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Dynamic control of an electrolyser for voltage quality enhancement

Outline

1. Introduction
2. Electrical system & Simulation model
3. Dynamic regulation of hydrogen production
4. Case studies
5. Conclusion

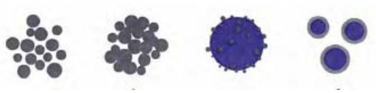
The research leading to these results has received funding from the Fuel Cells and Hydrogen Joint Undertaking under grant agreement n° 245262 – NEXPEL

NEXPEL main objective:

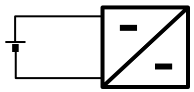
Develop and demonstrate a PEM water electrolyser integrated with RES:

75% Efficiency (LHV), H_2 production cost ~ €5,000 / Nm^3h^{-1}, target lifetime of 40,000 h

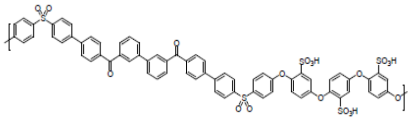
New catalysts

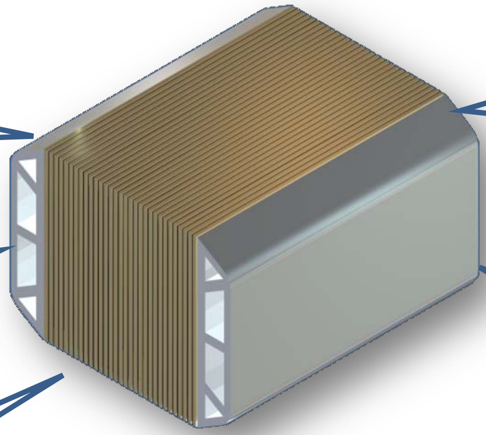


Improved DC-DC converter

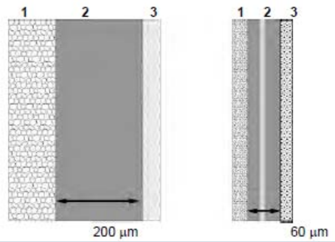


New membrane materials

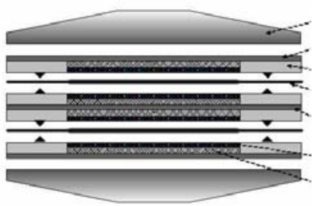




Improved MEAs



Novel stack design and new construction materials



Jan 2010 - Dec 2012
Co-ordination: SINTEF
Funding: Fuel Cells and Hydrogen JU
Total Budget: € 3,353,549
www.nexpel.eu

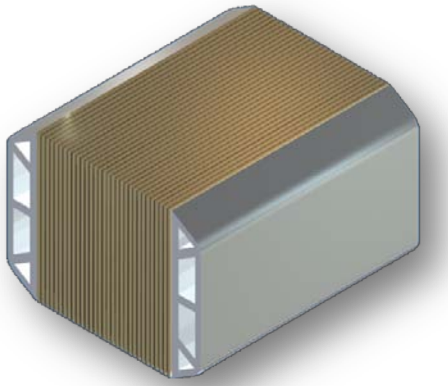
SINTEF | University of Reading | Statoil | cea | HELION HYDROGEN POWER | fumatech Funktionelle Membranen und Anlagentechnologie | Fraunhofer ISE

Hydrogen Production from RES

- Hydrogen production attractive for integration in wind turbine systems
  - Re-conversion is economically challenging
  - Hydrogen used locally
- "Smart" operation of electrolyser
  - Improvement of power quality at PCC
  - Reduction of system losses

Demonstrate the feasibility and advantages achievable from the integration of an electrolyser system for the production of hydrogen in a renewable energy system (RES)

Electrolyser Technology



- Fluctuating power output of RES influence the operation of electrolyser.

