FlyGrid

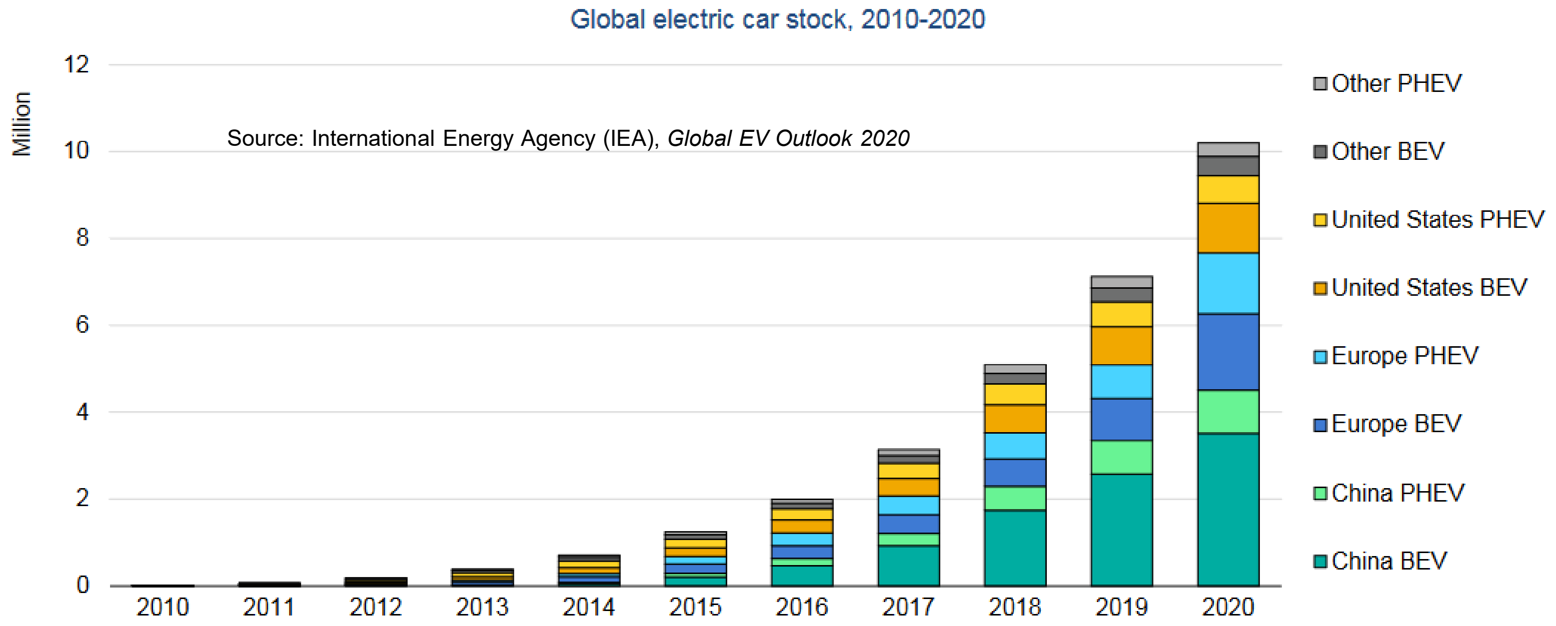
Energy Storage for Vehicle Fast Charging and Grid Integration

SCIENCE BRUNCH

www.klimafonds.gv.at

ems | dau A Miba Group Company | Easelink | Energie Netze Steiermark | Energie Steiermark | EVT Energieverbundtechnik | FWT Composites & Rolls | IME | myonic MinebeaMitsumi Group | secar technologie | THIEN eDrives

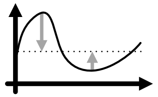
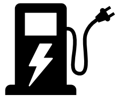
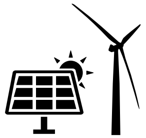
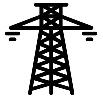
Transition to Electric Mobility



"Publicly available EVSE outlets need to grow by a factor that ranges between 7 and 25 by 2025, amounting to between 4 million and 14 million outlets globally in 2030."

(International Energy Agency, „Global EV Outlook 2017")

We all know the challenges…

1. Peak Loads 
2. Charging Network 
3. Volatility 
4. Cost 
5. Grid Stability 
6. User Friendliness 

Flywheel Energy Storage for Electric Mobility

„*Peak shaving*" for fast charging applications:

→ Avoid costly modification of existing electricity grid

→ Make use of local renewable sources such as wind / solar

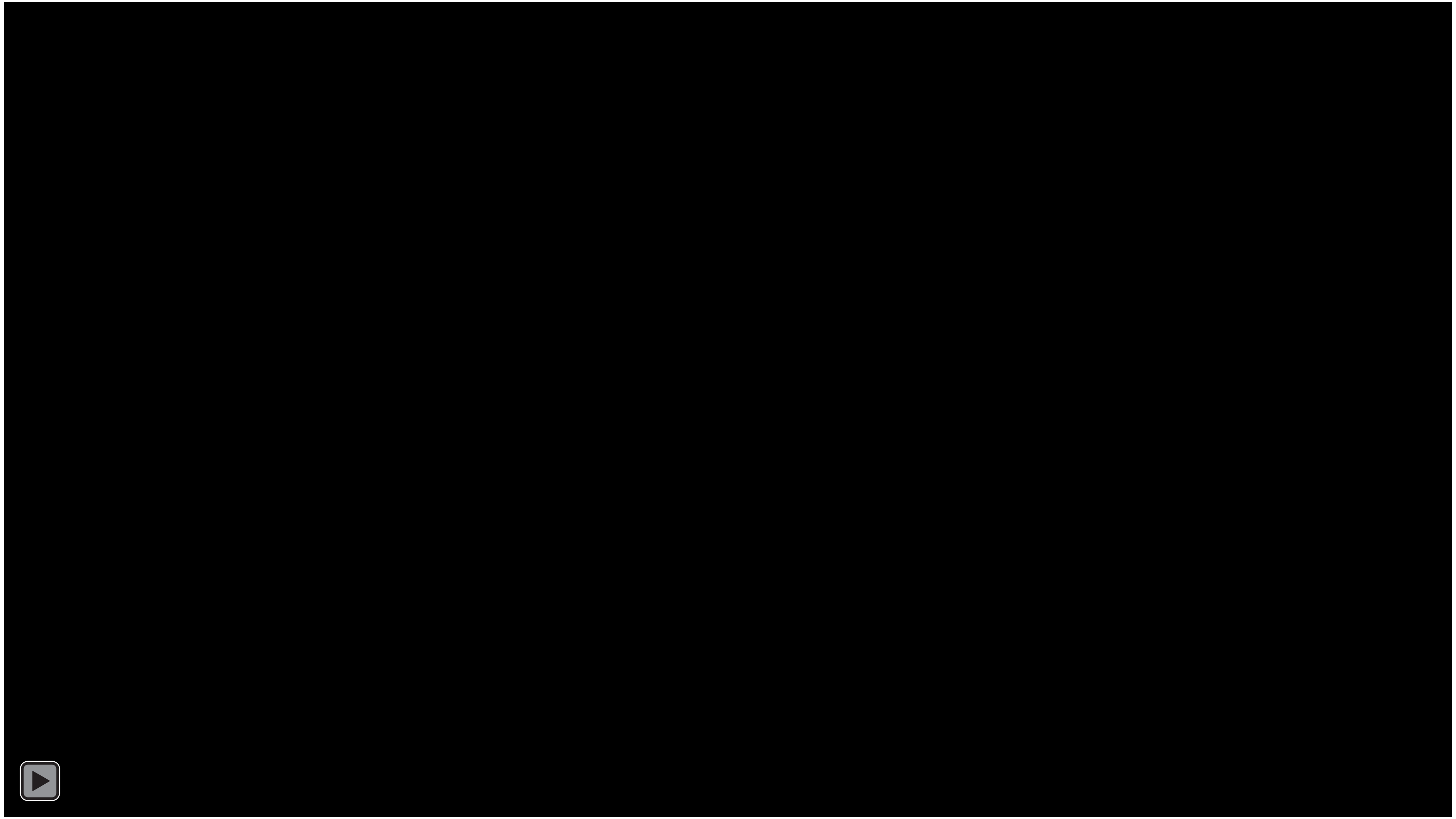
→ Increase grid stability and power quality

(Superior cycle life)

Public
Private
Enterprise

→ *FlyGrid* is a sustainable energy storage solution that can be manufactured in central Europe!

