Design and simulation of a SMES for grid primary control

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2nd Workshop for Sustainable Science
at Research Infrastructures
Geneva, 24.10.13

Structure

1. DESY in Hamburg
2. Motivation
3. SMES
4. Grid control/ control market
5. Viability of a SMES
6. Simulation results

DESY 2013

PETRA III
DESY II
PIA
LINAC II
FLASH
European XFEL
(under construction)
European
XFEL

DESY till 2007

Motivation

The energy turn-around with the use of renewable energies has a lot of interesting technical questions.

What possibilities has a research institute like DESY to deliver solutions to these questions?

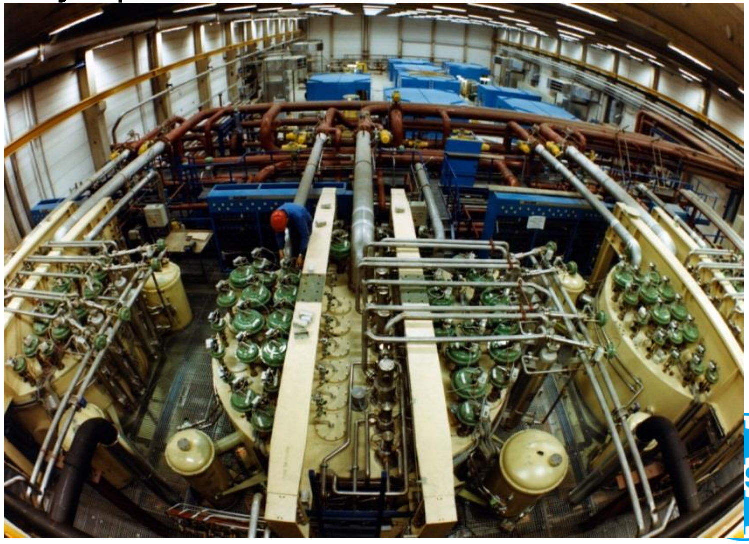
Assets of DESY

Power electronics

Operation of superconducting magnets

Quenchprotection

Kryo-plant



Assets at DESY

Expert knowledge

- Know How in operation of superconducting magnets including quenchprotection
- Know How in the operation of power converter up in the MW power range
- Know how in electrical grids
- Control technology, IT

Components that are available on site:

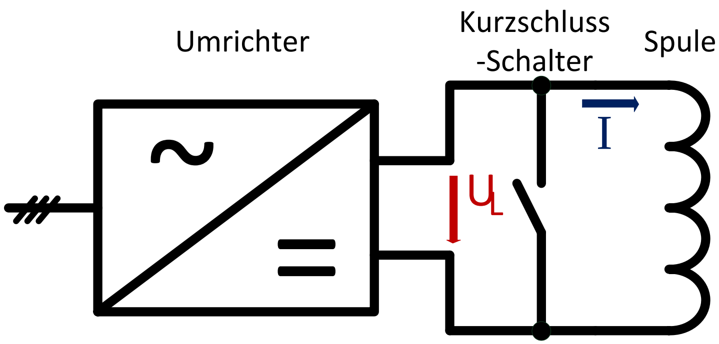
- Cryo plant
- 110 kV HV connection to public grid
- Reactive power filters
- Transformers

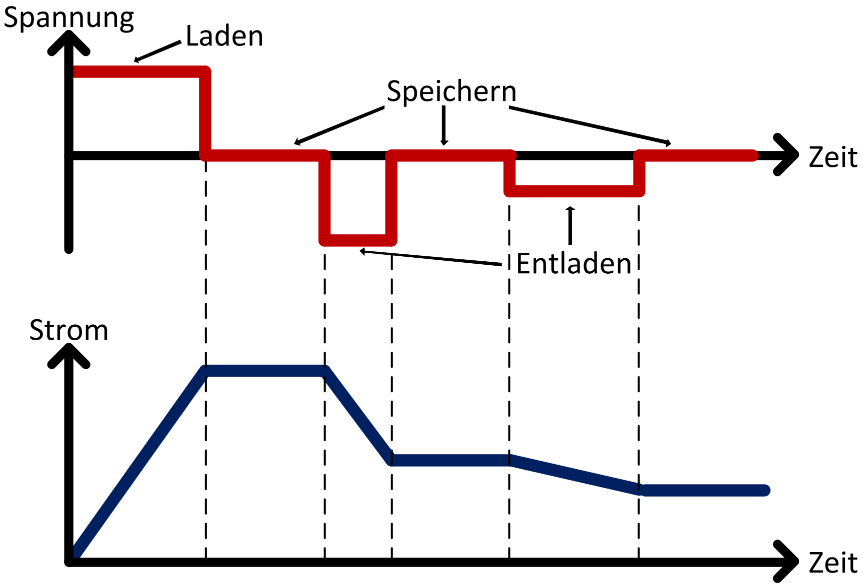
Findings and further steps

> With these assets it is obvious that a superconducting magnet energy storage (SMES) should be investigated.

- Technical design parameters
- Potential future working fields
- Calculation of viability

How does it work?





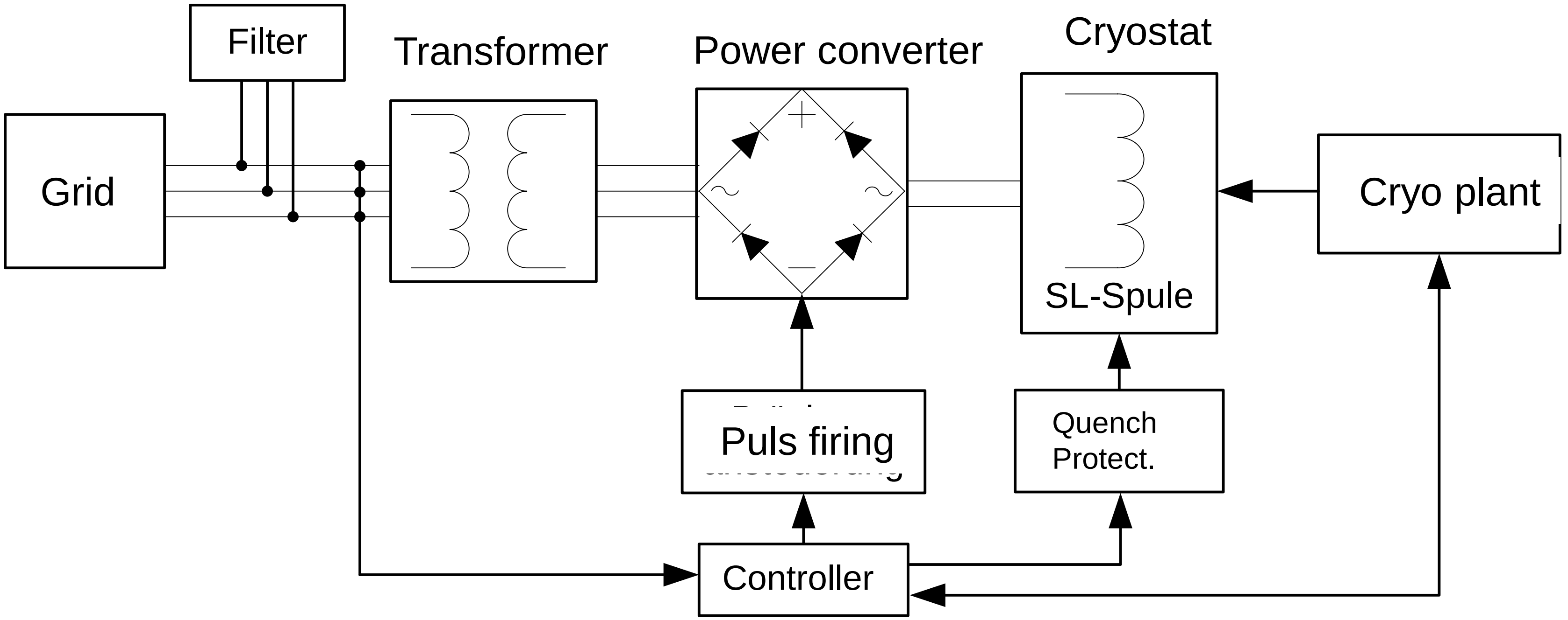
$$P = U_L \cdot I$$

$$E = \int P(t)dt = \frac{1}{2} L \cdot I^2$$

$$\frac{di}{dt} = \frac{U_L}{L}$$

Principle of a SMES

- Superconducting inductance with cryostat
- Cryo plant / cooling with liquid helium
- Power converter



Principle of a SMES

SMES

Advantages

- Direct storage without energy-transformation
- High efficiency
- Short reaction times in milli-seconds
- Very high number of load/unload cycles
- High lifetime

