The DRYSMES4GRID project: development of a cryogen free cooled 500 kJ / 200 kW SMES demonstrator based on MgB_2

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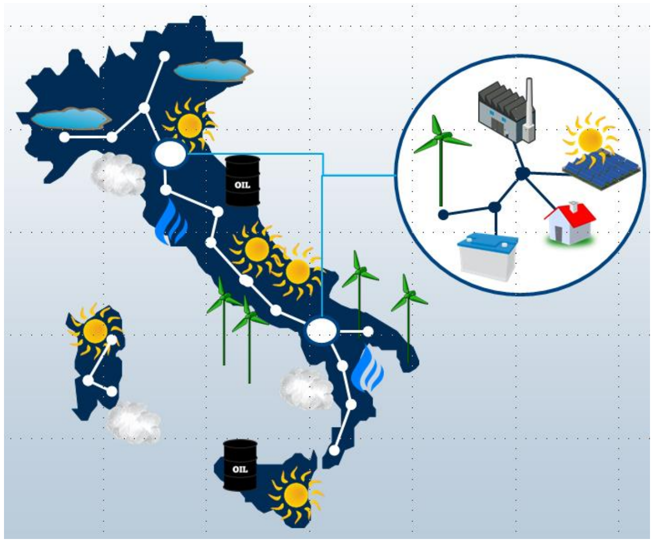
Outline

- SMES technology - a player in energy storage?
- Outline of the project
- The magnet system
- Power conditioning system
- Test facility
- Conclusion

The need for electric energy storage

Grid

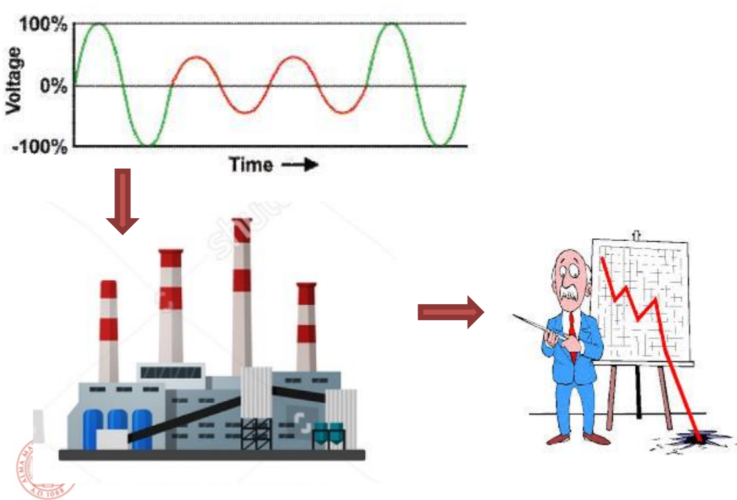


Inherent generation / load imbalance due to loads fluctuation and non programmable generation

Methods/technologies for grid energy management

- Curtailment of renewables
- Improved controllability of convent. generation
- Demand control
- Network upgrade (… Supergrid)
- **Energy storage**

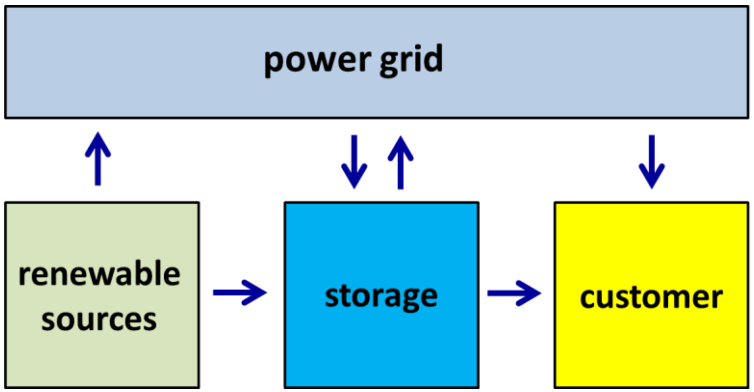
Customer



Energy storage

- Power quality and UPS
- Leveling of impulsive/fluctuating power (industry, physics, …)

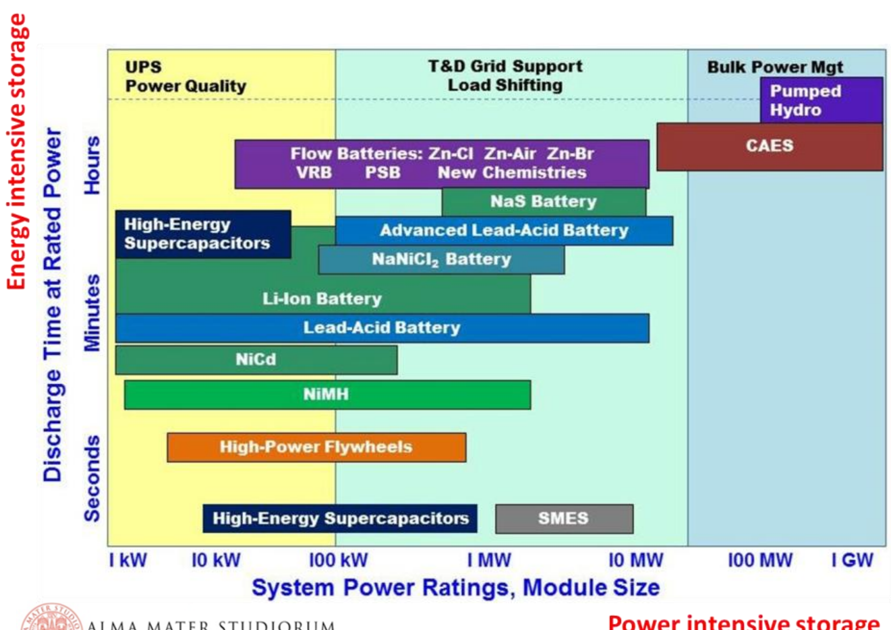
Which storage technology?