Flywheel Energy Storage for Electric Mobility

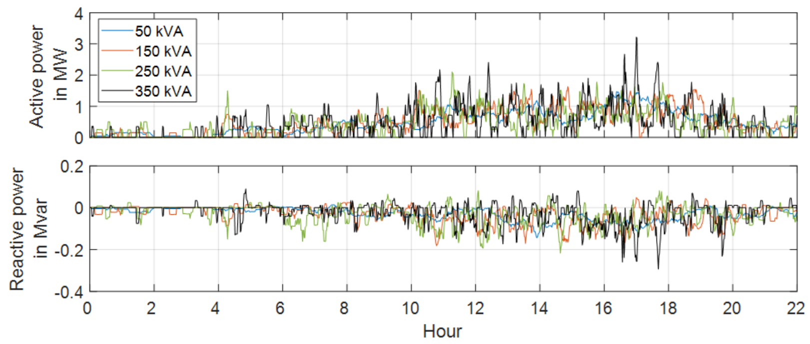


Grid Modelling and Use-Cases

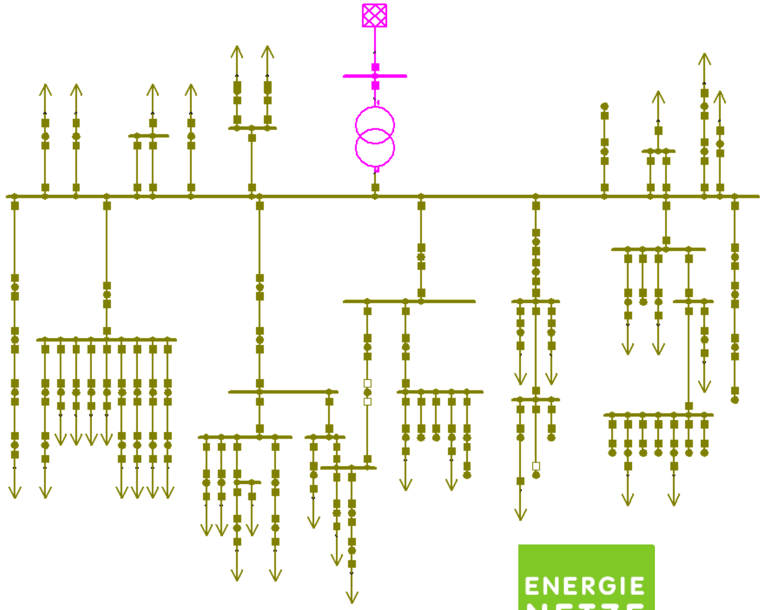
1. Modeling of time-resolved EV charging patterns

2. Identification of potential grid overloads

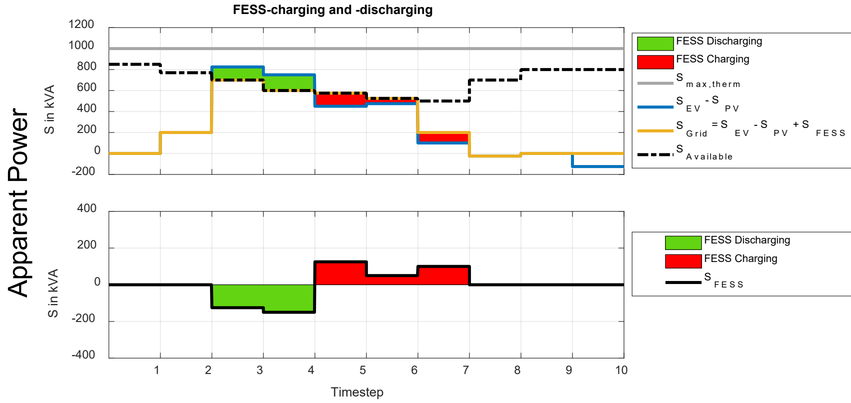
3. Determination of FESS target properties



	EV Use Case	Charging power (kVA)
1	Charging at public parking lots	3.7 – 100.0
2	EV car sharing	3.7 – 100.0
3	Highway fast charging	50.0 – 350.0
4	Public charging at shopping centers	3.7 – 100.0
5	Electrified busses	100.0 – 600.0
6	Electrified taxies	3.7 – 100.0
7	Electrified last-mile delivery trucks	100.0 – 350.0



ENERGIE NETZE STEIERMARK

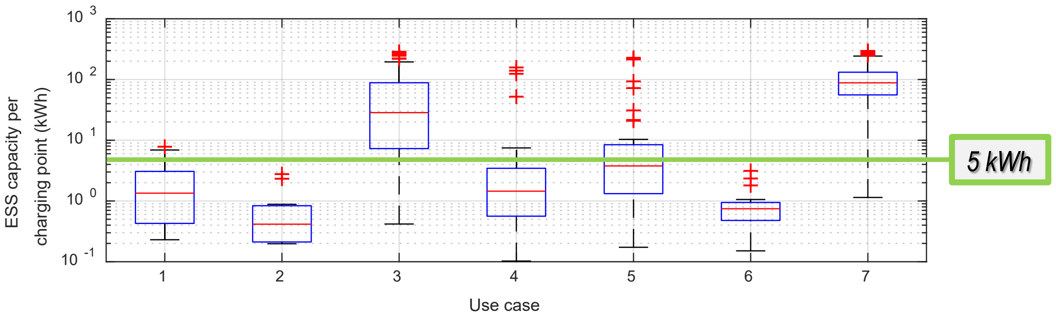


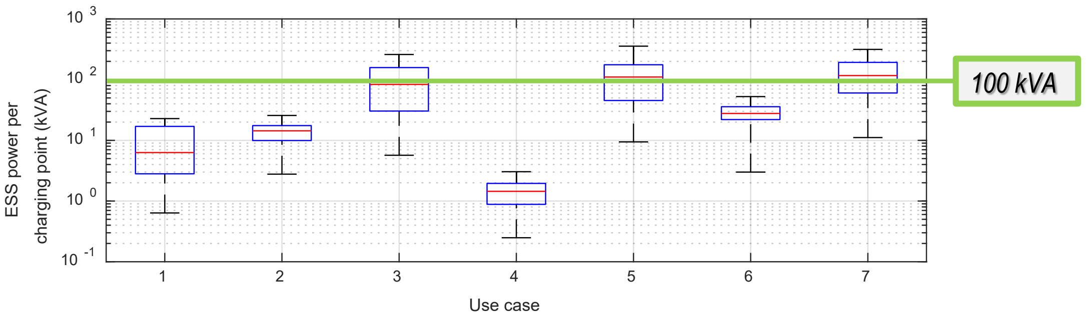
FESS parameter per module	Value
Efficiency: FESS charging	90 %
Efficiency: FESS discharging	90 %
Max. Idling losses	0.5 kW
Cos(ϕ): FESS charging	1.0

Methodology to Determine FESS Properties

FESS Target Requirements

Research question:
What are the desired FESS specifications in order to allow proper peak shaving in EV fast charging applications?

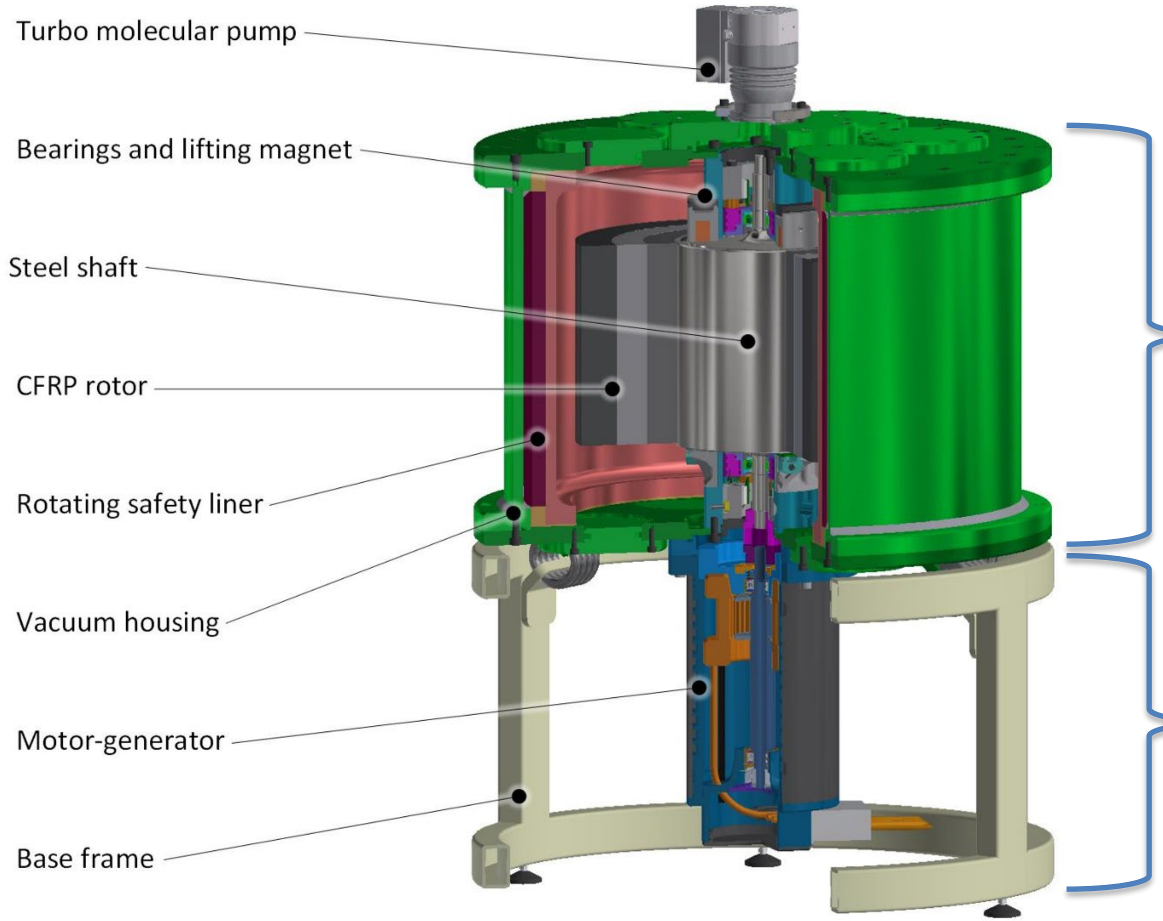




EV Use Case	
1	Charging at public parking lots
2	EV car sharing
3	Highway fast charging
4	Public charging at shopping centers
5	Electrified busses
6	Electrified taxies
7	Electrified last-mile delivery trucks