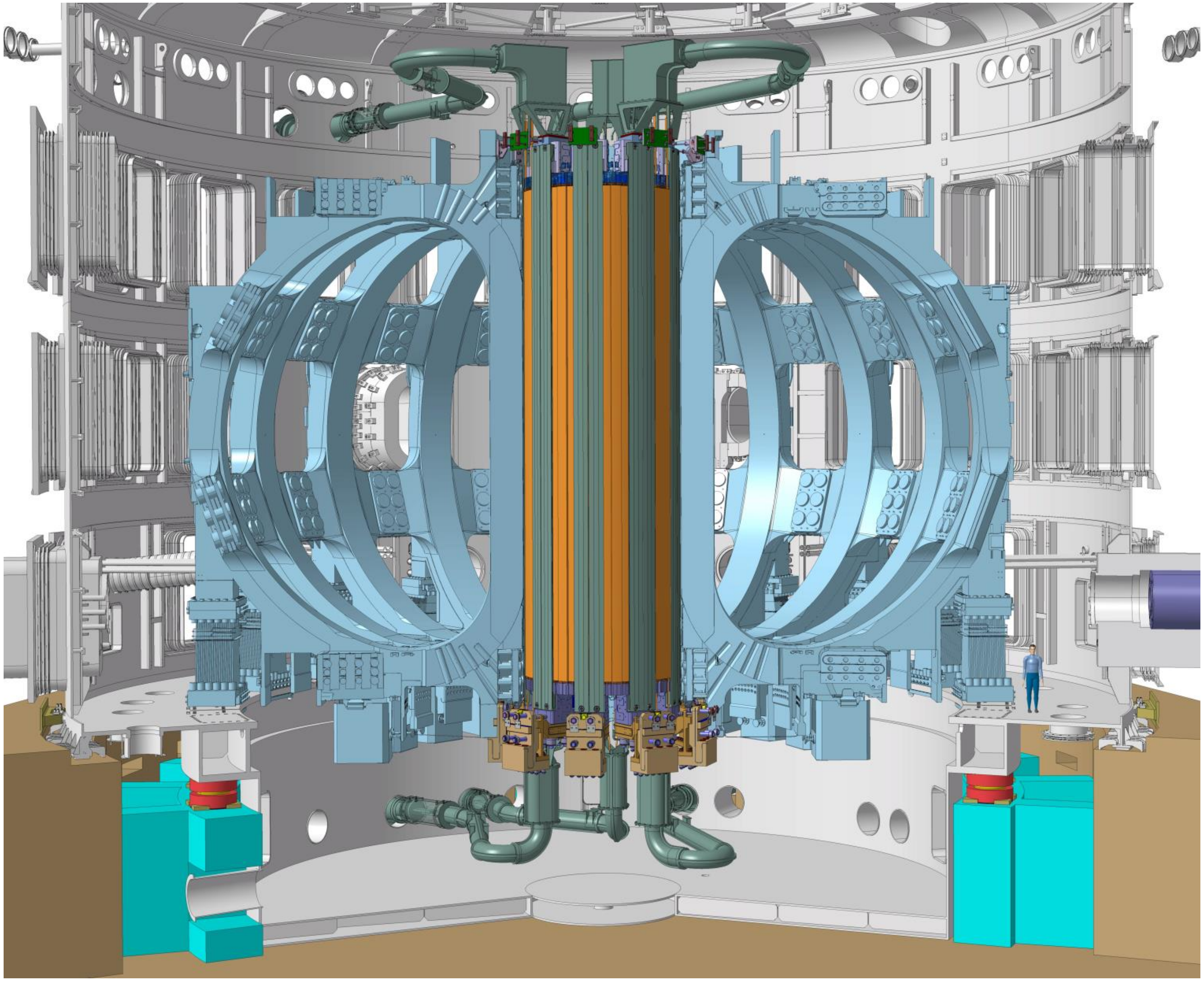
Disadvantages

- High Investment cost
- Losses due cryo plant
- Low energy density

Designparameters

- In the moment there is no SMES existing that is of a size suitable for energy storage in larger scale. The large superconducting units are in research institutes.
- It was checked for existing superconducting units that are either already in operation or under construction. A complete technical development has to many risks.
- From the electrical parameters the HERA machine would match for prototype however the power consumption for the cryo plant is to high.
- Another existing unit is the LHC (obvious that it is not suitable)
- A perfect match would be the solenoid of ITER (I nternational T hermonuclear E xperimental R eactor)

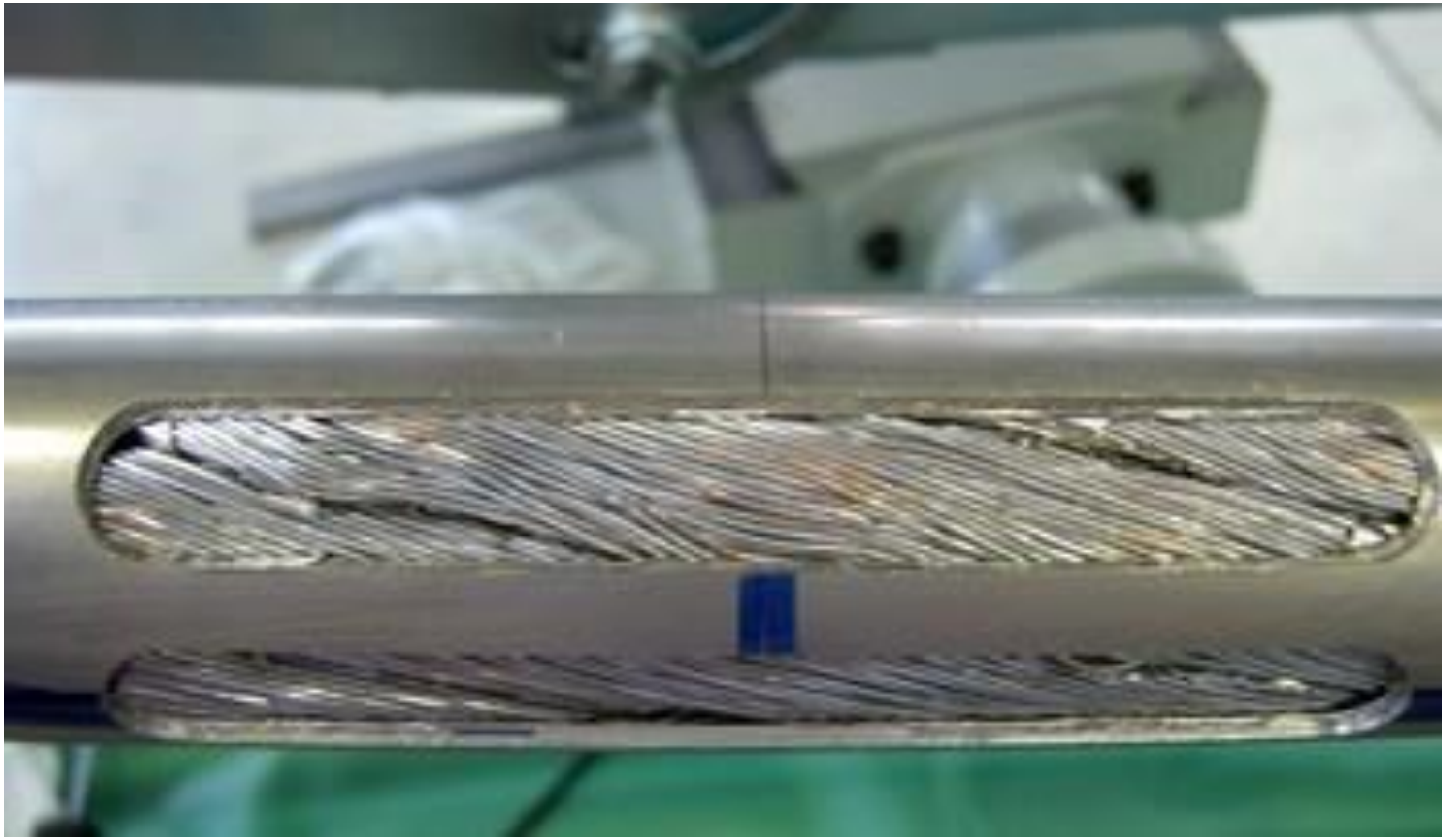
ITER



Credit © ITER Organization, http://www.iter.org/

Superconductor

- Two slots are machined on the jacket for helium entrance inside the conductor. Credit: Iberdrola Engineering, ASG Superconductors and Elytt Energy



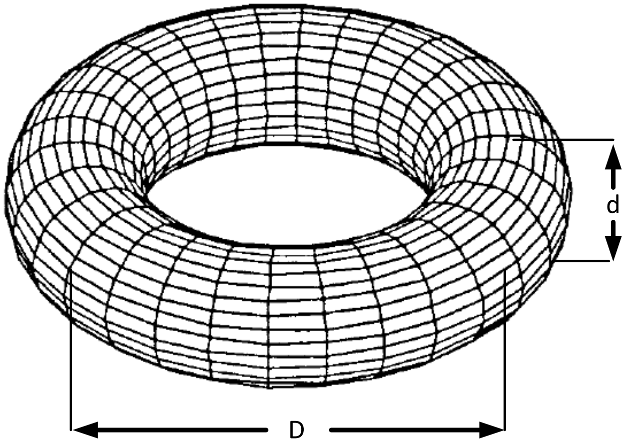
Production of the windings

- Winding operations in La Spezia for the European portion of ITER's toroidal field coils: spreading the double pancake before manufacturing starts on the helium inlet manifold. Credit: Iberdrola Engineering, ASG Superconductors and Elytt Energy

im

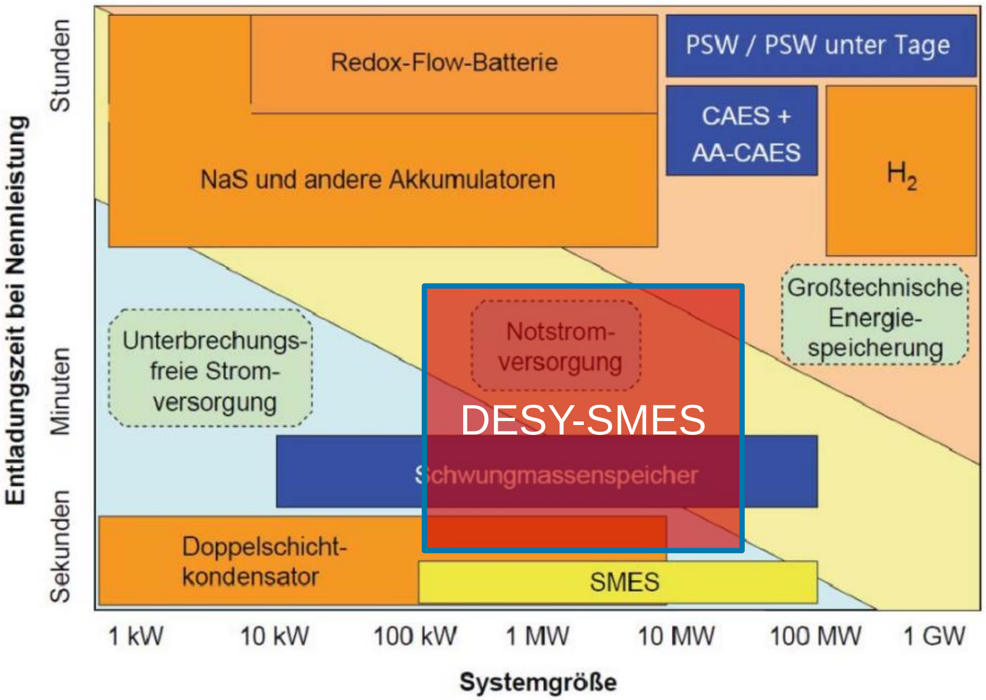
Design of the coil

• Inductance of the coil	50 H (double of the inductance of ITER)
• Current min, nom, max	19 kA, 42 kA, 60 kA
• Voltage	± 2,1 kV
• Power	± 40 MW
• Max. stored energy	25 MWh
• Coil material	Niob-Titan (4 K), Niob-Zinn (18 K)
• Design	Toroid, but D-Form of the coils



Electrical energy storages

- Pumped-storage or pressurized air storages are able to store large amounts of energy
- Germany has storage with a power of 7.4 GW and a capacity of 40 GWh
- Technical storages can only store small amounts of energy



Typical power and discharge times of technical storages [NEU-11]