Parameters of the energy storage system

- Absorbed/supplied power, P
- Duration delivery, Δt
- Number of cycles, N
- Response time, t_r

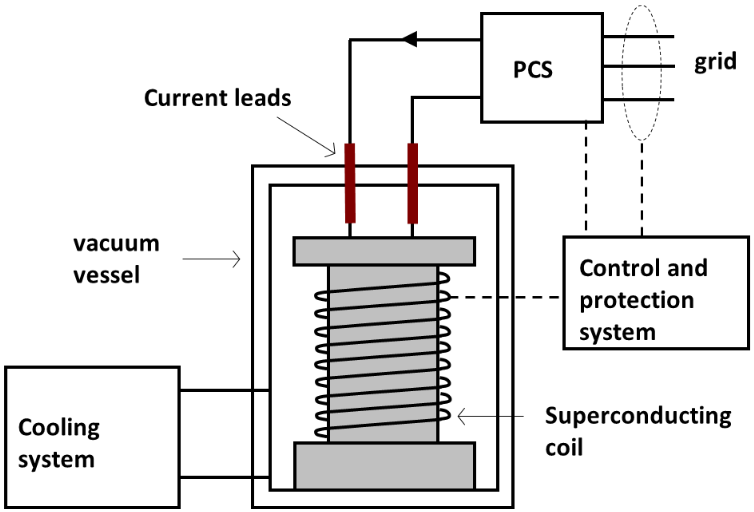
No unique storage technology exists able to span the wide range of characteristics required for applications



- Most suitable storage technology must be chosen from case to case

- Hybrid systems, obtained by combining different storage technologies, represent the best solution in many cases

Prospects for SMES



- High deliverable power
- Virtually infinite number of cycles
- High round trip efficiency
- Fast response (<1ms) from stand-by to full power
- No safety hazard

- **Low storage capacity**
- **Need for auxiliary (cooling) power**
- **Idling losses**

SMES is an option for

- **Fast delivery of large power for short time**

  UPS for sensitive industry customers, bridging power, pulsed load (physics), ….

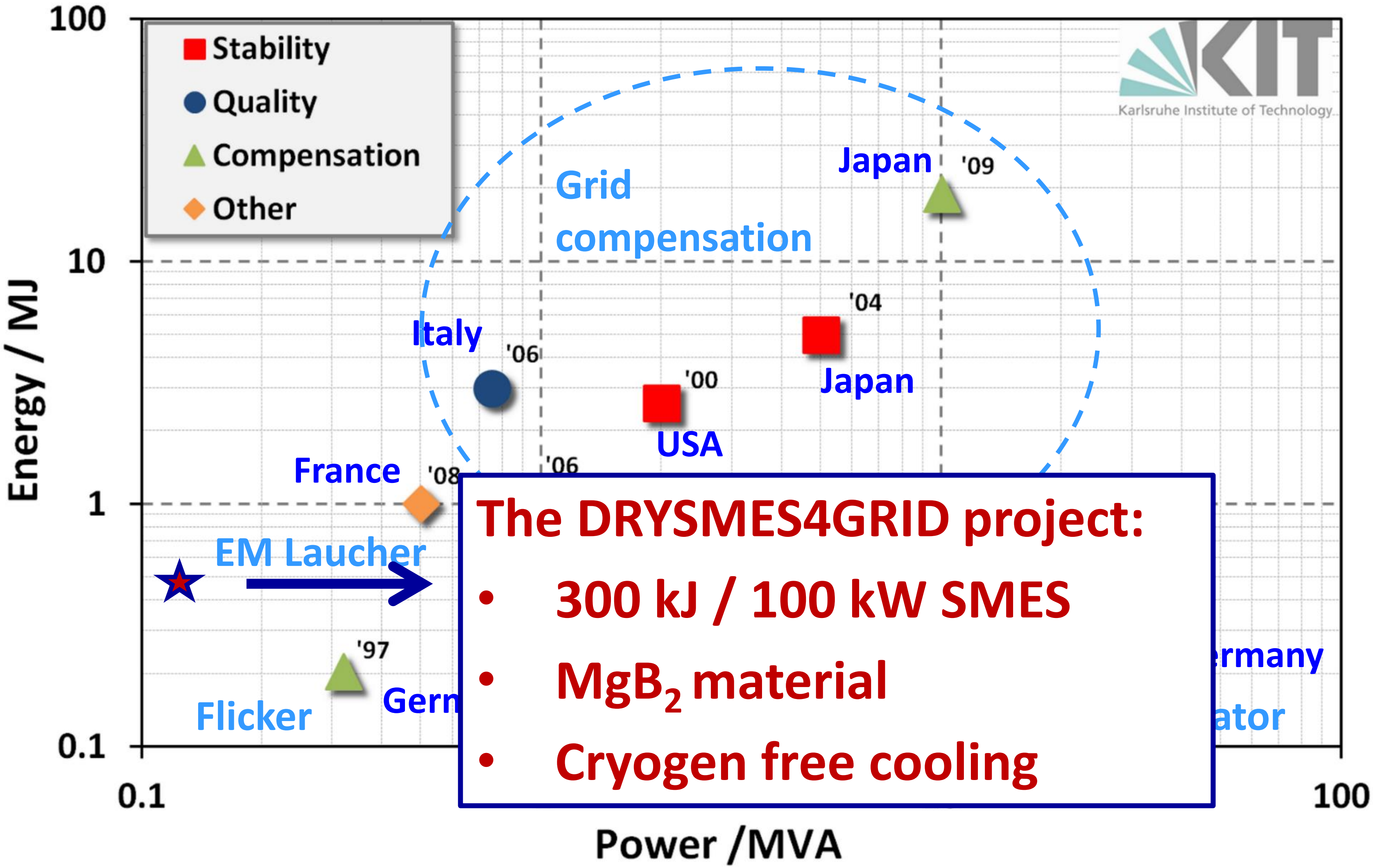
- **Short term increase of peak power of energy intensive systems**

  in combination with batteries, hydrogen, liquid air, ….