- ***2/3 of the current EV applications require:***
  < 5 kWh
  < 100 kVA
- *Remaining applications can be covered by a modular expansion of FESS*
- *Not all EV applications allow grid load mitigation via FESS*

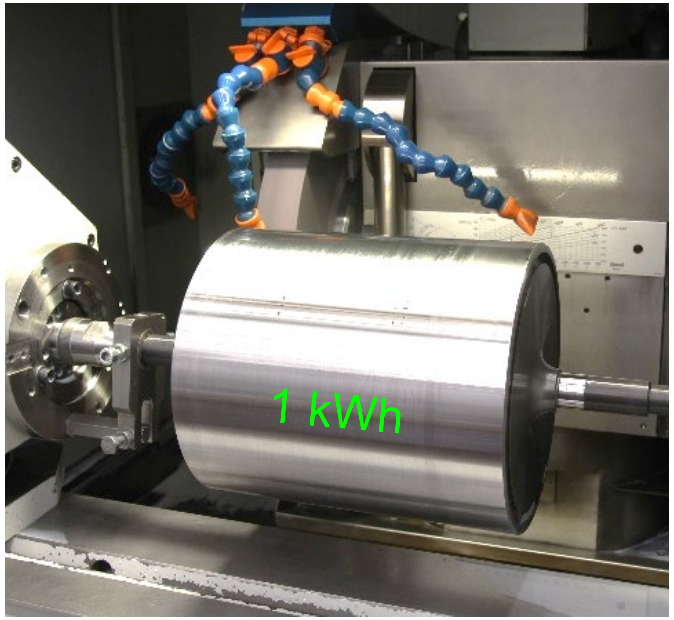
Modular and Flexible High-Performance FESS Design

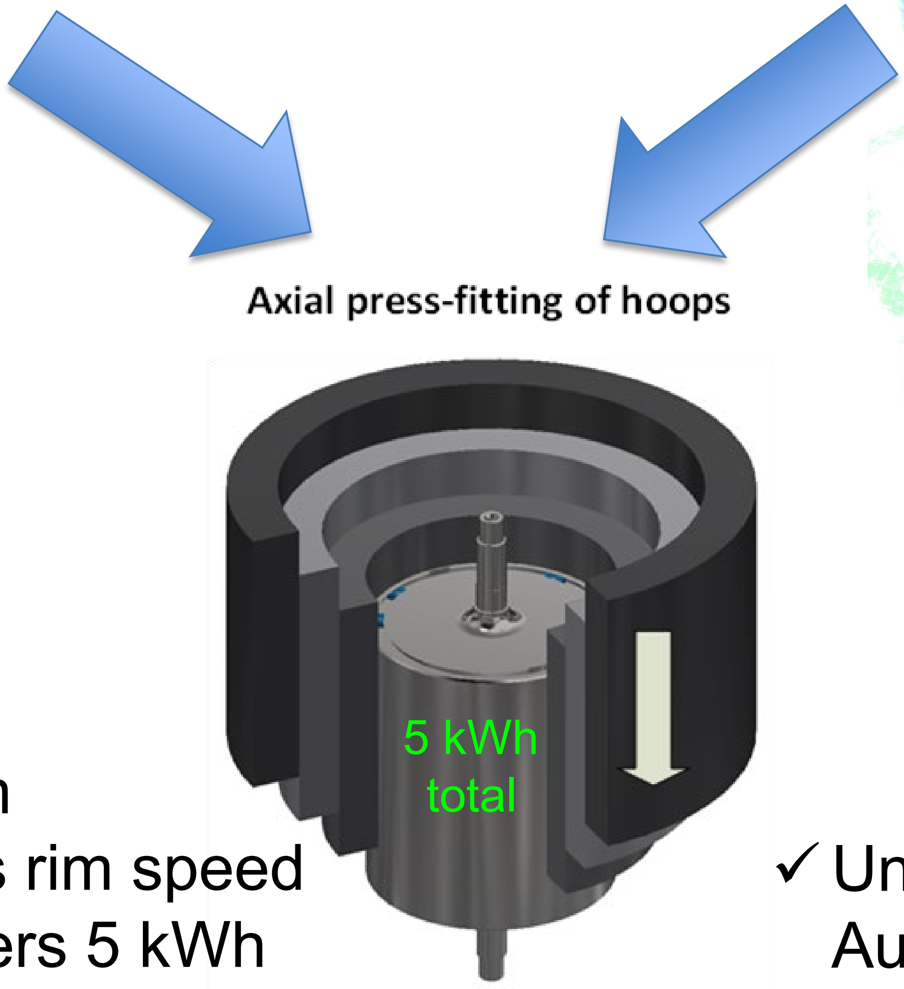


Rotor:
Determines Energy
(5 kWh)

Generator:
Determines Power
(100 kW)

High-performance CFRP Rotor



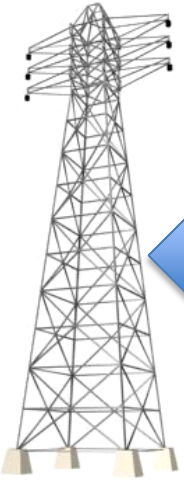


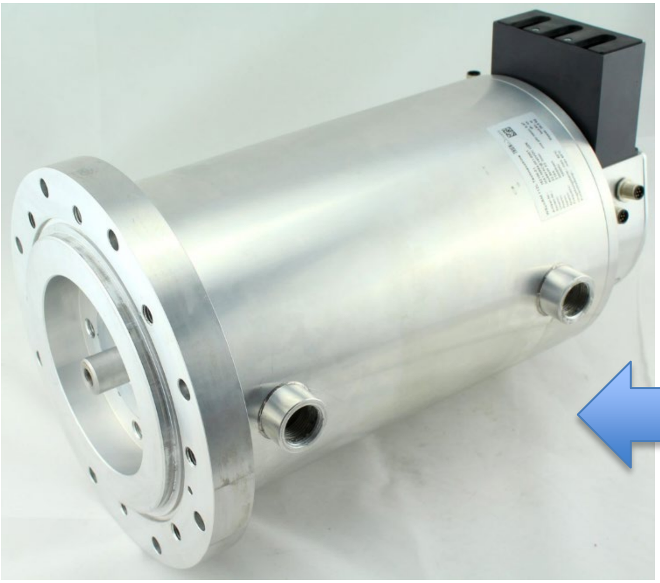
- ✓ Approx. 600 x 250 mm
- ✓ 30 000 rpm → 950 m/s rim speed
- ✓ Each rotor module offers 5 kWh

- ✓ Unique expertise as benefit for Austrian economy

Power-Unit: Synchronous Reluctance Machine

- **Low losses in rotor**
  → No current-carrying parts (important in vacuum)
- **High efficiencies** for standard applications (IE4)
- **No magnets / rare earths needed**
  → Easy to recycle
- **No cogging torque**
  → Ideal for FESS with low idling losses



