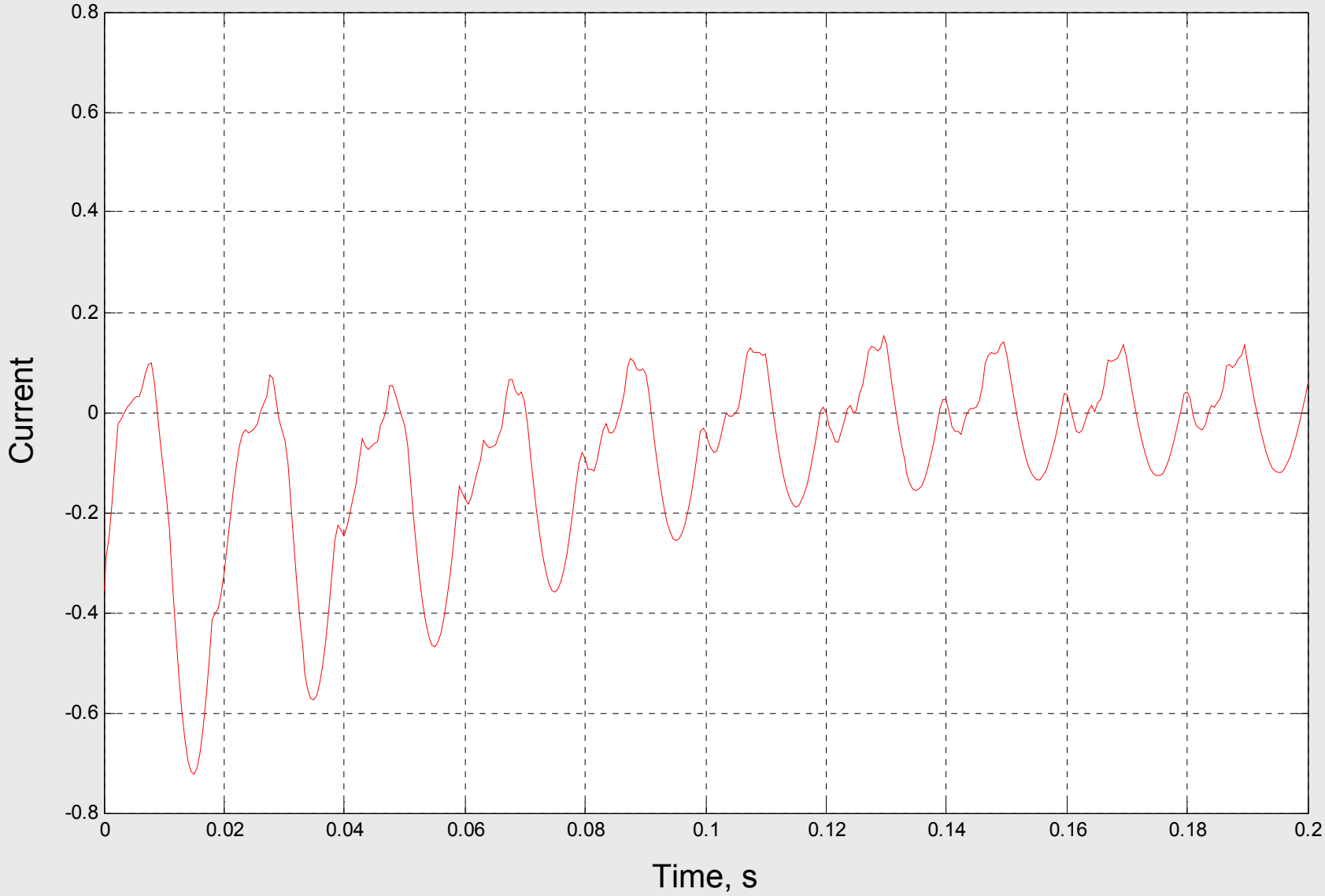
Explanation of Measurements



Grid current: measured vs analytical fitting



Estimated short-circuit contribution from turbine side



Conclusions

- During the test the wind turbine did not meet the E.on curve
- Readjustments of control parameters were necessary to meet the requirements of E.on Curve
- Measurement scheme is suitable to do live tests with minimum disturbance to customer

Questions?