"classical operation": power fluctuations to grid, constant power to electrolyser

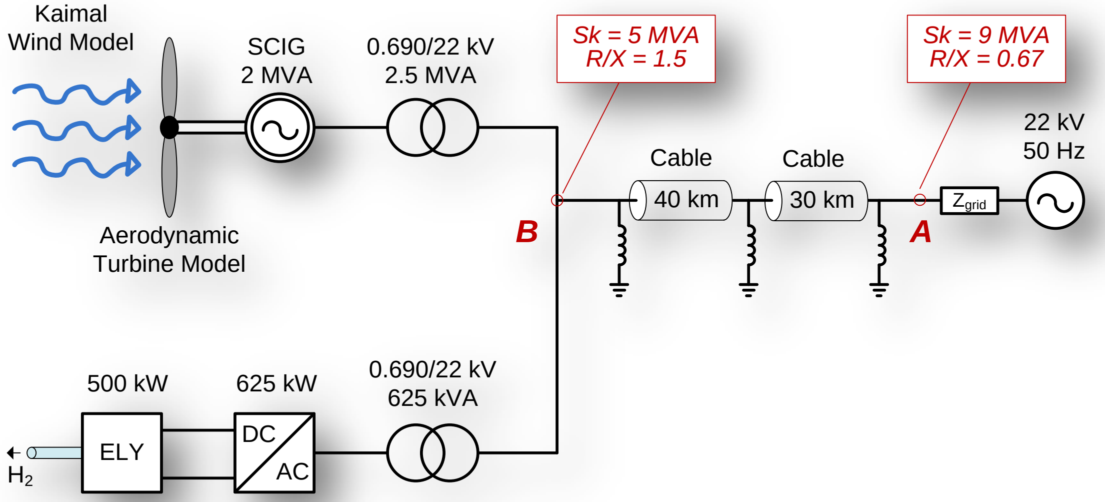
"smart operation": electrolyser absorbs fast fluctuations, grid receives smooth power

→ electrolyser with flexible operating capabilities

- Large atmospheric alkaline electrolyser: due to long response time (several minutes) are designed to operate at constant power.
- Pressurized alkaline electrolyser: faster response time, current interruption leads to increased degradation rate (min load 25-50%).
- Polymer electrolyte membrane (PEM) electrolyser: fast response time, no degradation with stop-start cycles, higher energy efficiency. Promising but immature technology, expected life time of 10 years.

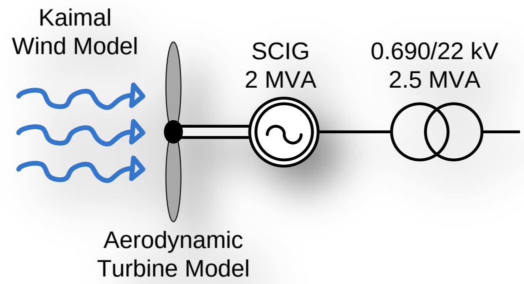
Electrical System

- Simplified representation of a possible island system: wind turbine and electrolyser connected to a relatively weak grid



Best wind resources often found in areas with weak grid connection to the main transmission grid: voltage variation and thermal limits may put a significant limit on the realizable wind power generation.