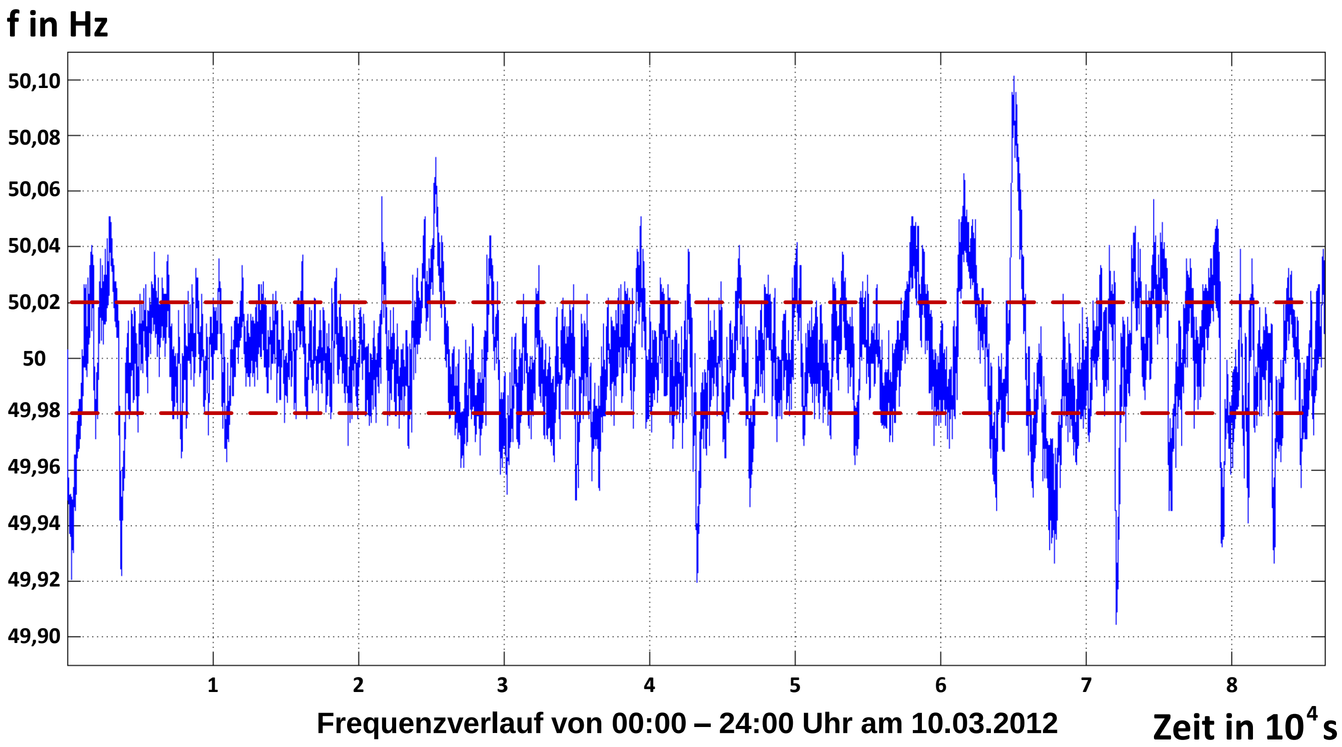
Size of the SMES and future use

- Although the SMES is already a very large device being at the highest edge of technical feasibility, the amount of energy is low in comparison to the demands of the electrical grid.
  - Example: Modern wind energy converter has about 5 MW max. power. Assuming 20 of these in a wind park. Within 15 min this SMES will be filled.

© dpa

- The participation at regulation market is the most promising approach

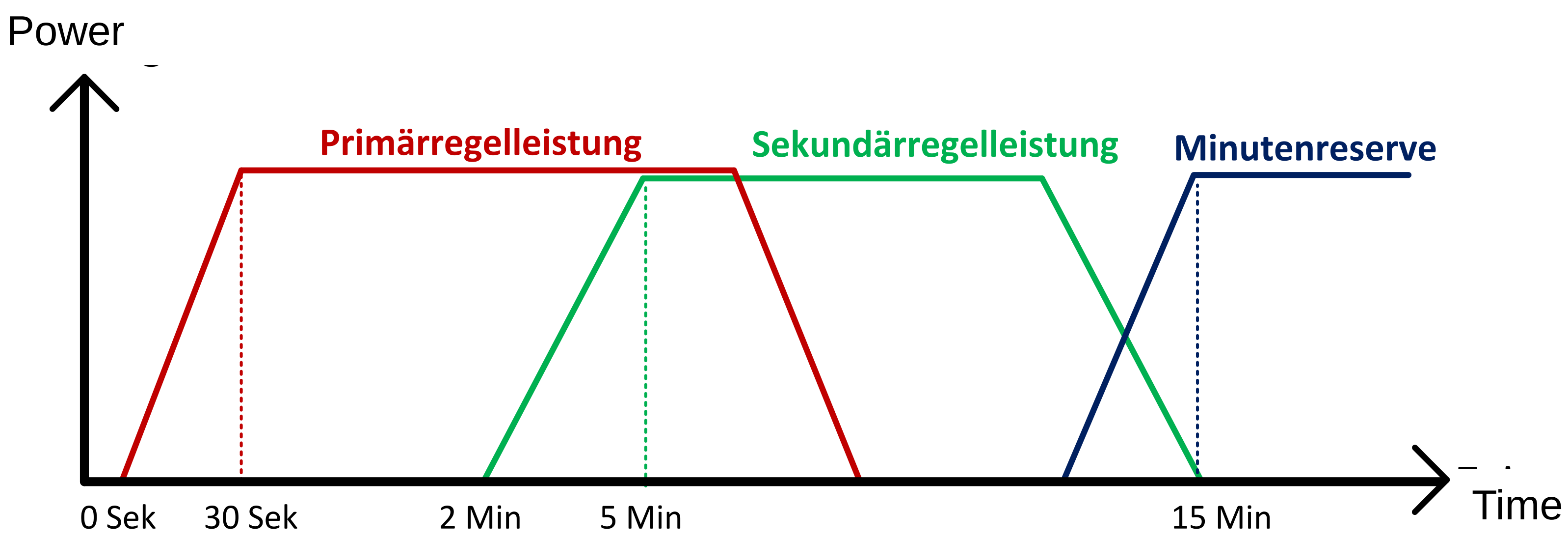
Grid frequency in 2012



Frequenzverlauf von 00:00 – 24:00 Uhr am 10.03.2012

Frequency-active power control

- Frequency deviations due to the difference between procuded and consumed power
- 1. Primary control power
- 2. Secondary control power
- 3. Minute reserve



Time dependancy of the different controls

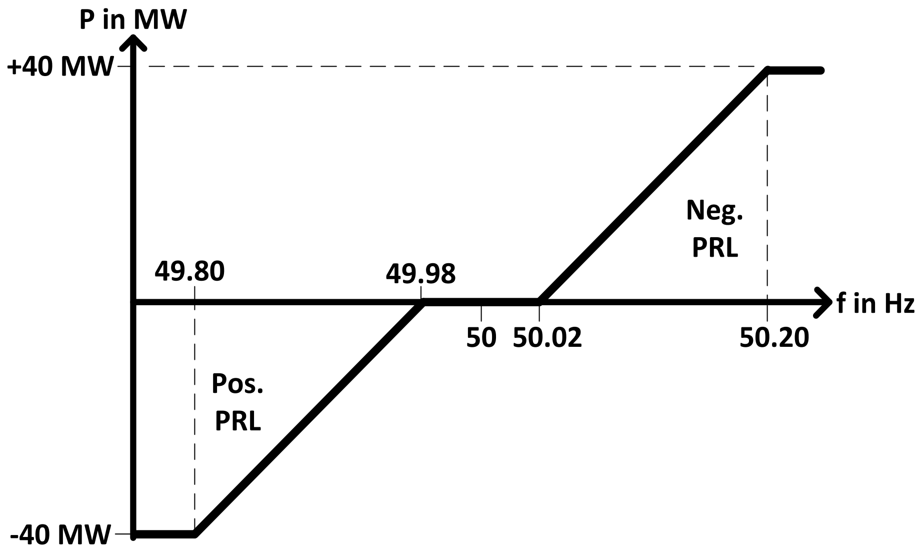
Primary control

- The grid frequency control is nowadays realized by conventional power plants. The possibility to influence is the steam pressure regulation and the supply of fuel.
- With the increase of installation of renewables, the power of conventional power plants is decreased. By this the possibility of the regulation is decreased.
- Renewables do not have this possibility of regulation
- Demand in Germany: ±592 MW (2012), ±576 MW (2013)
- SMES has 40 MW

- This is the ideal field of the use of a SMES

Primary control

- The primary control power (PCP) is delivered by all contributors synchronously
- PCP is realized via a P-regulation



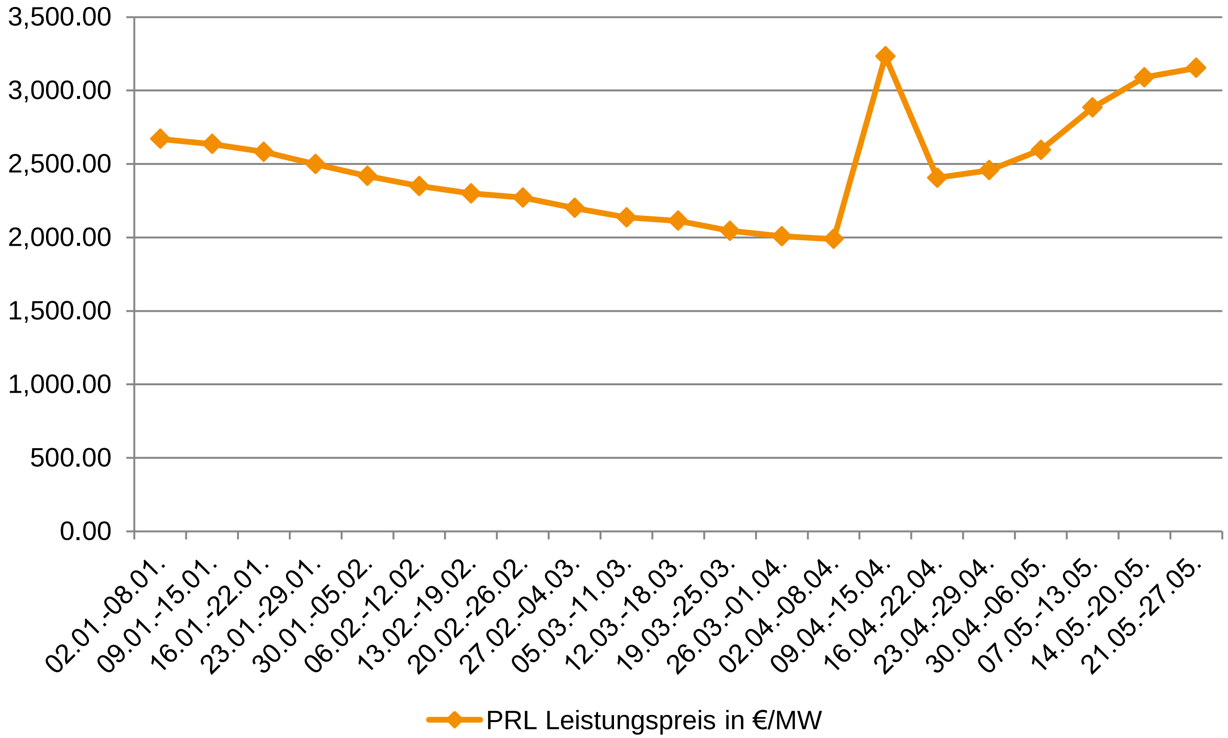
Frequency and active power of the PCP

Economical view of the control market

- 3 different markets for PCP, SCP and minute reserve forPRL, SRL und MRL
- For the PCP only the power is paid, independently of the real use
- The contract is aware via the price of the power
- Market volume for control energy in Germany is 1 Billion €/year