- **Continuous deep charge/discharge cycling**

  leveling of impulsive loads

The state of the art of SMES technology



The DRYSMES4GRID project:

- 300 kJ / 100 kW SMES
- MgB_2 material
- Cryogen free cooling

The DRYSMES4GRID Project

MISE - Italian Ministry of Economic Development
Competitive call: research project for electric power grid

- Transmission and distribution
- Dispersed generation, active networks and storage
- Renewables (PV and Biomass)
- Energy efficiency in the civil, industry and tertiary sectors
- Exploitation of Solar and ambient heat for air conditioning

Project DRYSMES4GRID funded

- **Budget: 2.7 M€**
- **Time: June 2017 – June 2020**
- **developm. of dry-cooled SMES based on MgB_2**
- **300 kJ – 100 kW / full system**

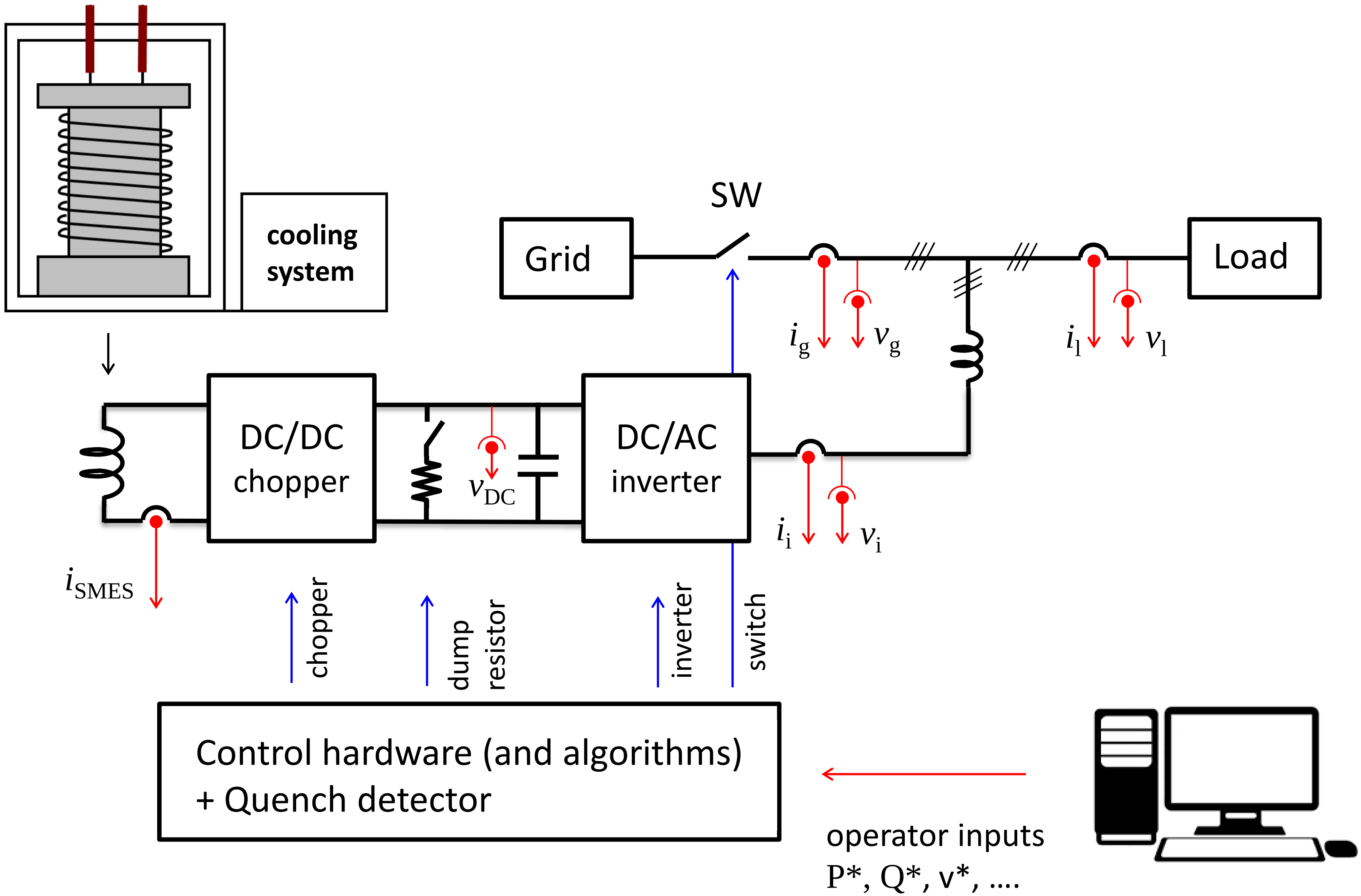
Project Coordinator:

- **Columbus Superconductors SpA, Genova, Italy**

Partners

- **University of Bologna**
- **ICAS - The Italian Consortium for ASC, Frascati (Rome)**
- **RSE S.p.A - Ricerca sul Sistema Energetico, Milan**
- **CNR – SPIN, Genoa**