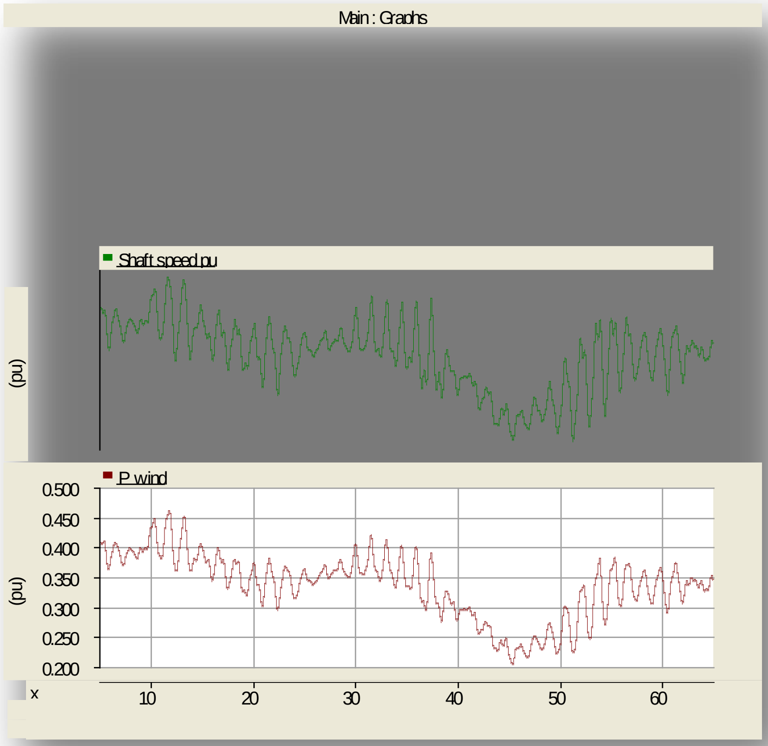
Representative for several location along the Norwegain coast: high wind speed, low local electricity demand. Hydrogen from electrolysis can be considered for local and sea transport.

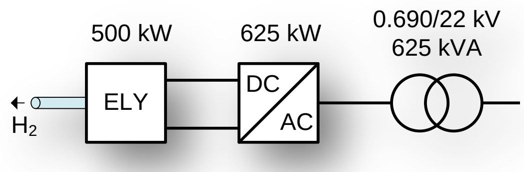


Simulation Model: Wind

- Stochastic wind speed: Kaimal model
  - Average wind speed = 7.5 m/s
  - Standard deviation = 1.0 m/s
  - 60 s window

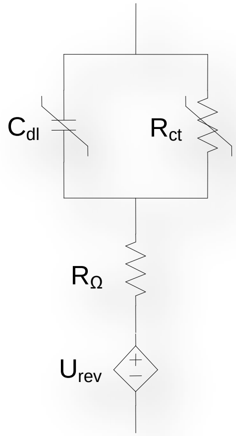
- General wind turbine aerodynamic torque model with 3P effect
- Squirrel cage induction generator (SCIG)



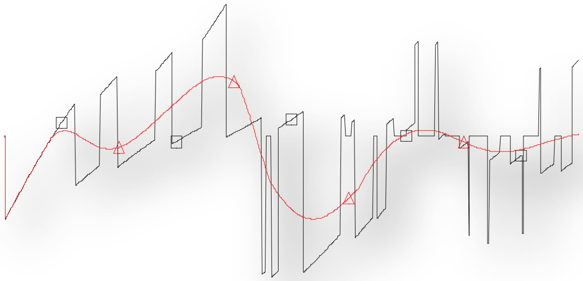


Simulation Model: Electrolyser

- Electrolyser: dynamic equivalent model
  - U_{rev}: reversible potential of water splitting reaction
  - R_{Ω}: ohmic resistance of the cell
  - R_{ct}: charge transfer resistance
  - C_{dl}: double layer capacity
  - Parameters based on in-house measurements on an alkaline electrolyser