Price of power for PCP

- PCP has no price for energy
- Average price for PCP: 2.480 €/MW/Woche



Economical view of PCP

Overview of profit for a power of P=40 MW

	PCP	SRL pos.	SRL neg.	MRL pos.	MRL neg.
Offered power in W	40	40	40	40	40
Average price for power in €/MW	**2478,07**	**220,89**	**929,37**	**0,94**	**10,12**
Average price for energy in €/MWh	0	180,27	22,59	224,02	152,66
Profit per year in €	5.154.385,60	459.451,20	1.933.089,60	13.686,40	147.347,20

Primary control:	5,15 Mio. €
Secondary control:	2,39 Mio. €
Tertiary control:	0,16 Mio. €

Cost of a SMES

> **Investment cost of a SMES**

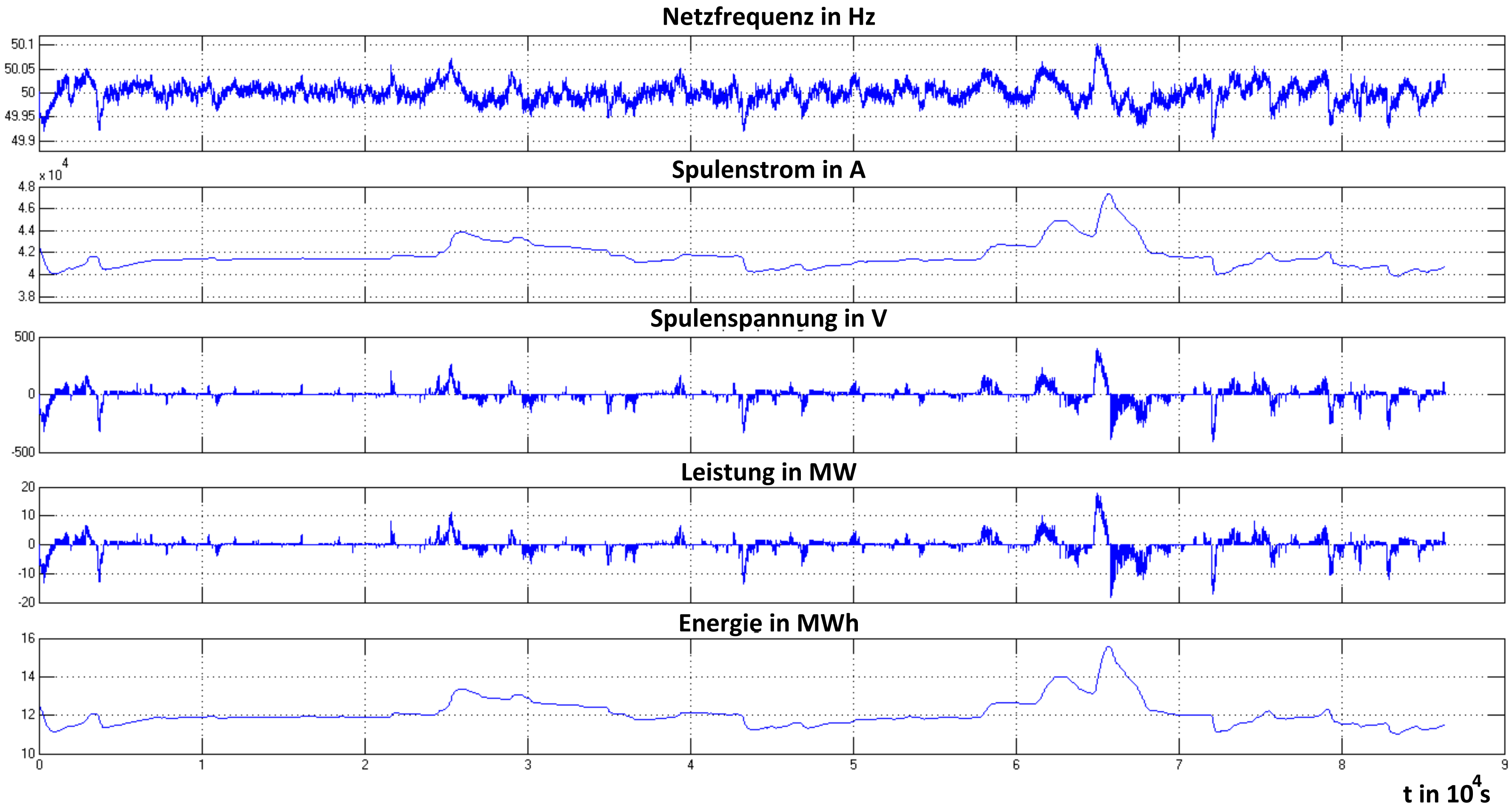
component	cost
coilsystem (Magnet, cryostat, cryoplant)	51,1 Mio. €
Power converter	8,1 Mio. €
Quench-protection, control	5 Mio. €
Total invest	**64,2 Mio. €**

Operation cost

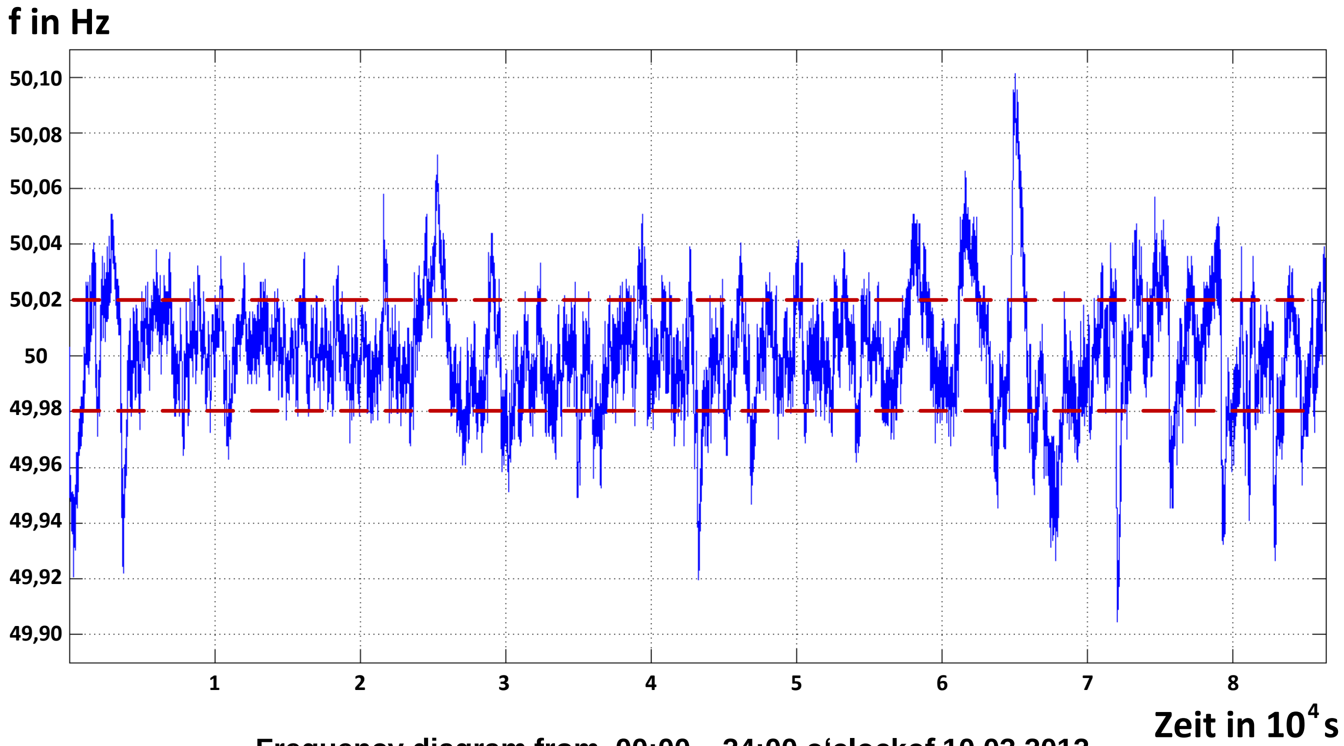
component	Cost per year
Cooling power	127.750 €
Standby-losses	110.380 €
Conversion losses	73.000 €
Cost for personal	150.000 €
Grid usage charge	167.500 €
Collateral cost	50.000 €
Total	**678.630 €**

- 100 % available unit
- With a storage today only possible with Pooling or collaterisation possible
- Amortisation:14 year

Simulation results



Comparison with real frequencydata from 2012



Frequency diagram from 00:00 – 24:00 o'clockof 10.03.2012

	Typ. day in January
Duration of PCP	7,9 hrs.
Aver. neg. PCP	-2,94 MW
Aver. pos. PCP	2,89 MW
Neg. PC-Energy in MWh	-10,90 MWh
Pos. PC-Energy in MWh	12,00 MWh

Conclusion

- In the future there will be a higher demand for grid control
- A SMES was dimensioned and simulated for the participation at the PCP
- Simulations show that a participation is possible
- Annual earning assuming 40 MW with PCP 5,15 Mio. €
- Investment cost of a SMES 64 Mio. €
- Battery plants are more cost effective in the invest, however these have a decrease in performance over time and a limited lifetime. The batteries have to be replace every few years

> Thank you for your attention

> Questions?