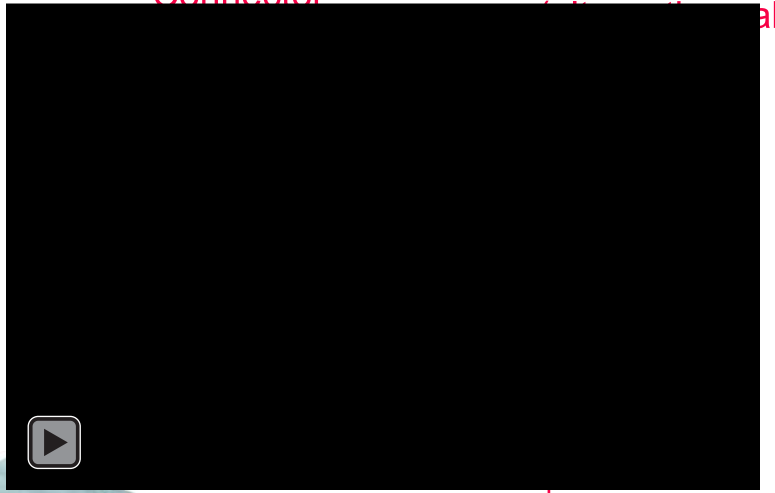


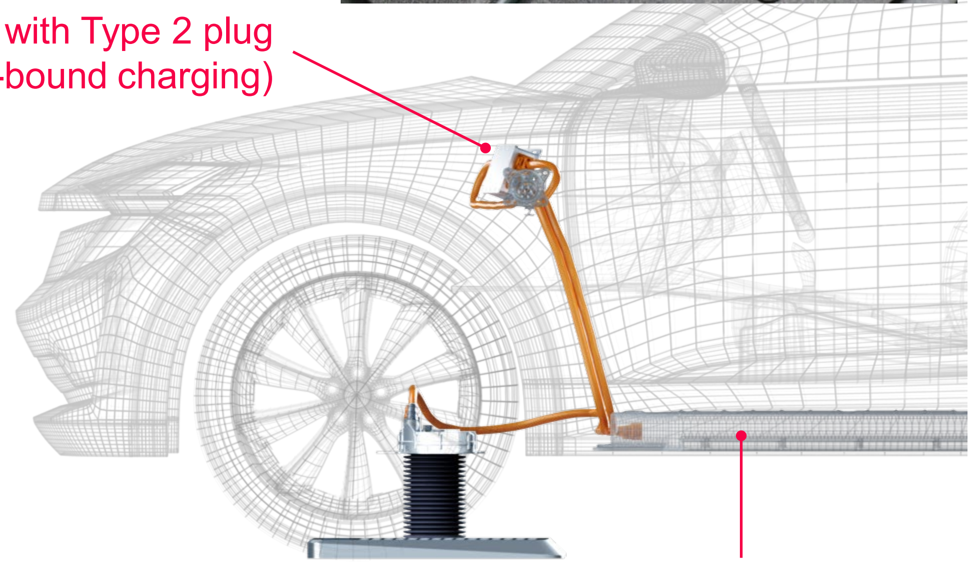
Automatic Conductive Underbody Charging

Optimization and Integration of Innovative Charge Point

→ Improved safety, power, communication, balanced single phase, enhanced service life etc.

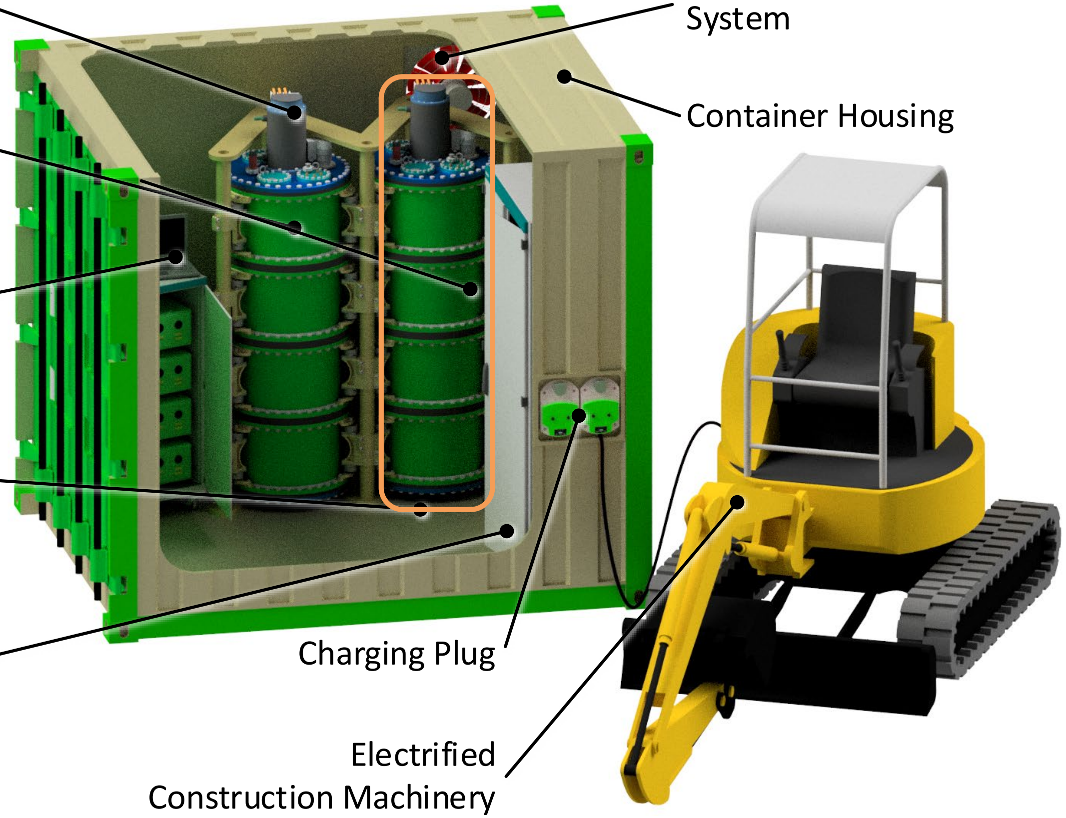
Matrix Charging® Connector





Other FESS Applications

FESS is not a hazardous good → easy transportation



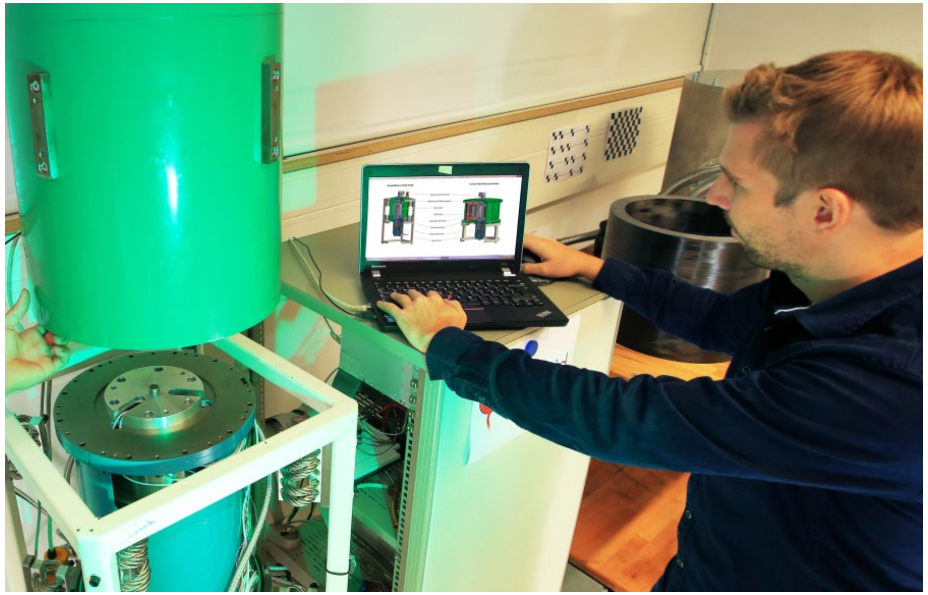
Suitable for other applications, e.g.:

- Grid stability, voltage control, …

Summary and Outlook

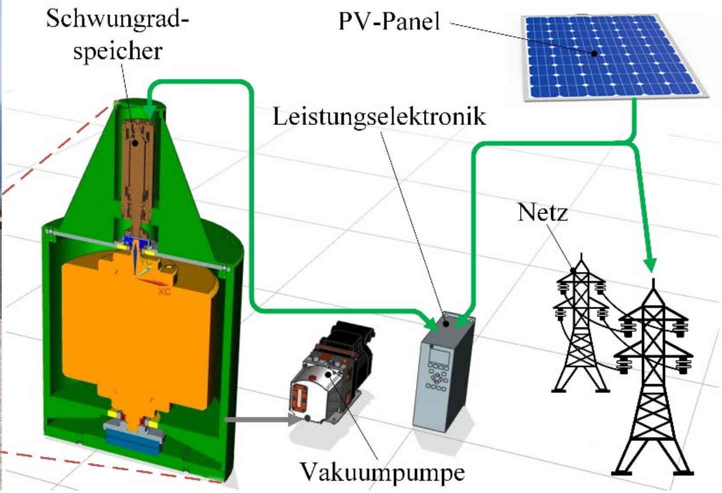
Achievements so far:

- Use-cases and possible grid overloads identified
- Target properties of FESS determined
- FESS prototype built and undergoing lab testing
- Matrix Charging system developed



Nest Steps

- Installation of Demo-Facility @ *Energie Steiermark*, Graz in fall 2022
- Commercialization and / or follow-up project planning
- Exploration of other use-cases, such as: grid stability, manufacturing companies, uninterruptable power supply etc.



Fly Grid TU Graz

Thank you for your attention!