The SMES system



Project Workplan

Design of the magnet

WP1. Electromagnetic & thermal design

Power conditioning system

WP2. Layout and functions

WP3. Detailed design and manufact. of converters

+ PE industry

Wire, cable and winding

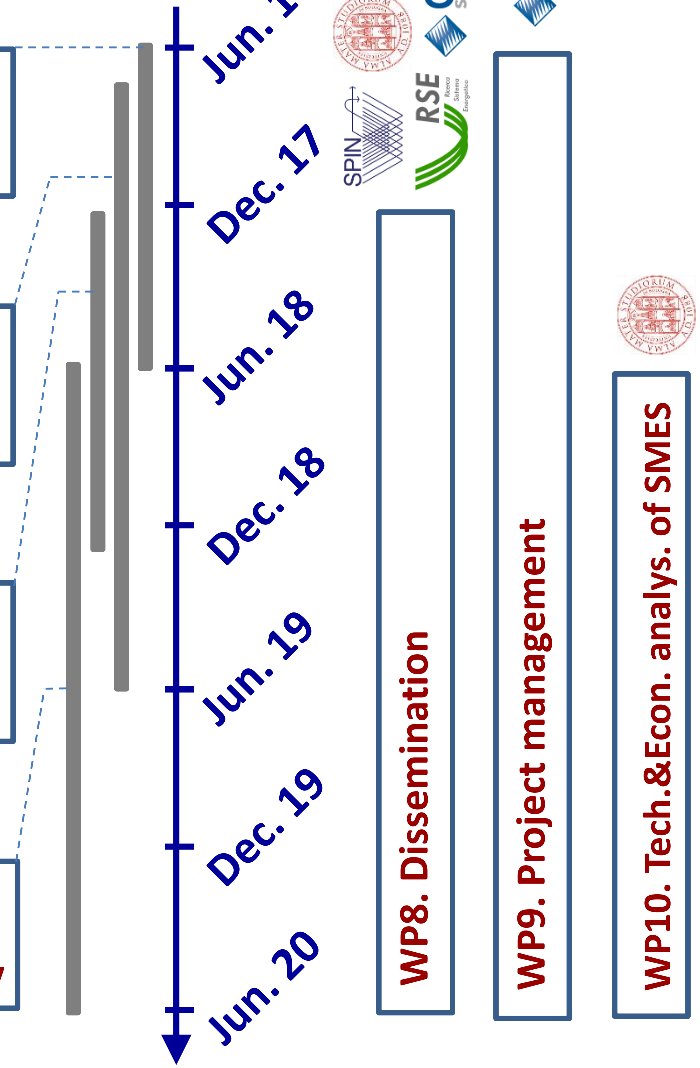
WP4. Optimization of in-field perform. of the wire

WP5. Manufacturing of wire, cable and winding

Assembling and test

WP6. Assembly of coil and cooling & prelim. test

WP7. Assembly of PCS & Experiments in test facility



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Design strategy of the MgB_2 magnet

System inputs →

- Power (100 kW)
- Delivery time (3s)

Additional copper on the conductor

Constraints & design parameters

- Jc(e)-B of conductor
- Operating temperature
- J/Jc
- Cu/total ratio of conductor
- Max field on the conductor
- Voltage of DC bus
- Max voltage of the coil
- Quench detection time
- Max temperature during quench
- Aspect ratio of the solenoid
- Filling factor of coil

Design choice

- Number of turns/inductance/Max. current

Output

- Layout conductor and cable
- Maximum current
- Layout of coil (diameter, height, thickness, layers, wire length …)
- Dump resistance

Check

- Manufacturability of conductor and cable
- Mechanical stress
- AC loss and total thermal load

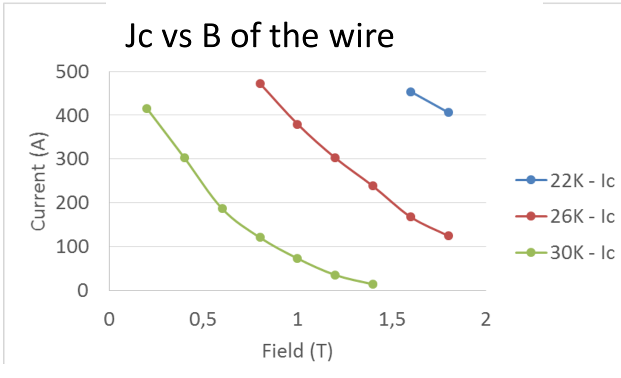
(optimization)

Task leaders

With the support of

- **Shared procedure**
- **Shared software**

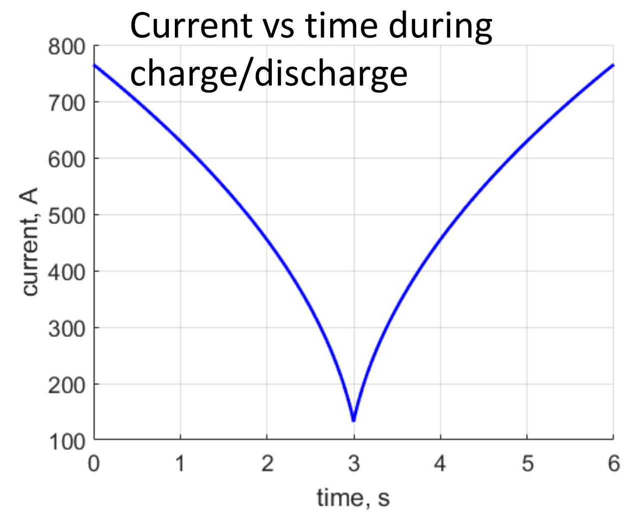
A preliminary lay-out

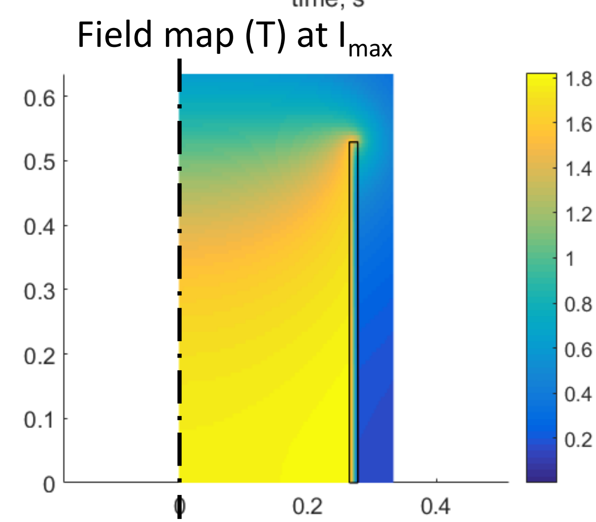


3 × ϕ 1.52 mm MgB2 wires
Monel + Internal Copper
+ 40 μm Cu Coating
630 A @ 1.8 T – 20 K