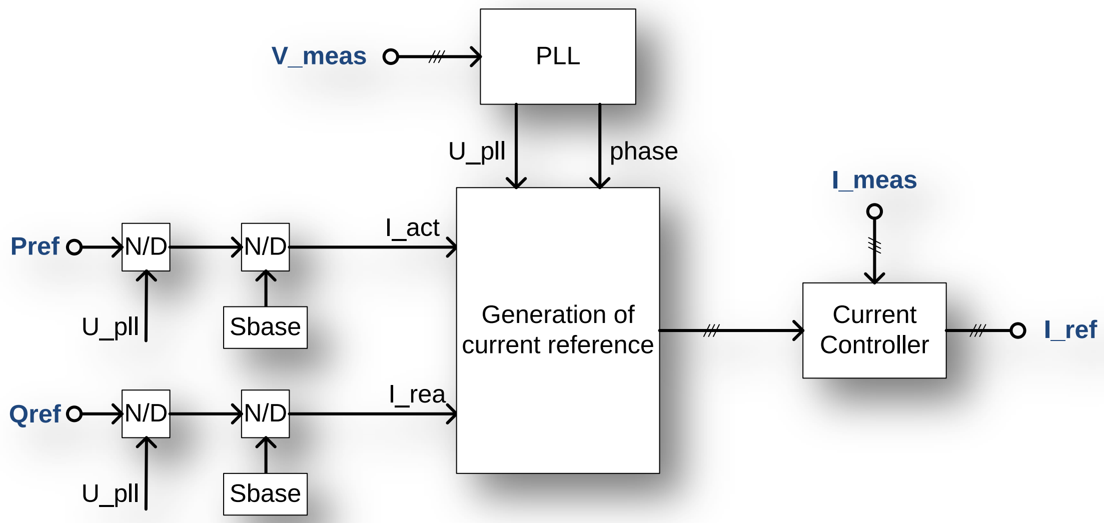


- Electrolyser converter: average model
  - Three-phase, two-level PWM converter
  - Switching effect phenomena averaged over the switching period



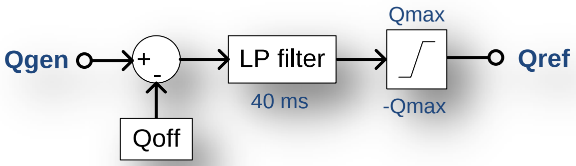
Dynamic Regulation of the Hydrogen Production

- Three-phase current reference for the electrolyser converters current conteoller is generated based on active and reactive power references.

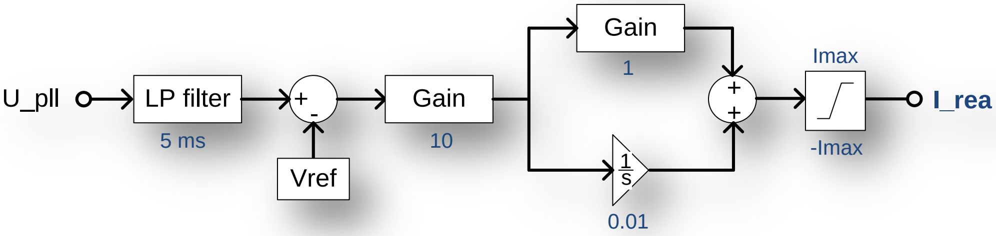


Dynamic Regulation of the Hydrogen Production

- Electrolyser converter used to compensate the reactive power fluctuation (STATCOM-like)
- Indirect control of the bus voltage: reactive power measured at the generator - Q_{off}