Slides about SMES by Hikaru Sato (KEK)

HELMHOLTZ
GEMEINSCHAFT

DESY

HISTORY OF THE STUDIES FOR ENERGY STORAGE SYSTEM AT KEK

1970's	▪ 100KJ SMES Experiment. ▪ 3MJ SMES Coil Design. ▪ Collaboration with Wisconsin University.
1997-2002 KEK Director Support Japan Society for the Promotion of Science	▪ Visit to ROTES at Okinawa. ▪ 75KW-FW experiment. ▪ Collaboration with Okayama University.
2003-2006 Collaboration with Univ. & RASMES	▪ Studies of SMES for J-PARC 50GeV-PS. ▪ Studies of SMES for Medical Accelerator. ▪ 10KJ-SMES simulation Experiment.
At this Present	▪ POP Experiment of Capacitor System. ▪ Studies of SMES for 30GeV Rapid Cycle Operation of J-PARC PS.

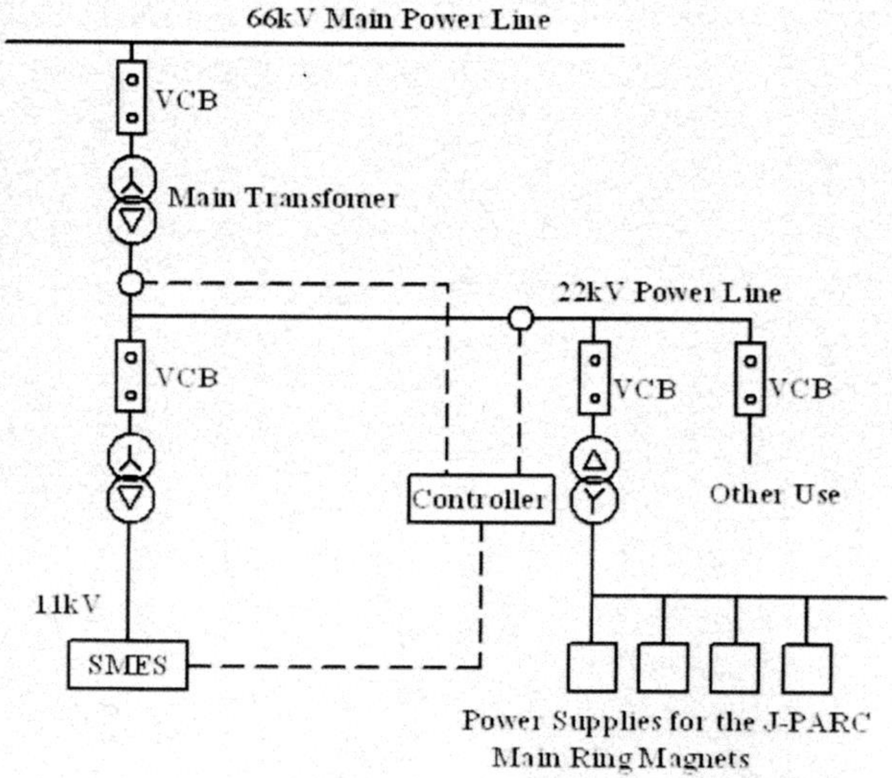
Y. Kurimoto will present.

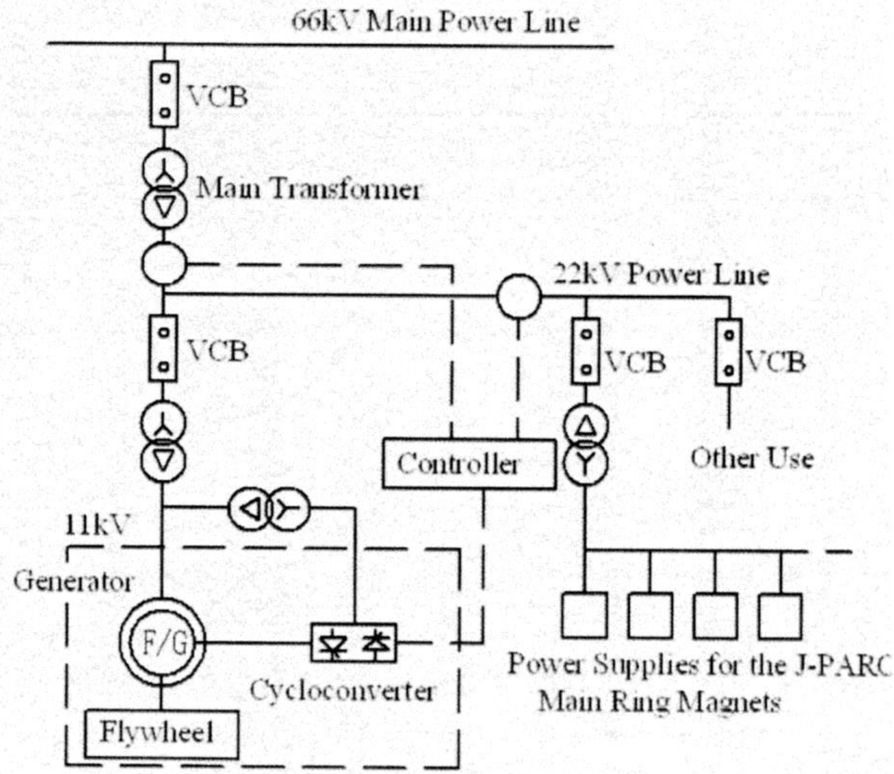
Research Association of Superconducting Magnetic Energy Storage : www.rasmes.com

H.Sato

50 GeV-PS Fluctuation Compensation
AC Link

SMES





Fly Wheel
(JHF Original)

SMES National project in Japan

2000 → 2007

Phase I（’91-’98)

Establishment of the key component technologies

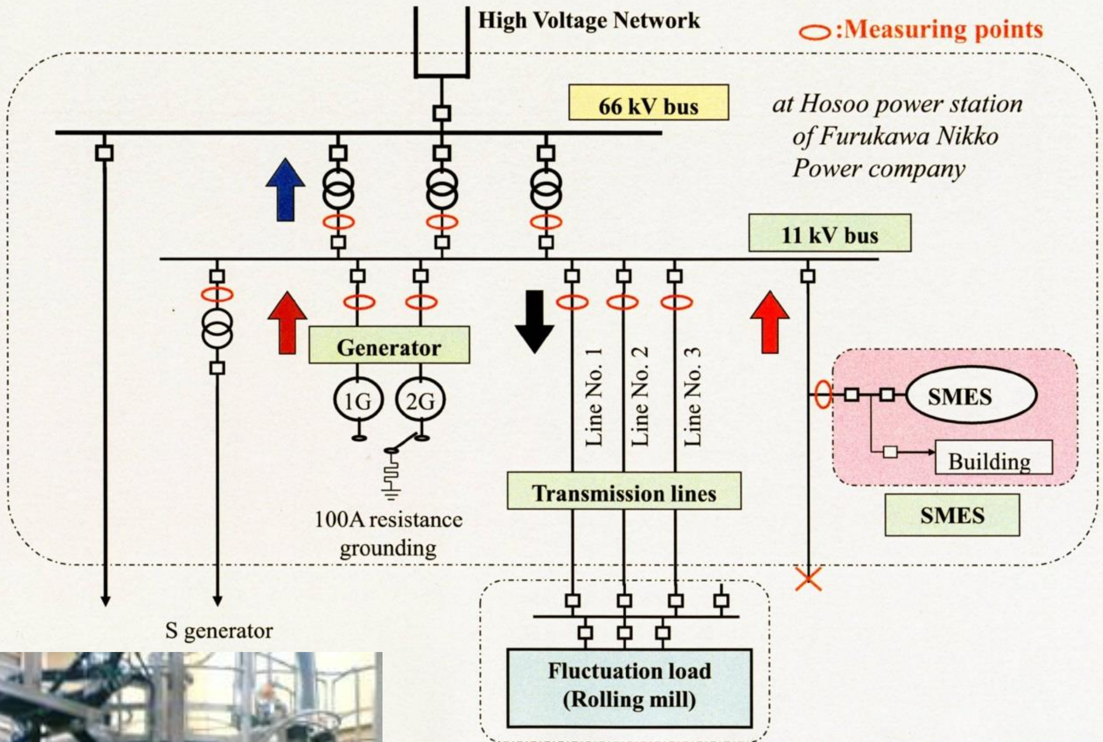
Phase II（’99-’03)

Cost reduction of SMES for power system stabilization for load fluctuation compensation

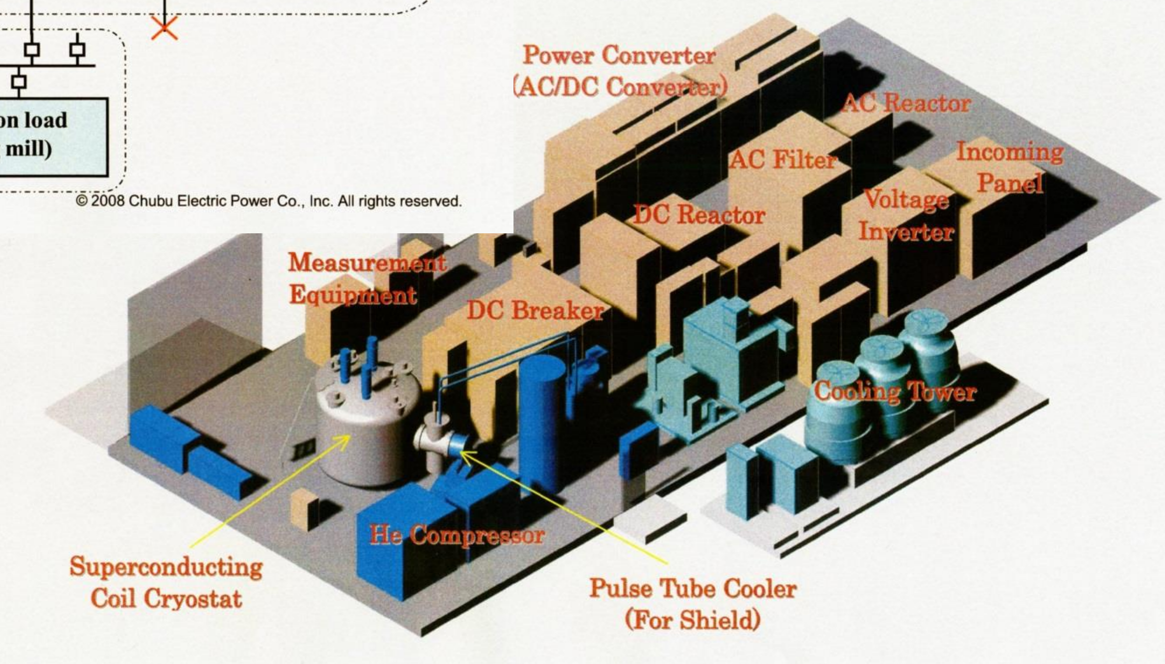
Phase III（’04-’07)