Main characteristics of the coil

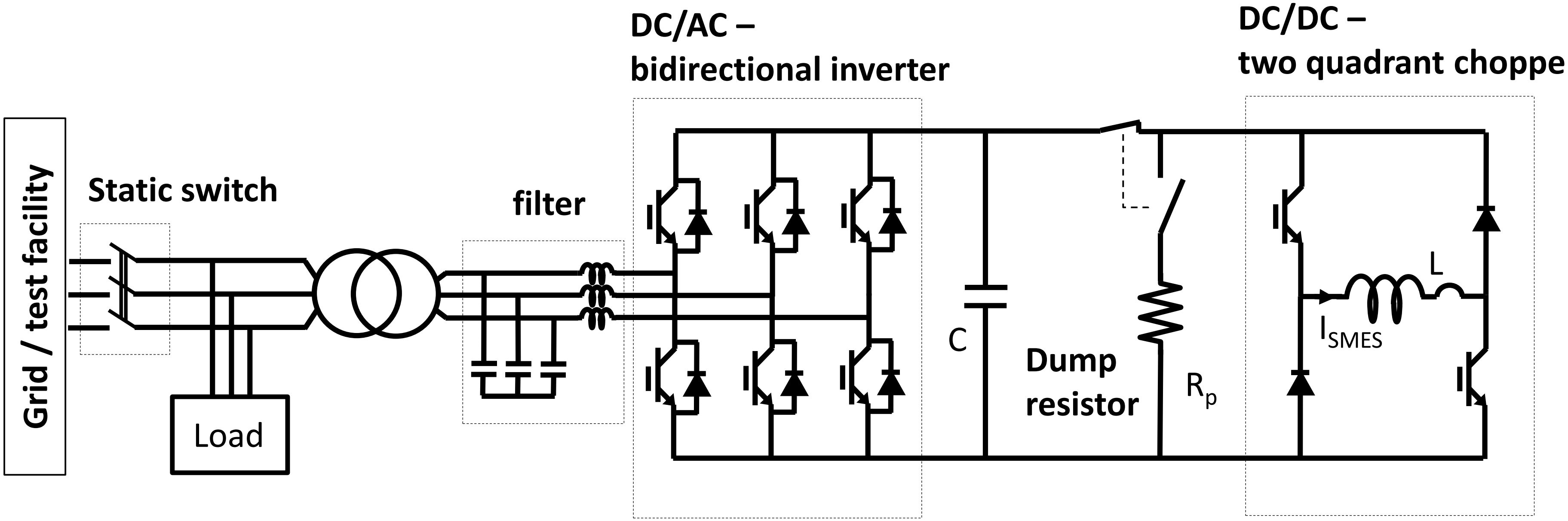
Operating temperature	20 K
Diameter	268 mm
Length	1060 mm
Max Current	776 A
Imax / Ic	0.6
Max field on the conductor	1.8 T
Max hot spot temperature (Δt = 0.3 s)	220 K
Iductance	1.06 H
Dump resistor	1.3 Ω
Length of conductor	3.7 km
Total stored energy at I_{max}	**310 kJ**
Deliverable energy (at 100 kW)	**300 kJ**