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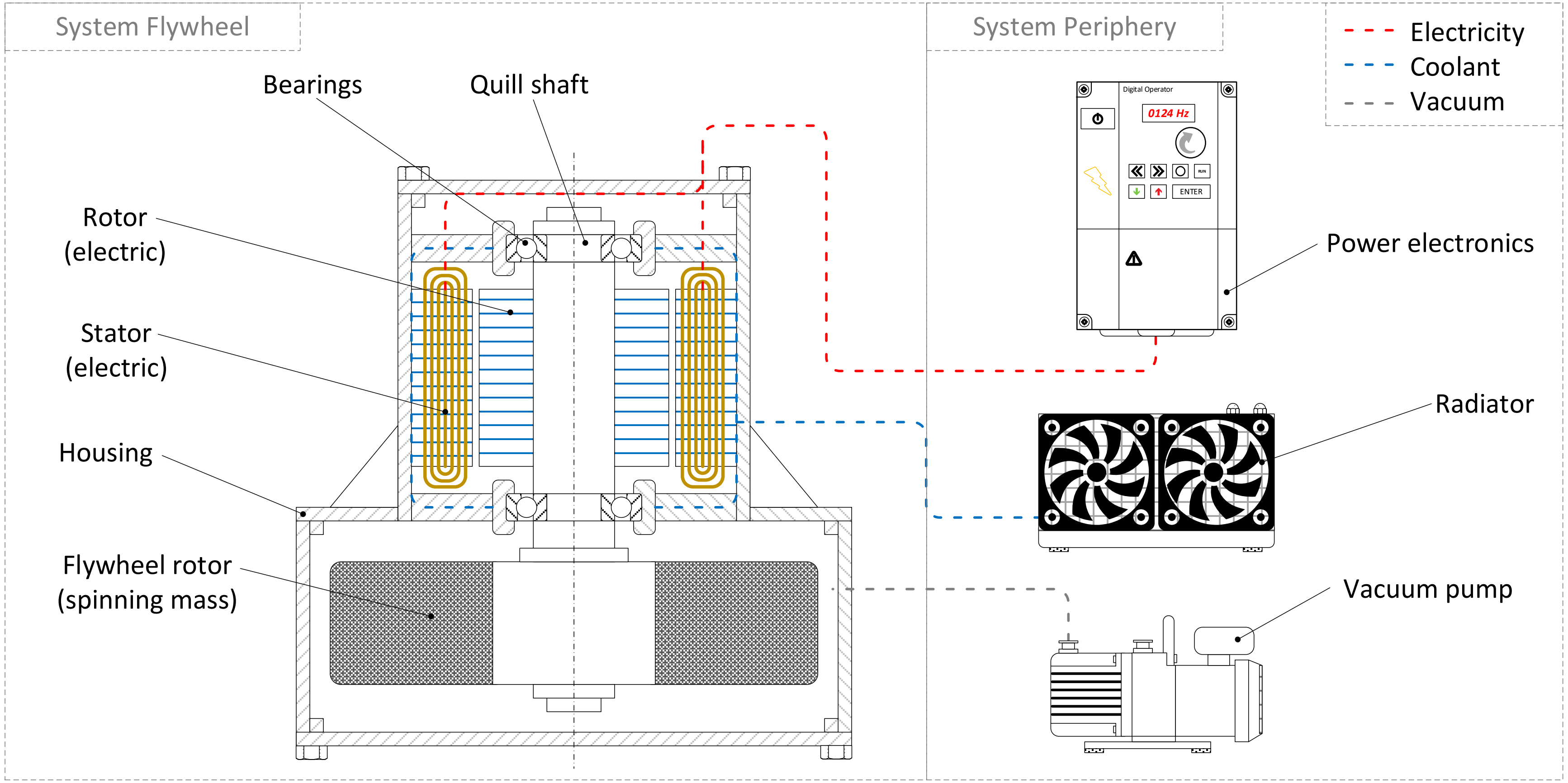
dau A Miba Group Company
Easelink
ENERGIE NETZE STEIERMARK
EVT Energieverbund TECHNIK
F W T COMPOSITES & ROLLS
myonic MinebeaMitsumi Group
THIEN eDrives

The *Electromechanical* FESS



Physical Advantages

- ✓ High power density
- ✓ Very high cycle life
- ✓ Uncritical deep discharge
- ✓ Precise SoC determination
- ✓ No capacity fade over time

Further Advantages

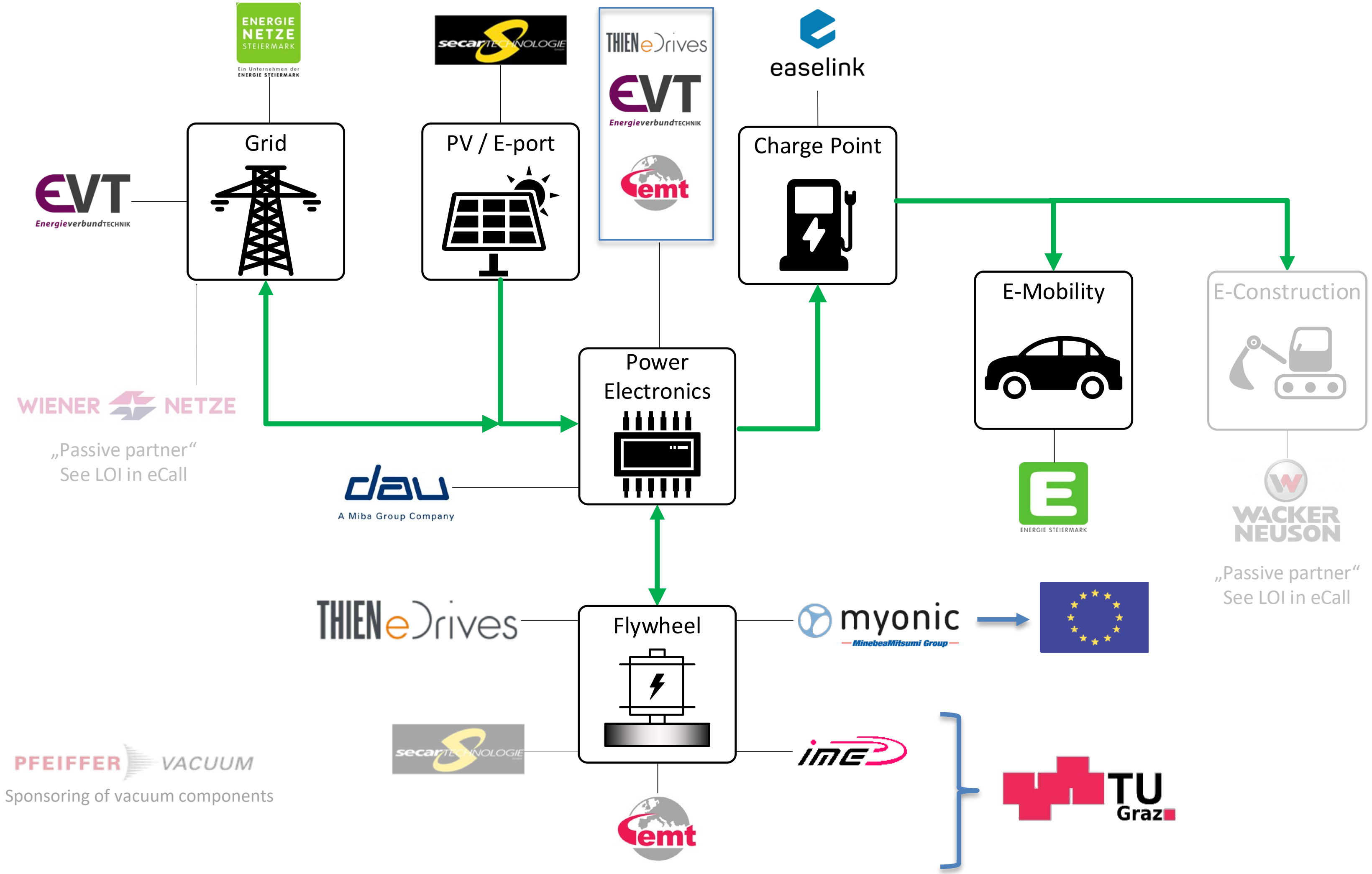
- ✓ High potential energy density
- ✓ Potential for low cost design
- ✓ Good recyclability
- ✓ Operation under low/elevated temperatures
- ✓ Manufacturing in AUT/ EU

Current Challenges

- Self-discharge
- Low energy density
- Manufacturing cost

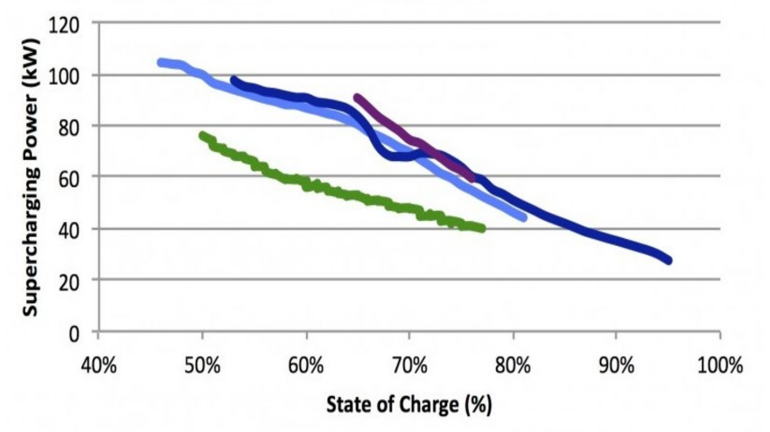
!