Establishment of power system control technologies of the SMES system.
Development of higher performance and lower cost components of the SMES system

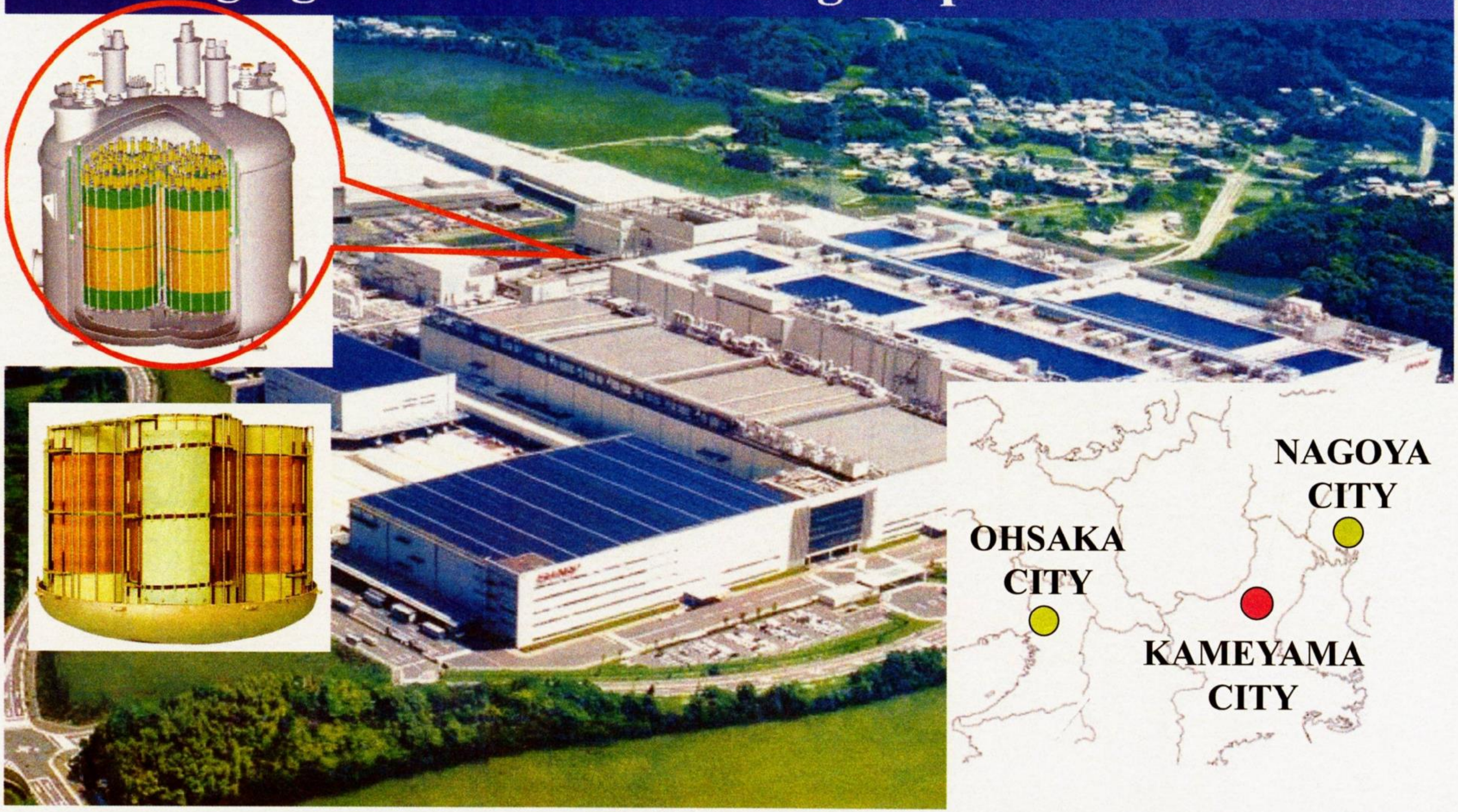
Schematic Diagram of the Field Test Site Power Grid



nponents of the SMES



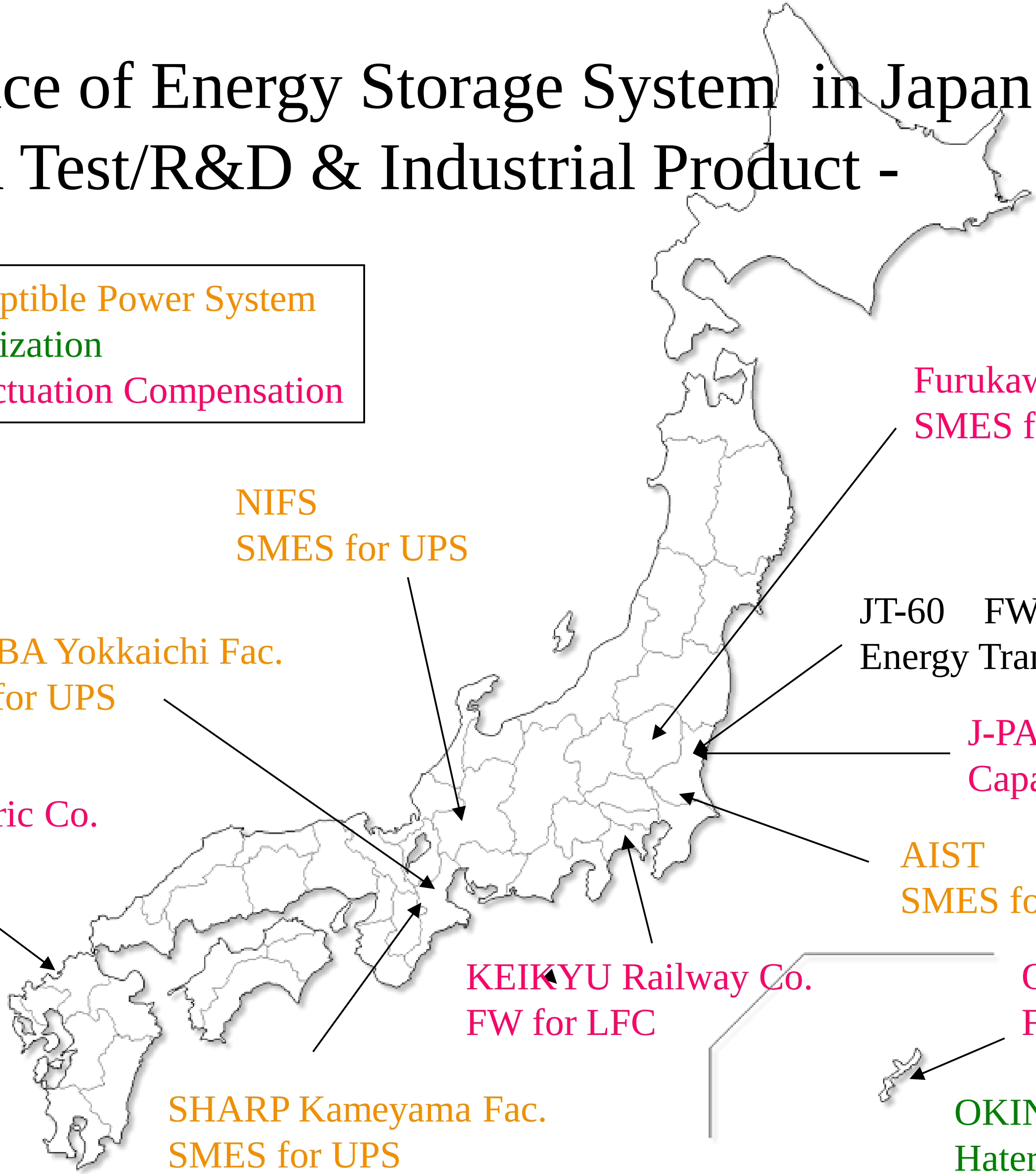
Field Test Site of the SMES System for Bridging Instantaneous Voltage Dips



At an advanced large liquid crystal plant in Kameyama since July 2003

Experience of Energy Storage System in Japan
- Field Test/R&D & Industrial Product -

UPS: Uninterruptible Power System
GS: Grid Stabilization
LFC: Load Fluctuation Compensation



RSMES contributed to IEA working Paper 2009. [Prospect for Large-Scale Energy Storage in Decarbonised Power Grids.]

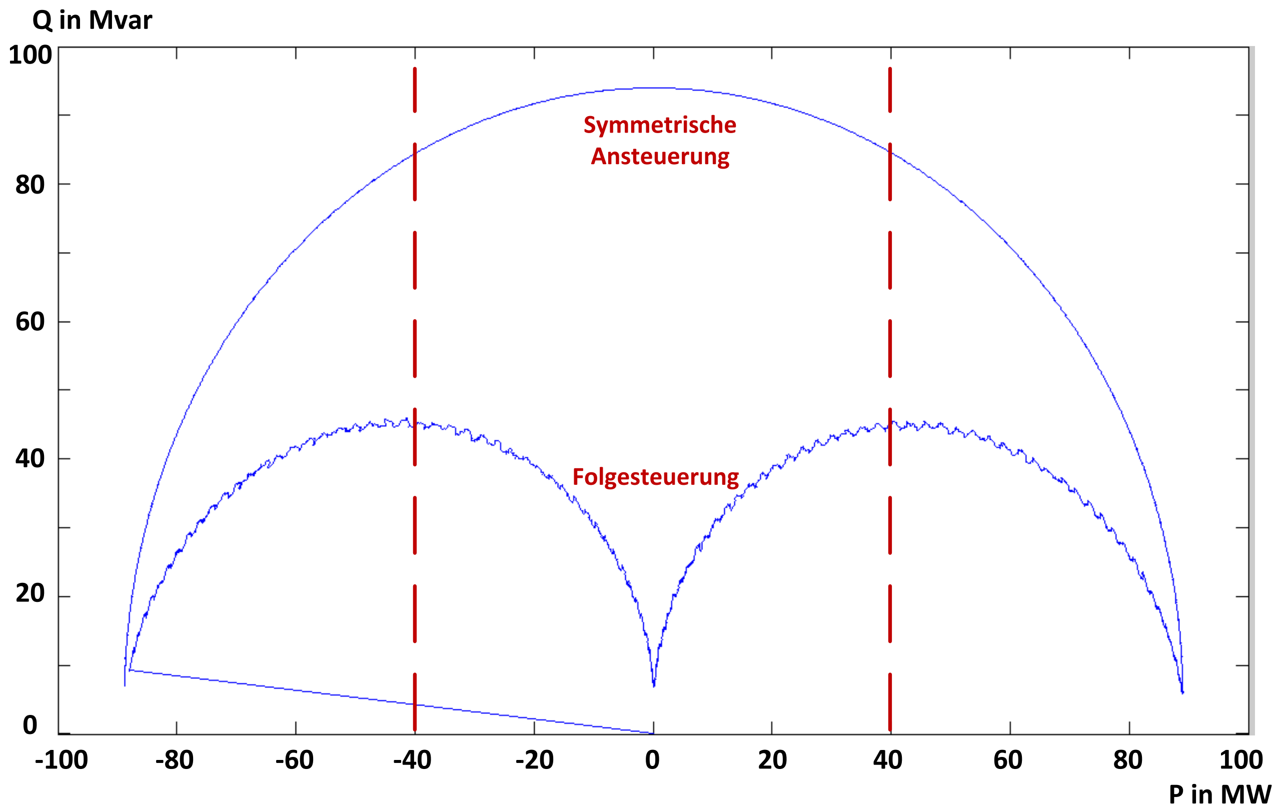
www.environmentportal.in/files/energy_storage.pdf

> Thank you for your attention

> Questions?