Numerical modelling is in progress of estimation of AC loss

Power conditioning system – power hardware

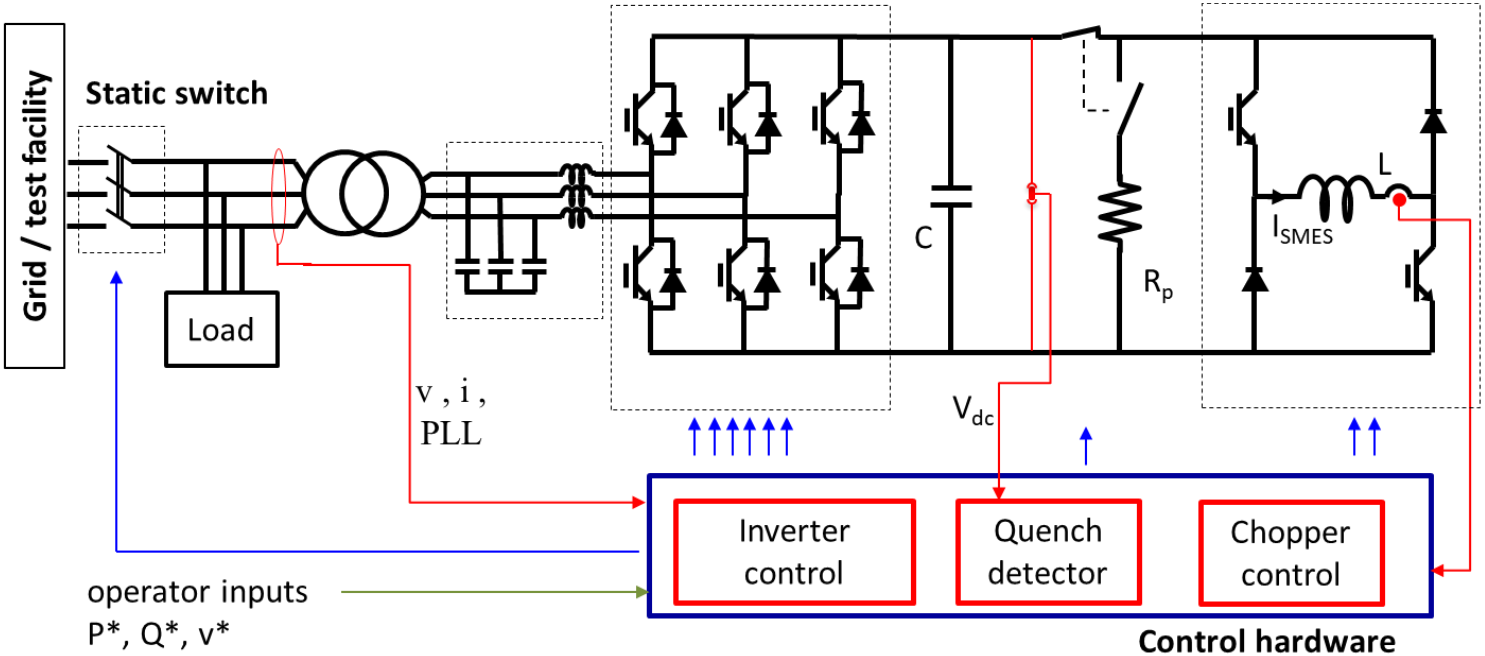


Detailed design of converters (architecture and switch technology), filter, switch → **Specifics for commissioning and type testing**

Mimimization of stand-by loss

- SiC technology
- Multilevel structure with MOSFET
- Additional low-loss switch
  (cryogenic integration of silicon device?)

Power conditioning system – control hardware and algorithms

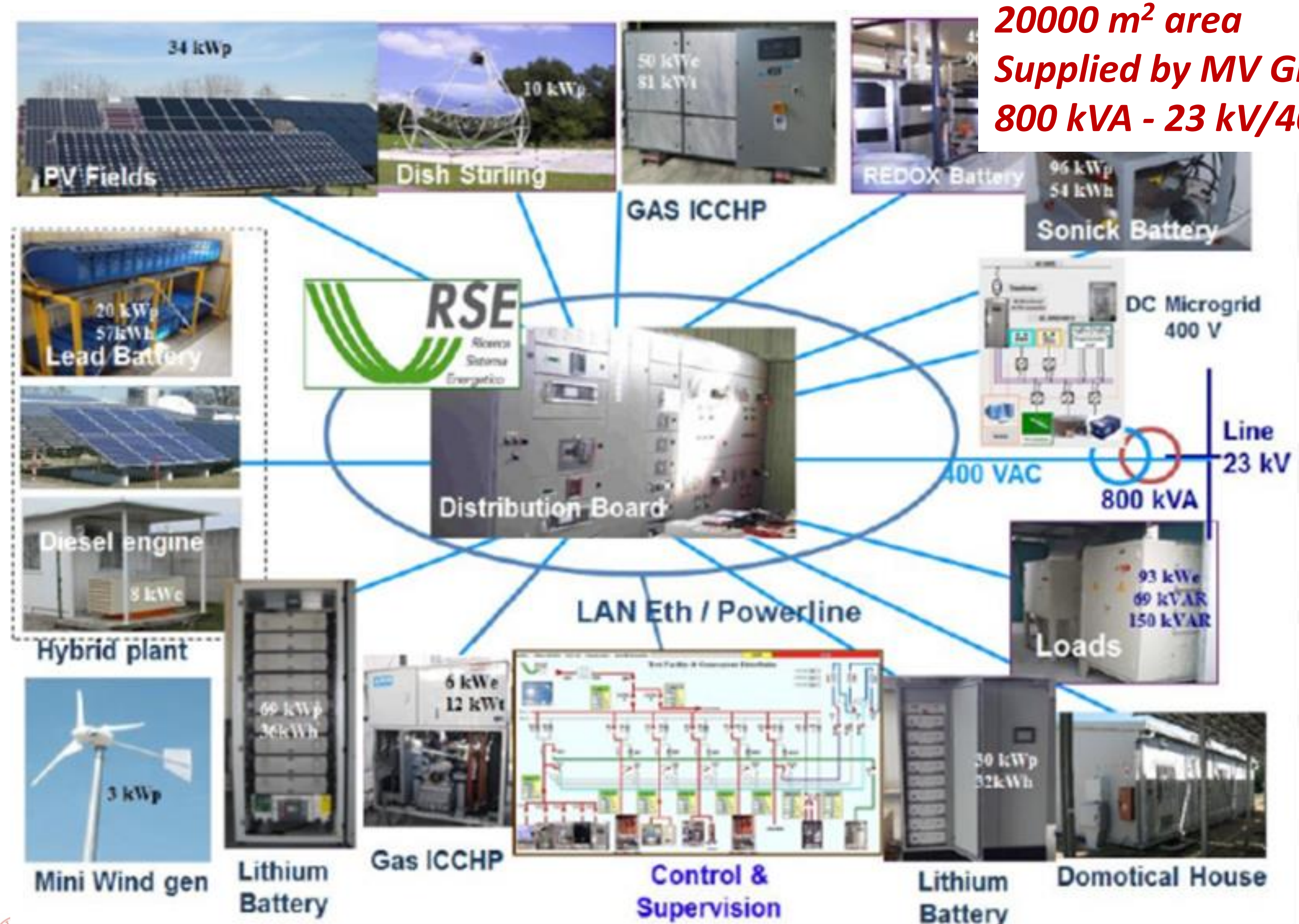


- **Detailed definition of control algorithms (logic, schemes, parameters)**
  - Shunt operation (power modulation, active filter) and islanding operation
  - Shift from shunt to islanding operation
- **Control hardware in the loop testing**
- **Integration of the magnet protection system**

RSE DER (Distributed Energy Resources) Test Facility

A real low voltage microgrid that interconnects different generators, storage systems and loads to develop studies and experimentations on DERs and Smart Grid solutions.

20000 m² area
Supplied by MV Grid
800 kVA - 23 kV/400 V transf.