Consortium

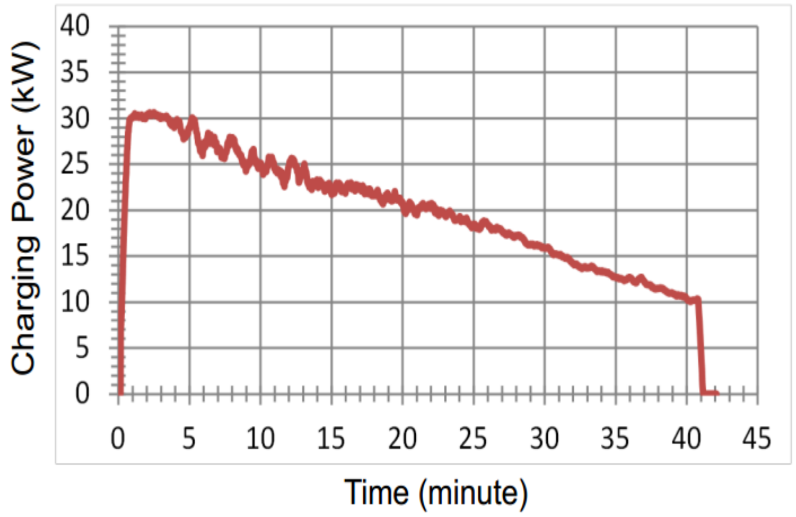

Grid
PV / E-port
Charge Point
easelink
E-Mobility
E-Construction
Power Electronics
Flywheel
„Passive partner"
See LOI in eCall
A Miba Group Company
„Passive partner"
See LOI in eCall
Sponsoring of vacuum components

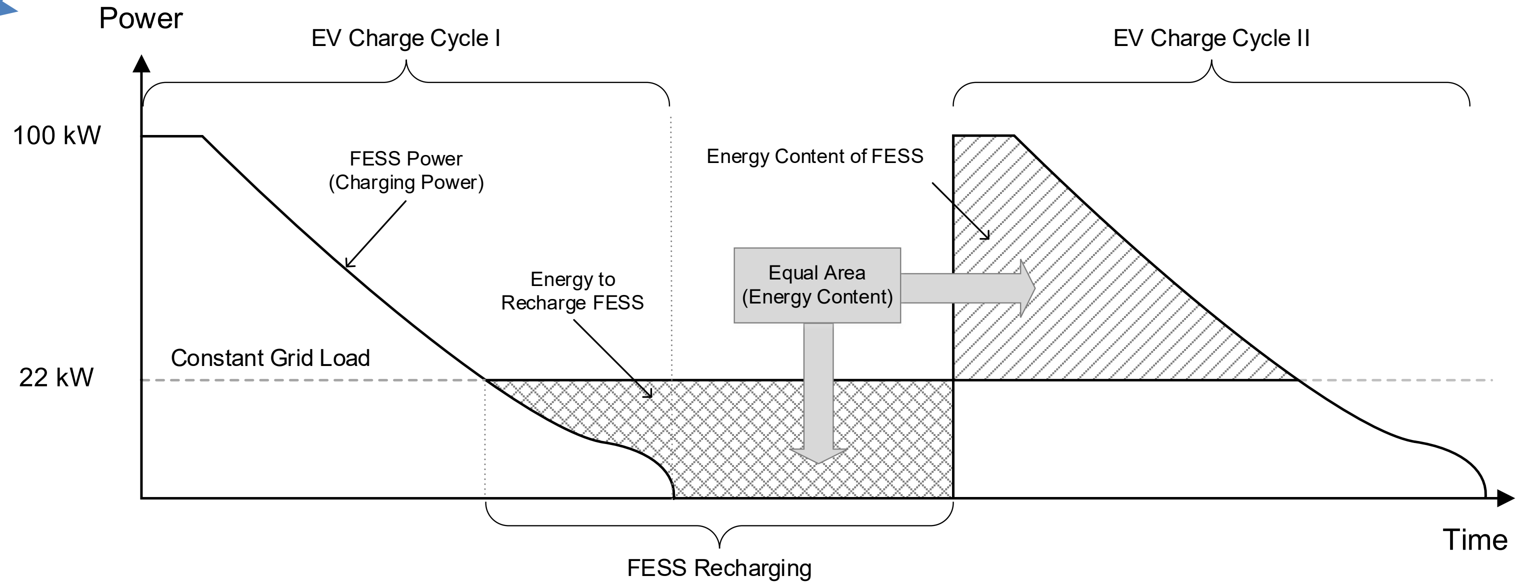
Implementation of FESS

Buffer energy storage with limited energy content?



Charging power over time for *Tesla Model S* (top) and *Nissan Leaf* (bottom).





Chemical Battery vs. Flywheel

Li-Ion Battery ***(Tesvolt TS HV 70)***

- Roundtrip efficiency < 94 %
- 76 kWh
- 75 kW (1C), 4C short term
- 6,000 cycles (1C, 70% EoL, 100 % DoD)
- 30 years
- ~ 550 €/kWh
- **LCOS → 0.10 €/kWh**
- 860 kg

www.tesvolt.com

Flywheel ***(Chakratec KPB)***

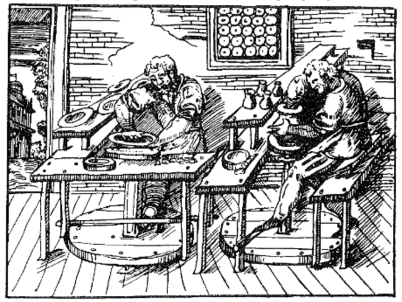
- Roundtrip efficiency < 90 %*
- 10 x 3 kWh
- 100 kW (50 kW nominal)
- 20 years / > 200,000 cycles
- ~ 2500 €/kWh
- **LCOS → 0.015 €/kWh**
- 10,000 kg

www.chakratec.com

* No manufacturer data available. Value taken from *www.stornetic.com*

Why develop a new FESS?

a. Chr. - 1550



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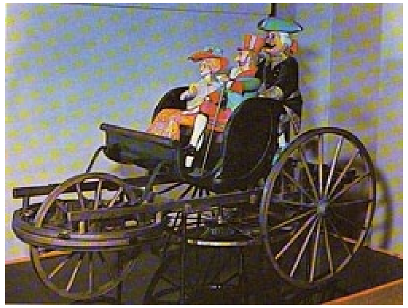

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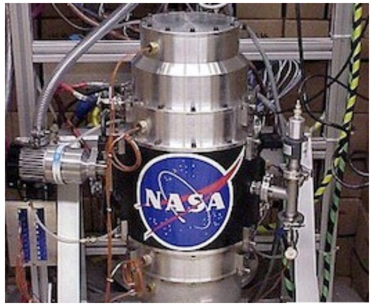
2006



© NASA

2011

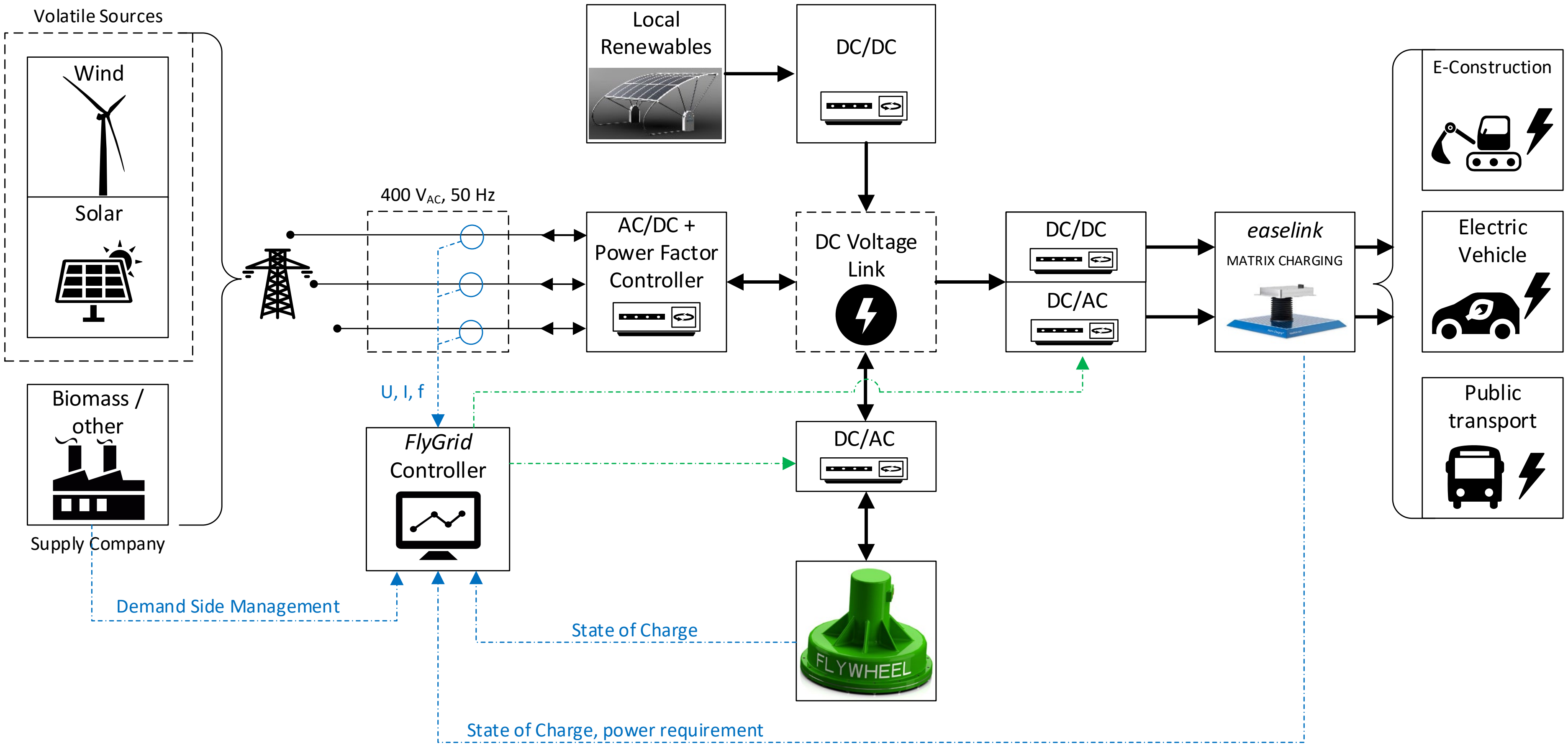
© Porsche

2020

© Storenetic

- Technological advantages and potential compared to batteries
- Goal is an improvements beyond state of the art and cost reduction
- Sustainable energy storage will play a major role also in other sectors
- *FlyGrid* does not only develop the FESS, but has a bigger scope
- Bringing technology and know-how to Austria