P-Q-Diagramm Simulation

$$Q_{max} = \frac{1}{2} \cdot U_{di} \cdot I_d \cdot (sin\alpha_1 + sin\alpha_2) = 44\ Mvar$$

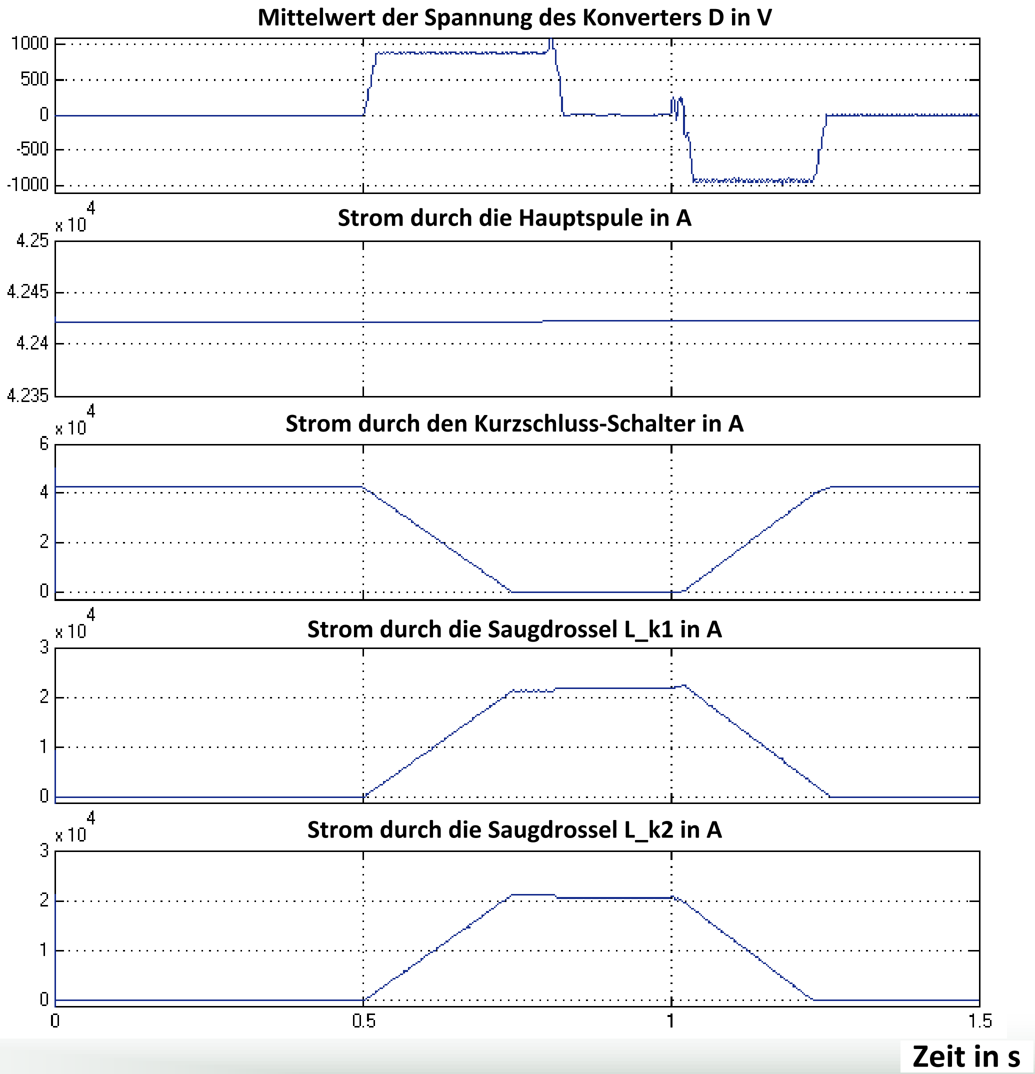


Regelung

$$P_{neg}(f) = m \cdot f + b_{WR} = 222{,}2\,\frac{MW}{Hz} f - 11{,}116\,GW$$

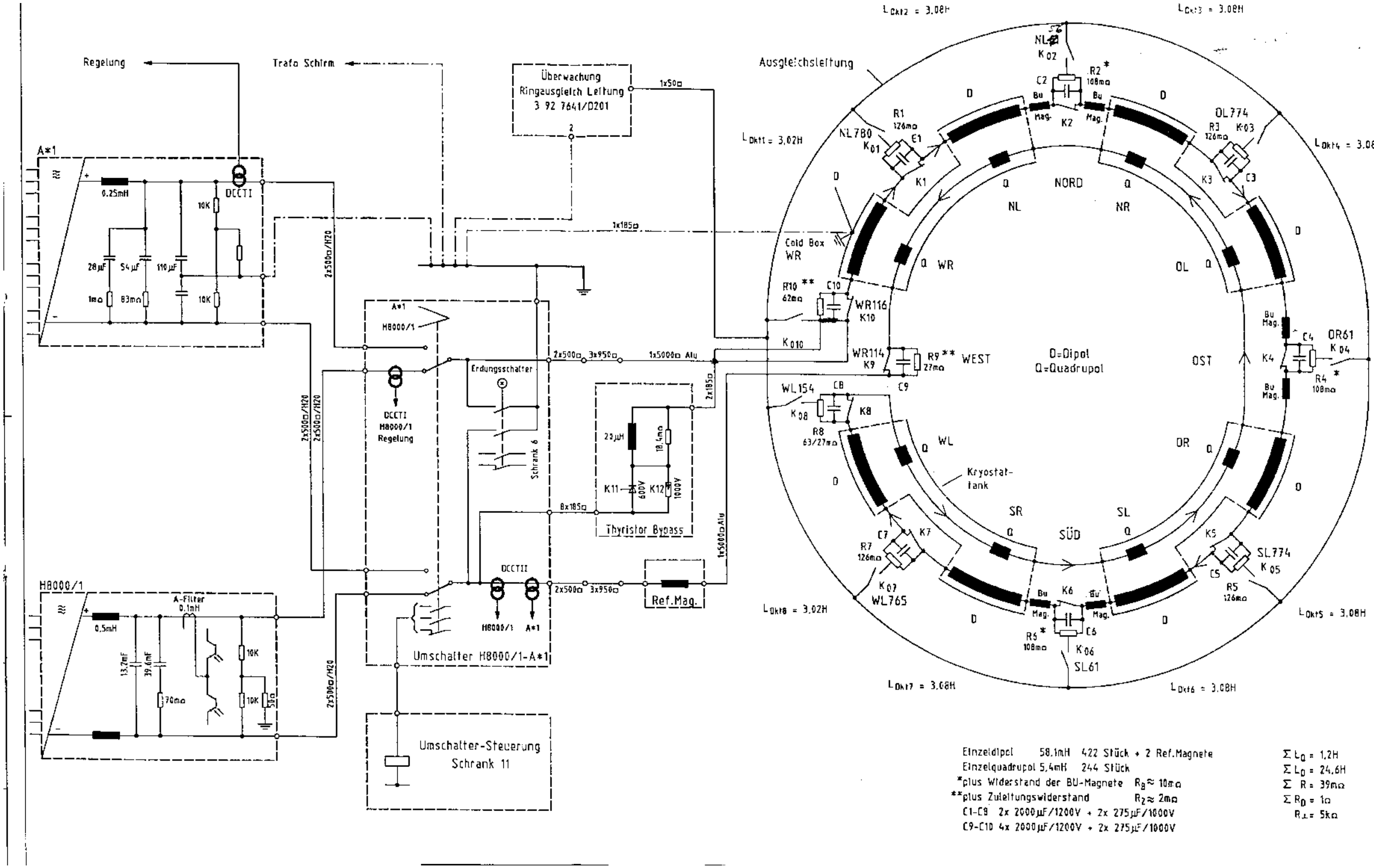
	Positive PRL	Negative PRL
Energie	Energieabgabe	Energieaufnahme
Betrieb	Wechselrichterbetrieb	Gleichrichterbetrieb
Frequenz-Bereich	49,80 - 49,98 Hz	50,02 - 50,20 Hz
Schaltwinkel	α_1=180° α_2=0 - 180°	α_1=0 - 180° α_2=0°
Stromrichter-Spannung	$U_{di\alpha} = \frac{U_{di}}{2}(-1 + cos\alpha_2)$	$U_{di\alpha} = \frac{U_{di}}{2}(cos\alpha_1 + 1)$
Variabler Schaltwinkel	$\alpha_2 = \arccos(\frac{m \cdot f + b_{WR}}{i \cdot U_{di}} \cdot 2 + 1)$	$\alpha_1 = \arccos(\frac{m \cdot f + b_{GR}}{i \cdot U_{di}} \cdot 2 - 1)$