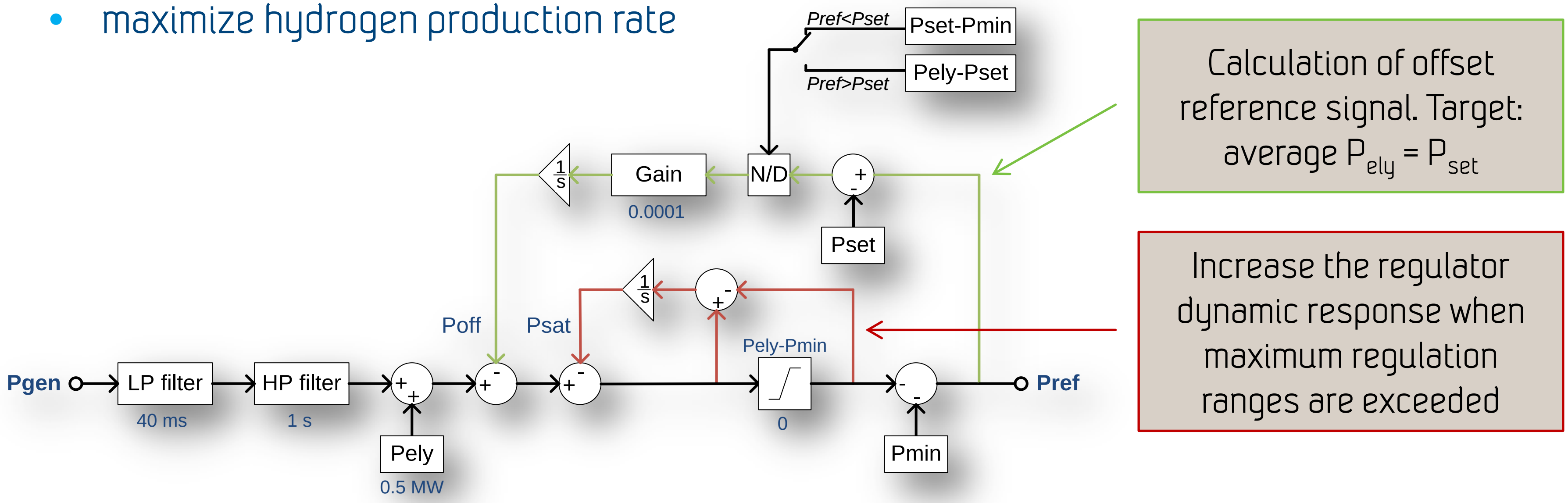


- Direct voltage control:
  - Droop function and load compensation units may be added



Dynamic Regulation of the Hydrogen Production

- Strategy used for Q control is not very flexible for P control: constant offset
- Flexible control strategy:
  - compensates (fast) active power fluctuation
  - allows slow variation
  - maximize hydrogen production rate



Case Studies

- Nine case studies with different control strategies:

Case	E wind [kWh]	E grid [kWh]	E ely [kWh]	E loss line [kWh]	E loss Ely [kWh]	Kg H2 [kg]	Nm3 H2 [Nm3]	E H2 [kWh]
1: No Ely	12.3	10.5	0.00	1.78	0.00	0.00	0.00	0.00
2: Ely Max	12.3	3.08	8.23	0.998	3.04	0.16	1.74	5.2
3: Ely Max, Q comp	12.3	3.17	8.15	0.997	3.00	0.16	1.72	5.15
4.1: 100% reserve	12.3	6.33	4.82	1.16	1.58	0.1	1.08	3.24
4.2: 50% reserve	12.3	5.01	6.22	1.08	2.13	0.12	1.37	4.09
4.3: 20% reserve	12.3	3.78	7.53	1.01	2.71	0.14	1.61	4.82
5.1: Const Ely at E_H2 of 4.1	12.3	6.28	4.82	1.21	1.53	0.1	1.10	3.29
5.2: Const Ely at E_H2 of 4.2	12.3	5.02	6.22	1.08	2.12	0.12	1.37	4.09
6: 50% reserve, V control	12.3	4.98	6.2	1.14	2.13	0.12	1.36	4.07

Electrolyser reduces the losses in the line, but high conversion losses: electrolyser efficiency is crucial

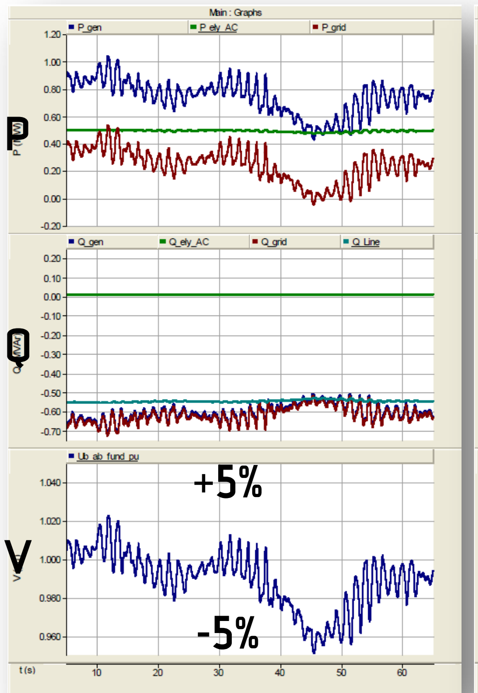
Hydrogen production only slightly affected by best dynamic control strategies