Conclusion

- SMES is viable storage technology for power intensive applications and for operation in hybrid storage systems

- Improvements of SMES technology can be obtained by means of HTS superconductors compatible with cryogen free cooling

- A three year research project has been recently started in Italy aimed at developing a 300 kJ / 100 kW SMES demonstrator with cryogen free cooling based on MgB2

- All engineering aspects needed of the practical development of SMES technology, ranging form magnet technology to power electronics and control, will be dealt with in the project

Thank you for your attention

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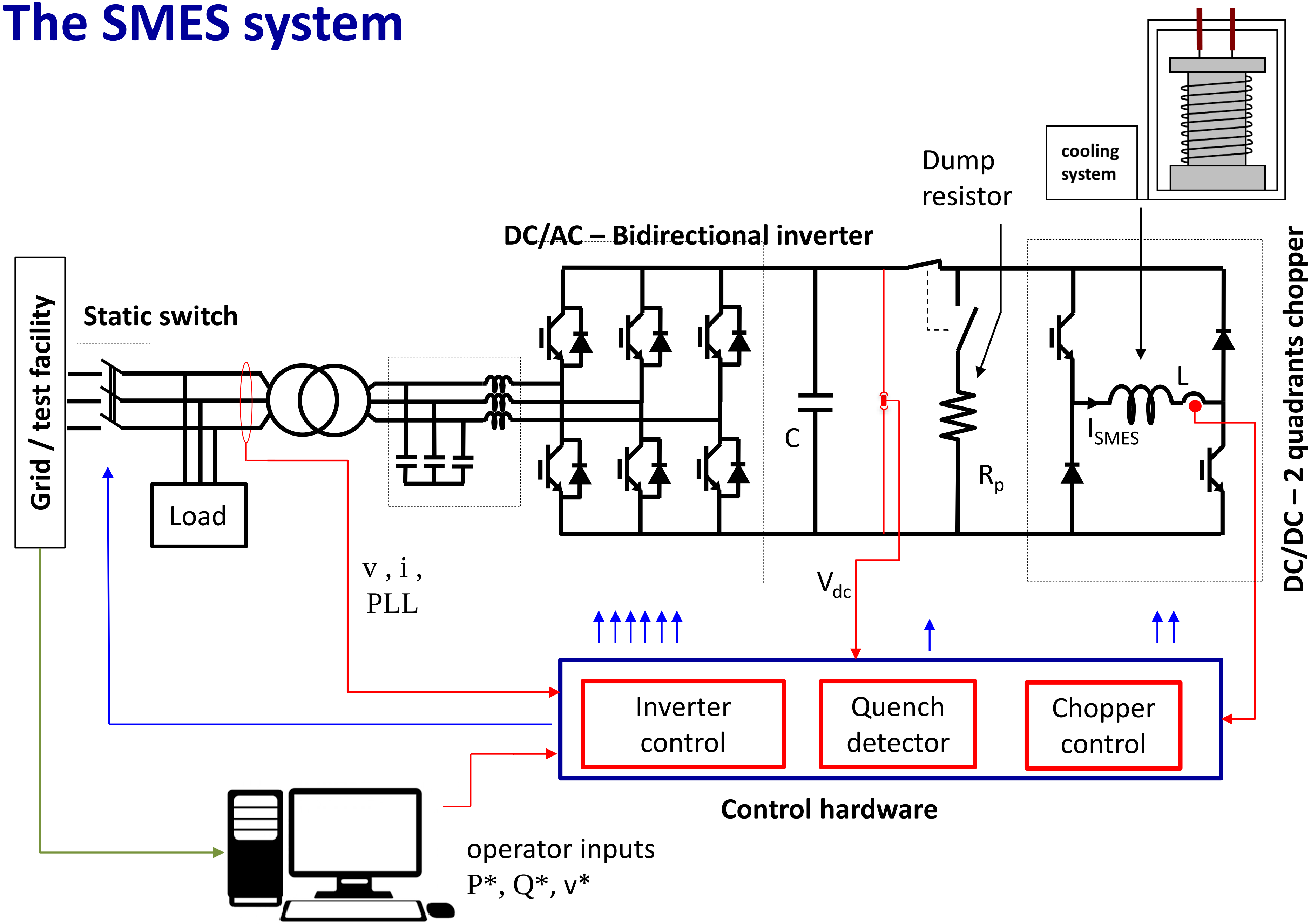
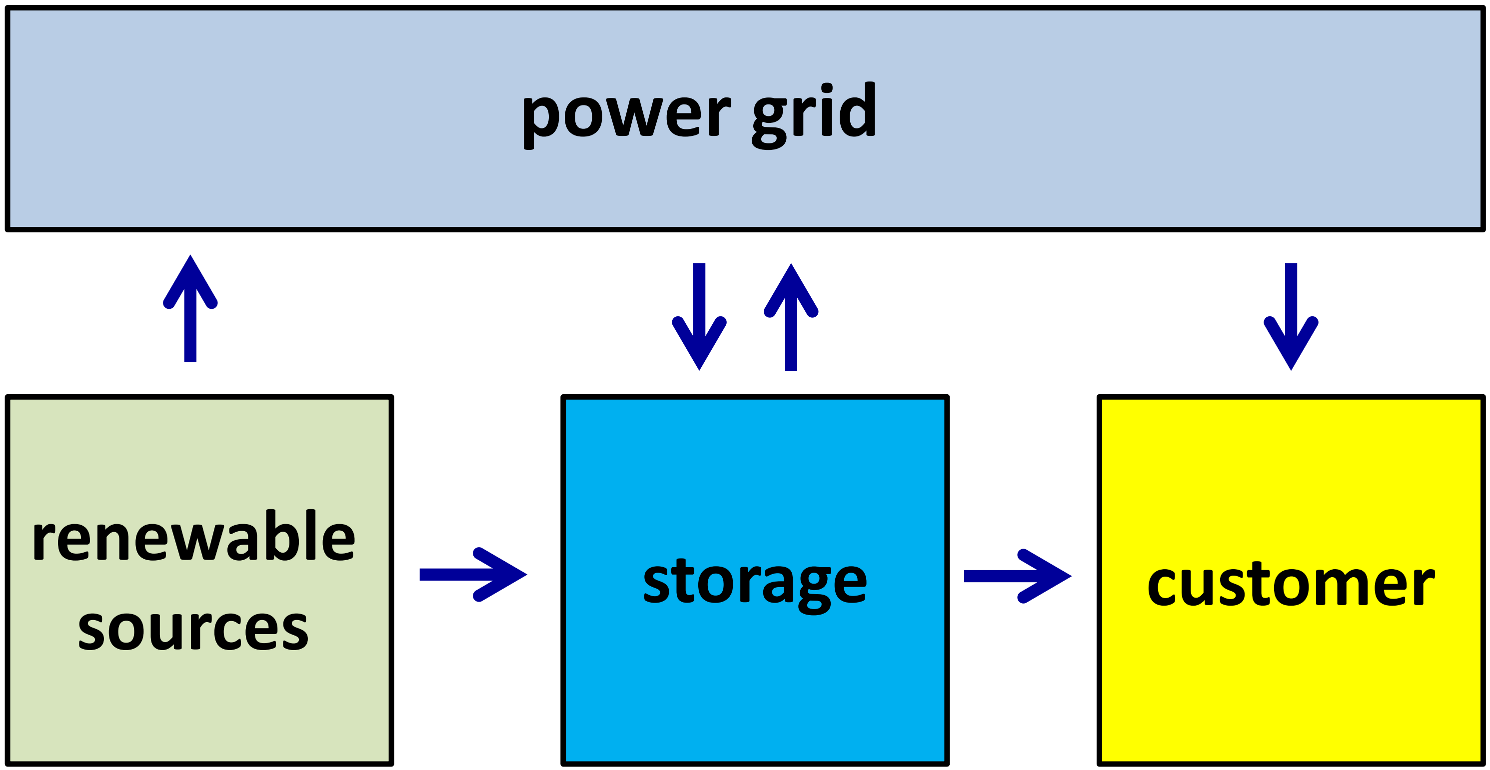
The SMES system