Kurzschluss-Schalter



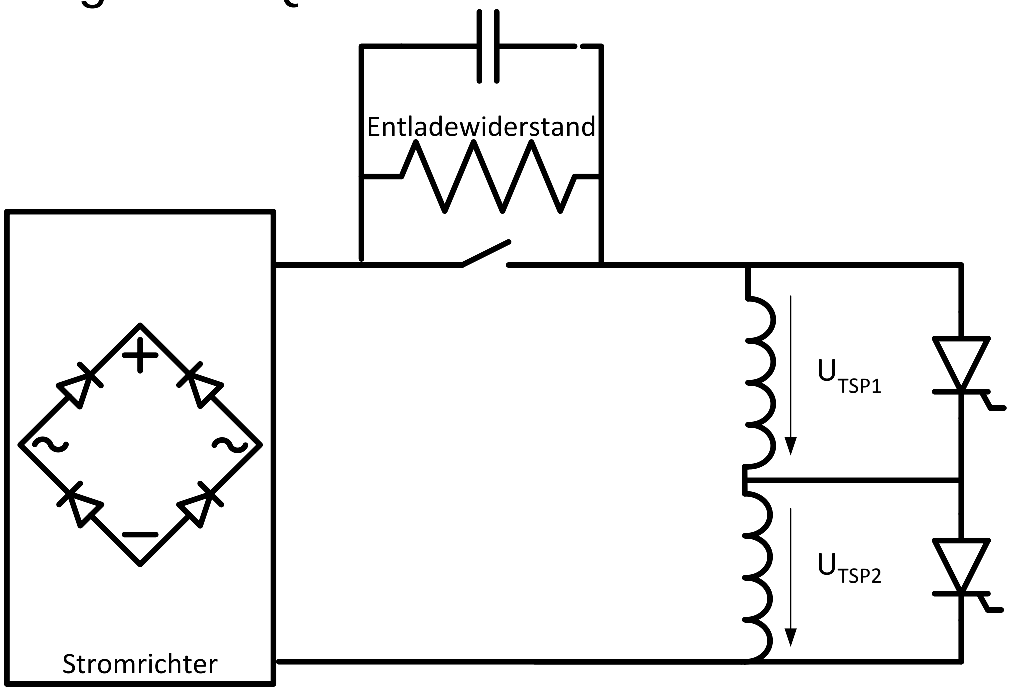
Übernahmeverhalten des Kurzschluss-Thyristors

HERA Maschine in der Übersicht



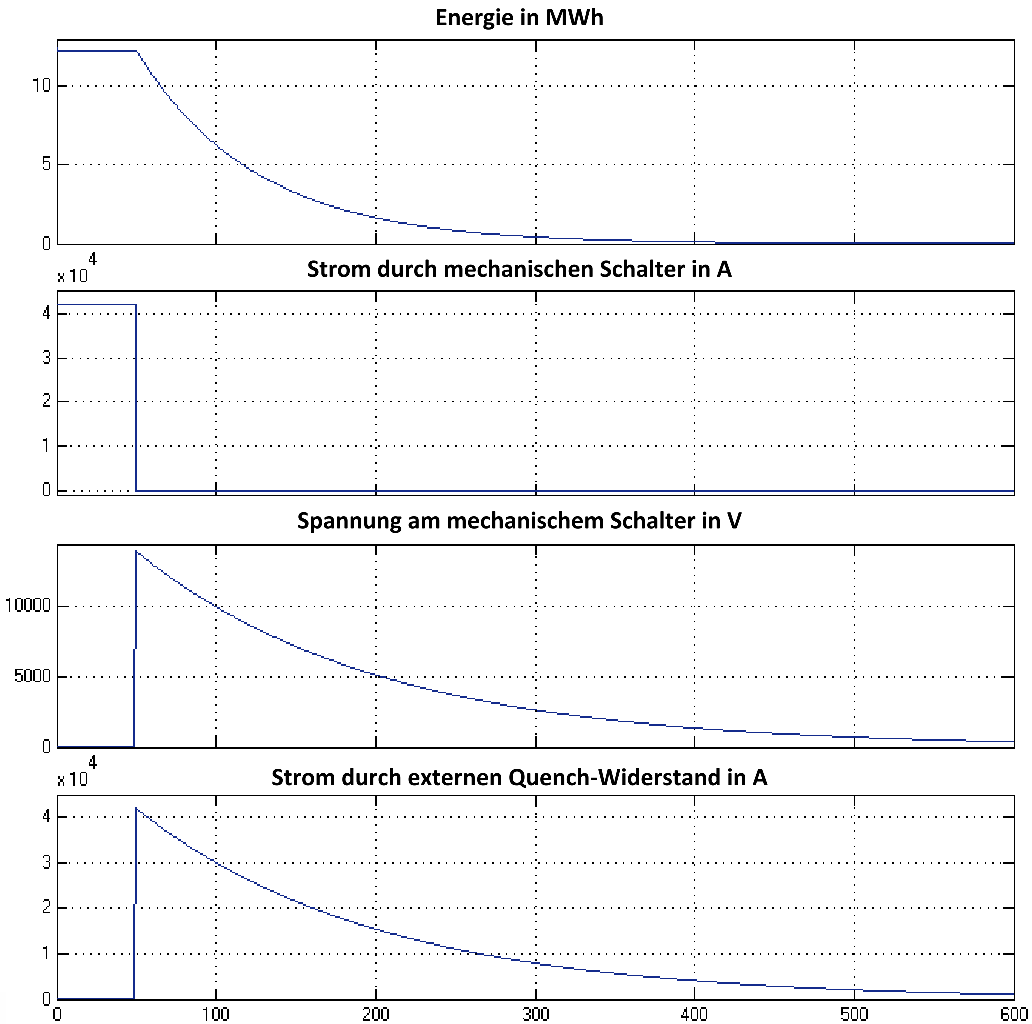
Quench

- Quench: Übergang vom supraleitenden in den normalleitenden Zustand
- Feldenergie wird in Wärme umgesetzt
- Schutzschaltung muss Quench detektieren und Feldenergie abbauen

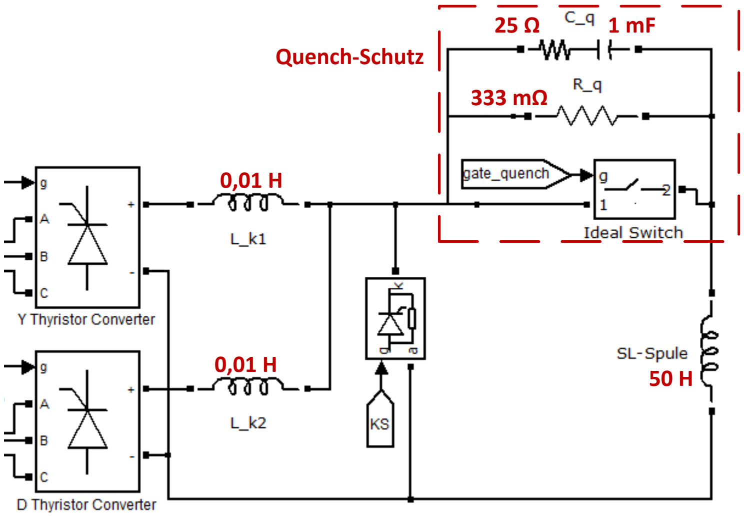


Quench-Schutz und Quench-Detektion

Quench-Schutz



Auslösen des Quench-Schutz



$$\tau = \frac{L}{R_q} = \frac{50\ H}{333\ m\Omega} = 150\ s$$

- Quench-Schalter im Normalfall geschlossen
- Widerstand R_Q im Strompfad
- Entladezeit vs. Isolationsspannung

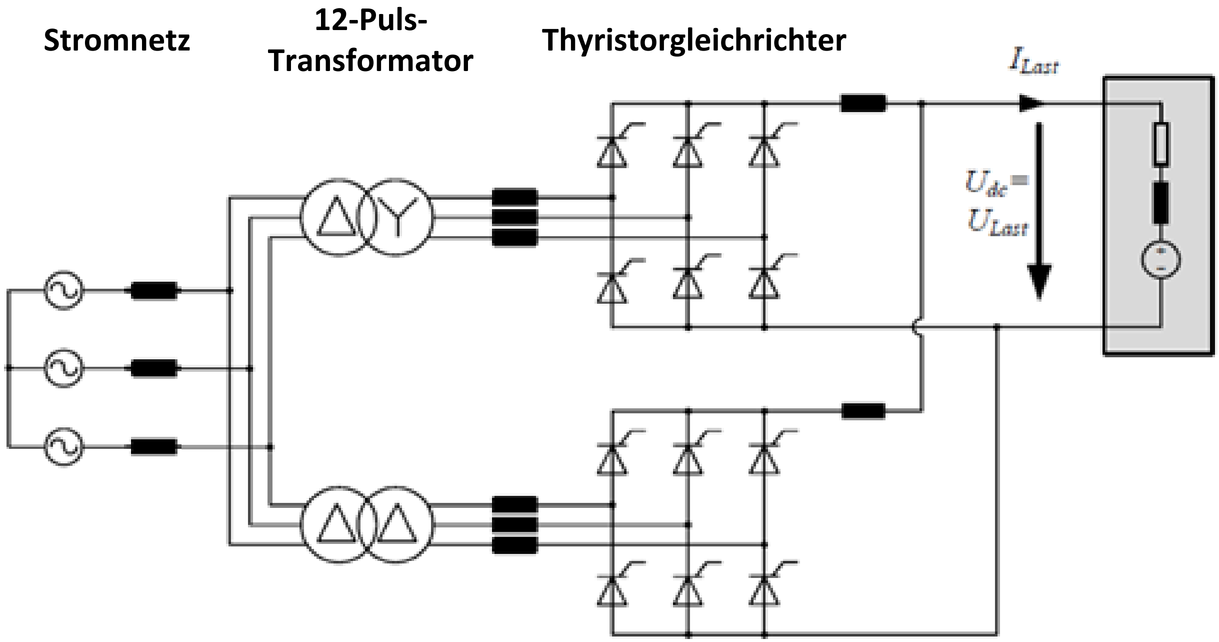
Stromrichter

- Thyristors
- Trafo sekundary side in Delta/wye
- 12-pulse to reduce harmonics
- Symmetrical control

$$U_{di\alpha} = U_{di} \cdot \cos(\alpha)$$

$$P_{\alpha} = U_{di} I_d \cos(\alpha)$$

$$Q_{\alpha} = U_{di} I_d \sin(\alpha)$$



Zwölfpulsige Thyristorschaltung für Hochstromanwendungen [HER-09]

Reduction of reactive power by sequential control

- 2 switching angles

$$Q_{max} = \frac{1}{2} \cdot U_{di} \cdot I_d \cdot (sin\alpha_1 + sin\alpha_2) = 44\ Mvar$$

- Max. reactive power is 50% in comparison to symmetrical control

$$U_{di\alpha} = \frac{U_{di}}{2}(cos\alpha_1 + cos\alpha_2)$$