Dynamic vs. Constant electrolyser power: no increased losses and same H2 production

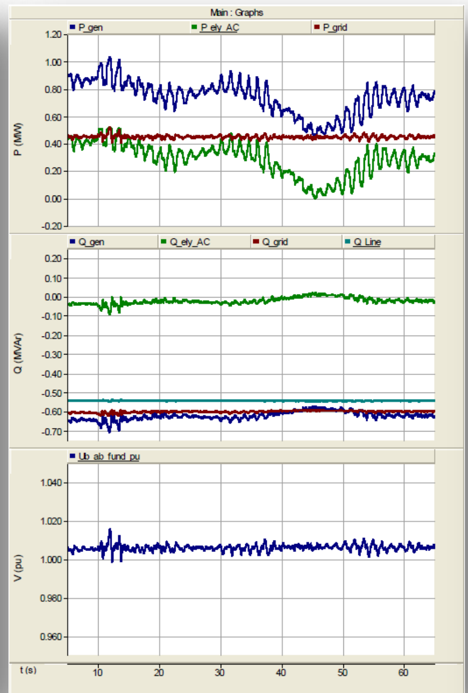
Indirect vs. Direct voltage control: almost identical average behavior

Case Studies

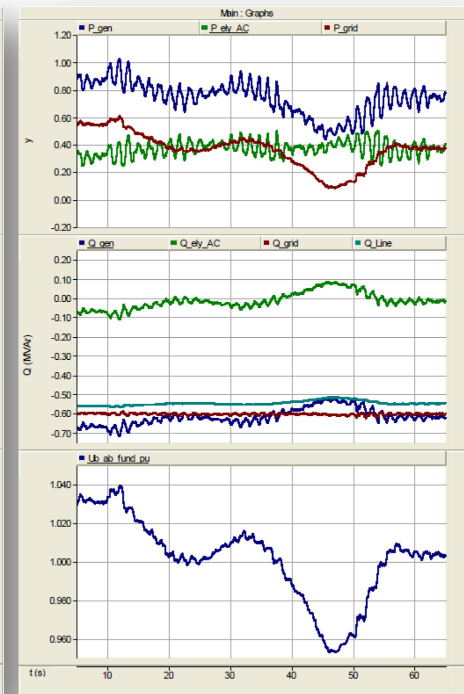
2: Constant max H2 production



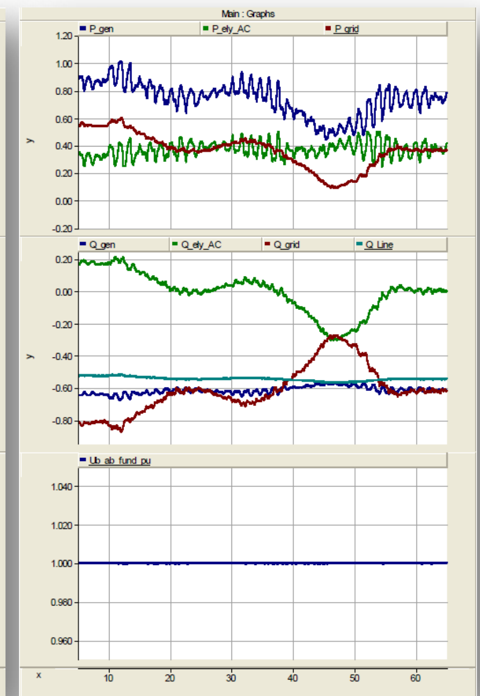
4.1: 100% reserve, PQ ctr, fix offset



4.2: 50% reserve, PQ ctr, dyn. offset

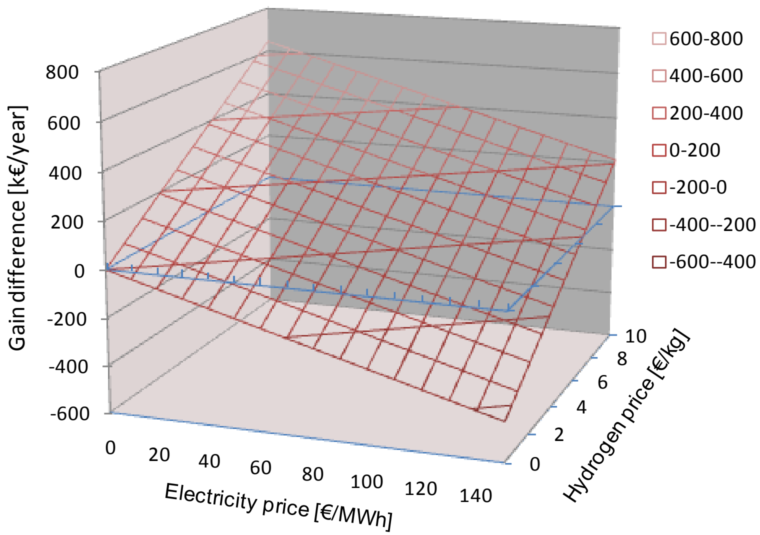


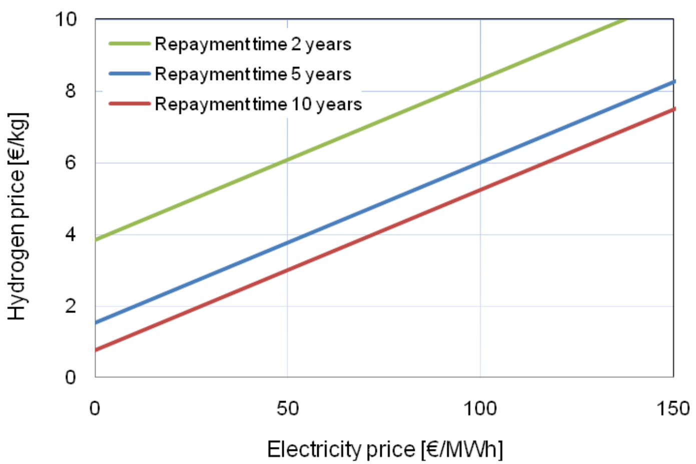
6: 50% reserve, PV ctr, dyn. offset



Cost Analysis

- Simplified cost analysis of the wind-electrolyser system with the best control strategies
  - The simulated 60 second time period is taken as basis for the economic calculations, by assuming it to be representative for one year
  - The total annual wind generation then sums up to 5534 MWh for the 2 MW turbine, corresponding to a capacity factor of 32 %
  - Economical estimates based on an electricity price 50 €/MWh, a hydrogen price 5 €/kg and an electrolyser total cost of 5 000 €/Nm3. The margin and the payback time are calculated with reference to the case with no electrolyser. O&M costs are not considered.
- Payback time between 2 to 3 years.





Conclusion

- Demonstration of possible and "smart" use of an electrolyser in a RES
- Voltage quality at PCC is improved by introducing an electrolyser with flexible operating capabilities
- Modelling approach and analysis tools demonstrated in the paper are valuable instruments for the investigation, planning and evaluation of future possibilities for the integration of hydrogen and wind energy technologies
- Economical considerations demonstrate that at today's electricity prices and expected hydrogen prices, the production of hydrogen from wind energy can become economically feasible
- Can the improved power quality and/or the improved wind energy utilization defend the extra costs of a larger electrolyser required for dynamic control? Other alternatives are flywheel energy storage or reinforcing the local grid
- The effect of dynamic vs. constant load on the electrolyser on the aging rate of the stack need to be further verified (lifetime)

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