Year	Institution	Country	Typ	Power	Stored Energy	Superconductor	Application	Ref. #
2009	KERI	Korea	quality		2.5 MJ	YBCO	Power quality	[12]
2009	Chubu	Japan	compensation	10 MVA	19 MJ	NbTi	Load compensation	[8]
2008	CAS	China	other	500 kVA	1 MJ	Bi 2223	-	[9]
2007	CNRS	France	other		800 kJ	Bi 2212	Military application	[11]
2007	KERI	Korea	quality		600 kJ	Bi 2223	Power-, Voltage quality	[10]
2006	KERI	Korea	quality	750 kVA	3 MJ	NbTi	Power quality	[6]
2006	Ansaldo	Italy	stability	1 MVA	1 MJ	NbTi	Voltage stability	[7]
2004	Chubu	Japan	stability	5 MVA	5 MJ	NbTi	Voltage stability	[4]
2004	Chubu	Japan	stability	1 MVA	1 MJ	Bi 2212	Voltage stability	[5]
2002	KIT	Germany	other	25 MVA	237 kJ	NbTi	Power modulator	[3]
2000	AMSC	USA	stability	2 MVA	2.6 MJ	NbTi	Grid stability	[2]
1997	KIT	Germany	compensation	320 kVA	203 kJ	NbTi	Flicker compensation	[1]

Nr.	Digital Object Identifier	Reference
1		Operation of a small SMES power compensator, Juengst KP, Salbert H, Simon O, APPLIED SUPERCONDUCTIVITY 1997, VOLS 1 AND 2 - VOL 1: SMALL SCALE AND ELECTRONIC APPLICATIONS; VOL 2: LARGE SCALE AND POWER APPLICATIONS
2		
3	10.1109/TASC.2002.1018512	Juengst, KP; Gehring, R; Kudymow, A, et al., "25 MW SMES Based Power Modulator ", IEEE Transact. on applied superconductivity Volume: 12 Issue: 1 Pages: 758-761 (2002)
4	10.1109/TASC.2004.830076	Nagaya, S; Hirano, N; Kondo, M, et al., "Development and Performance Results of 5 MVA SMES for Bridging Instantaneous Voltage Dips", IEEE Transact. on applied SUPERCONDUCTIVITY Volume: 14 Issue: 2 Pages: 699-704 (2004)
5	10.1109/TASC.2004.830105	Dips, Nagaya, S; Hirano, N; Shikimachi, K, et al., "Development of MJ-Class HTS SMES for Bridging Instantaneous Voltage", IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY Volume: 14 Issue: 2 Pages: 770-773 (2004)
6	10.1109/TASC.2006.871329	Kim, H.J., Seong, K.C., Cho, J.W., et al., "3MJ - 750kVA SMES System for Improving Power Quality", IEEE Transactions on Applied Superconductivity Volume:16 Issue: 2 Pages: 574-577 (2006)
7	10.1109/TASC.2005.869677	Ottonello, L; Canepa, G; Albertelli, P, et al., "The largest Italian SMES", IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY Volume: 16 Issue: 2 Pages: 602-607 (2006)
8	10.1109/TASC.2009.2018479	Katagiri, T., Nakabayashi, H., Nijo, Y., et al., "Field Test Result of 10 MVA/20 MJ SMES for Load FLuctuation Compensation", IEEE Transactions on Applied Superconductivity Volume: 19 Issue: 3 Pages: 1993-1998 (2009)
9	10.1109/TASC.2008.922234	Xiao, LY; Wang, ZK; Dai, ST, et al., "Fabrication and tests of a 1 MJ HTS magnet for SMES", IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY Volume: 18 Issue: 2 Pages: 770-773 (2008)
[illegible]	[illegible]	Seong, K.C., Kim, H.J., Kim, S.H., et al. "Design of HTS Magnet for a 600 kJ SMES", Physica C: Superconductivity Volume: 463-465 Pages: 1240-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