Implementation of FESS



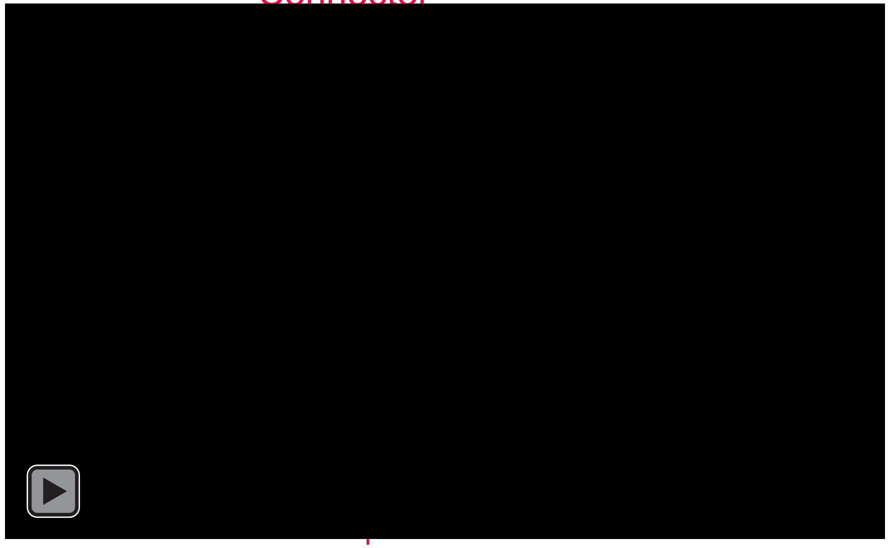
Key facts of 4th project year

- **Project ready to enter the final phase** without any major drawbacks
- Integration of new partner FWT composites and rolls successful → catching up on previous delay of **Task 5.1** (rotor manufacturing)
- A small-scale 1-kWh flywheel energy storage unit was built and is undergoing lab-testing at system level
- **Major progress in WPs 5, 6, 7** achieved according to plan.
- **Some minor delays** due to **supply chain issues.**
- Successful completion of the **Half-Time Symposium** within the framework of the *A3PS Ecomobility Symposium.*
- The final steps for the **roll out of the demonstrator facility** planned.

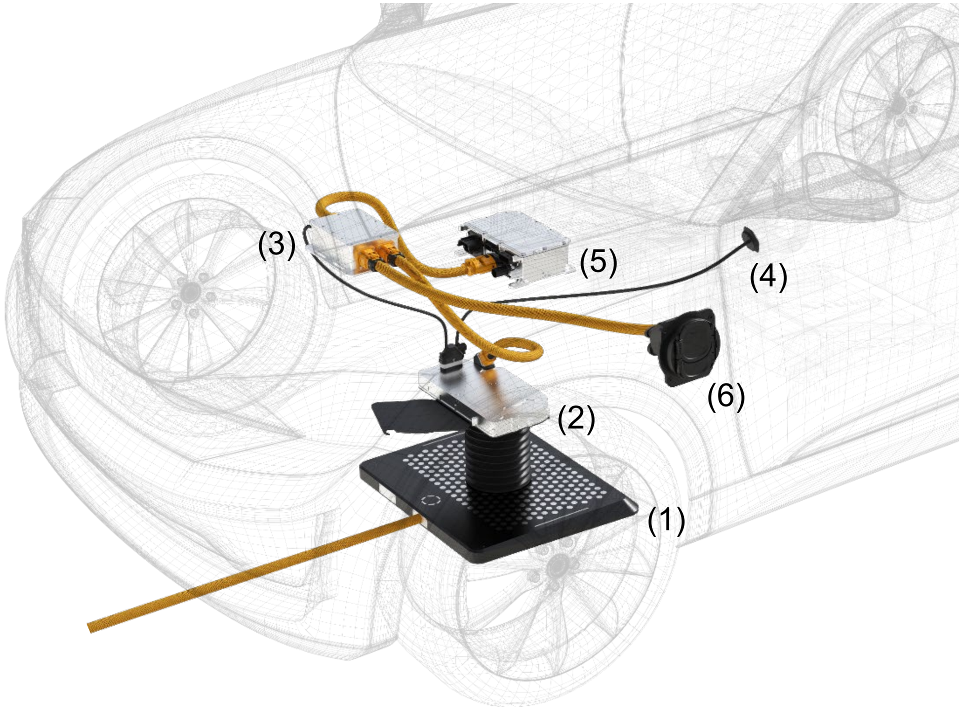
WP7: Power Electronics, Controls and Charge Point Interface Development

Task 7.3: Optimization and Integration of Innovative Charge Point

Matrix Charging®
Connector



Matrix Charging®
Pad

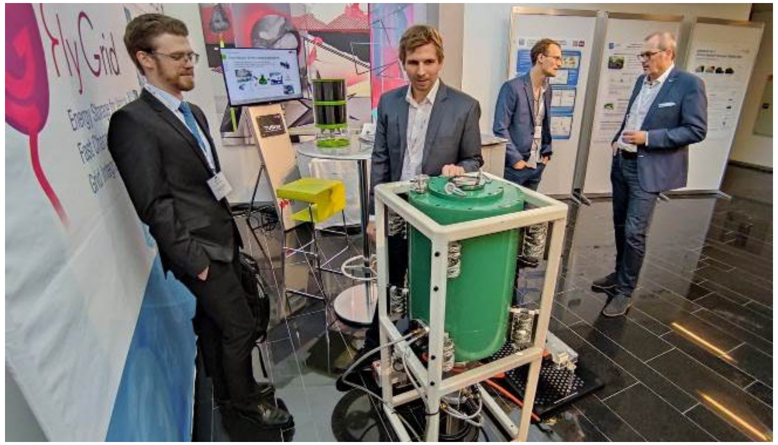


(1) Matrix Charging® Pad
(2) Matrix Charging® Connector
(3) Switch box
(4) User interface
(5) Onboard charger
(6) Type 2 inlet

Dissemination

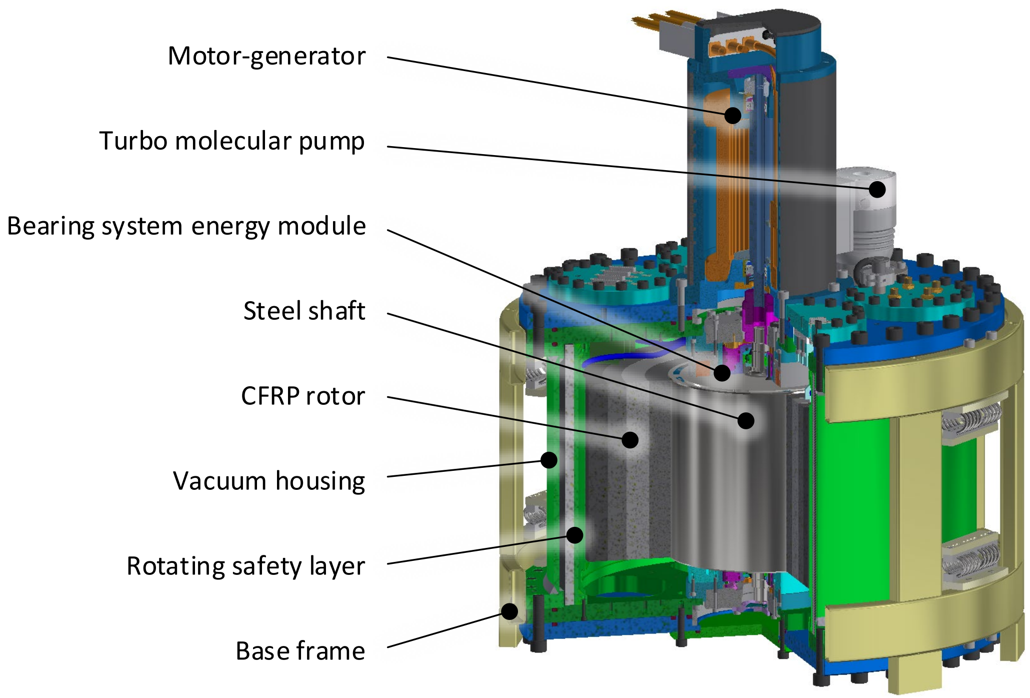
Show-casing various technologies:

- *TeD Motor-Generator*
- *Flywheel System*
- *New Generation Matrix Charging*
- *FWT CFRP Rotor*
- *Bearing technology*
- *Small-scale demonstrators*



WP4: FlyGrid Energy Storage

Full scale 5 kWh FESS (Demonstration unit)



- ✓ Based on target properties (WP3/4)
- ✓ Suitable for many industrial applications

Down-scaled 1 kWh FESS (Delay mitigation measure)

- ✓ Ready to demonstrate full functionality
- ✓ Important tool for R&D and project itself

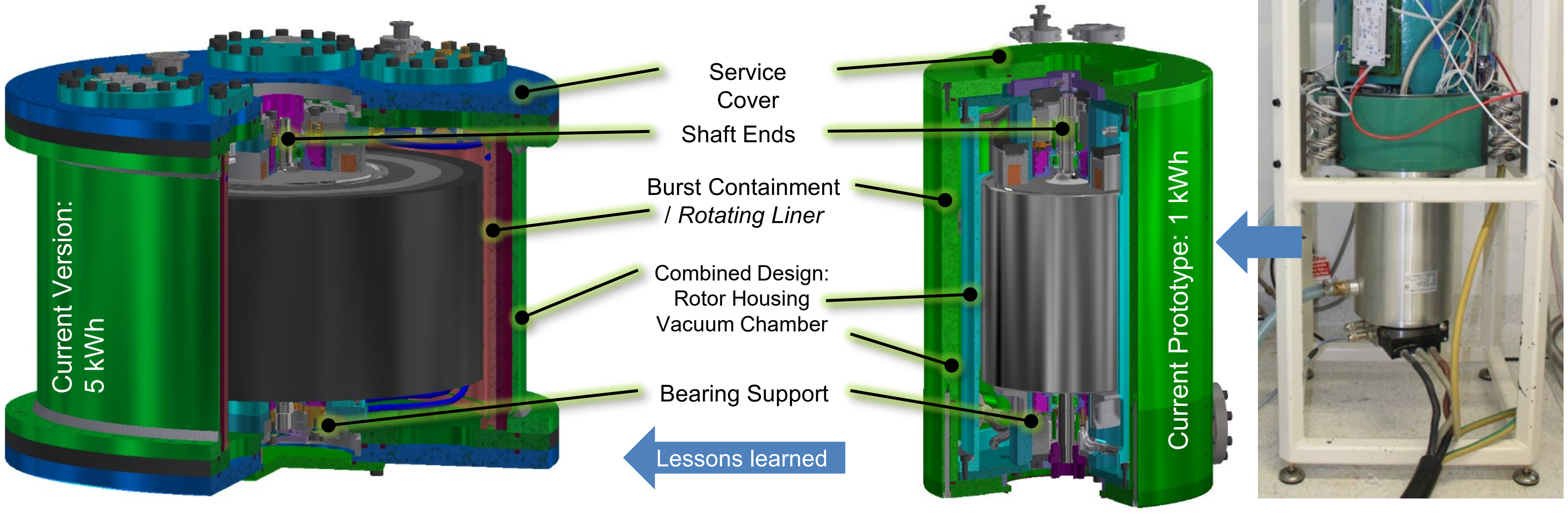
Task 6.2.: Housing Design

Design Optimization & Adjustments → Based on „Lessons learned“ from the current Prototype

- New sensor arrangement
- Space-optimized mechanical components
- Redesign of the *Rotating Liner* & the CFRP rings
- Modified cover design

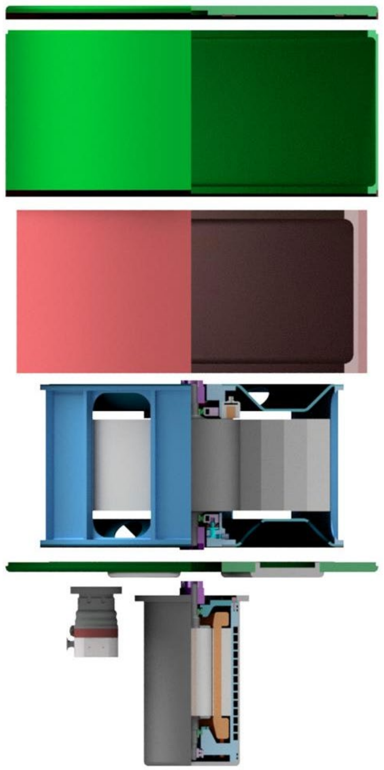
Leads to

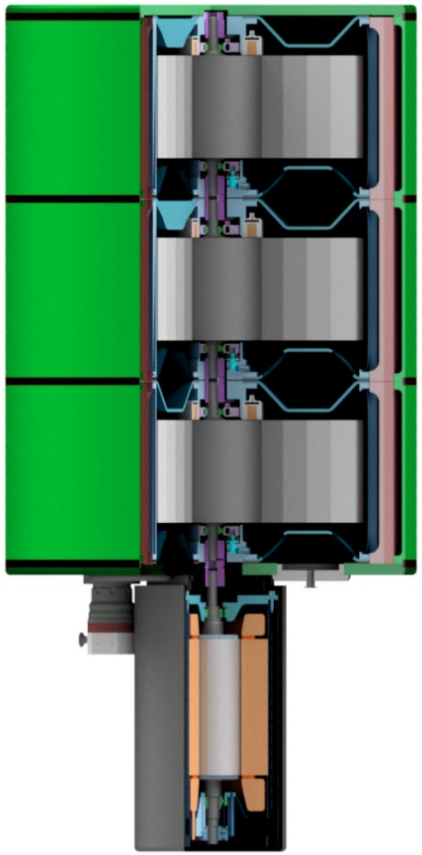
- Shorter fail-safe shaft ends
- Equally safe more compact housing design
- Weight savings
- Improved accessibility



FlyGrid TU Graz

FESS Modular System Design



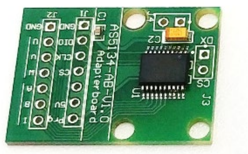


High Power, Triple Energy Unit:
300 kW
15 kWh

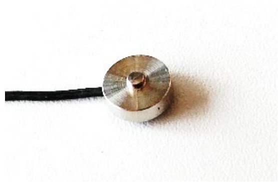
Sensor Overview

Adapted Commercial Sensors

- **Magnetic Rotational Encoder**
  - Magnet in axle
  - Measures speed and angular rotor position




- **Force Sensors**
  - In the bearing shields
  - Measure bearing load

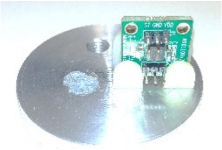


- **Pyrometers**
  - Inner bearing ring temperature
  - (later also CFRP ring temperatures)

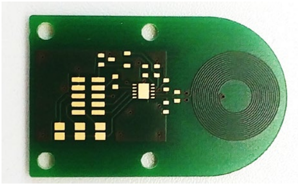
- **PT1000**
  - Small 2.5 mm sensor
  - Outer bearing ring temperature
  - Magnet temperature

Sensors custom built by TUG (EMS)

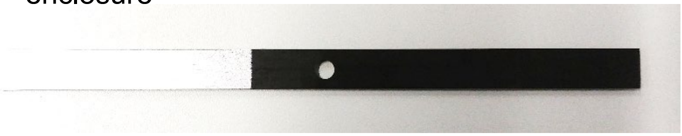
- **3-Axis MEMS Accelerometer**
  - Eval. board tested on shaker
  - Custom 3-axis PCB



- **Inductive Distance Sensors**
  - Custom PCB for inductive sensor system



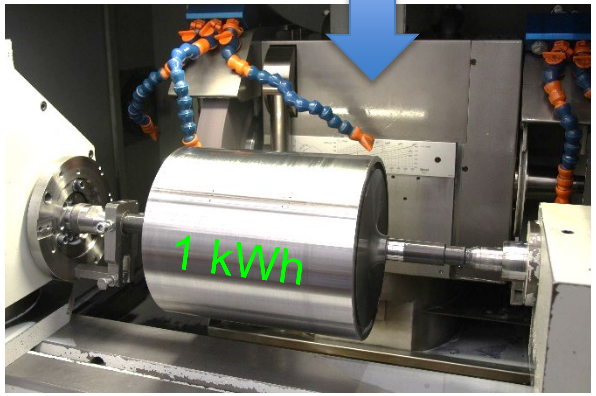
- **CFRP-Rotor Strain/Deformation Measurement**
  - Paint Adhesion Verification
  - A painted pattern has to be applied to the rotor for contactless, optical strain/deformation measurement
  - Samples of painted CFRP are accelerated in a burst enclosure



FESS Rotor – Outlook

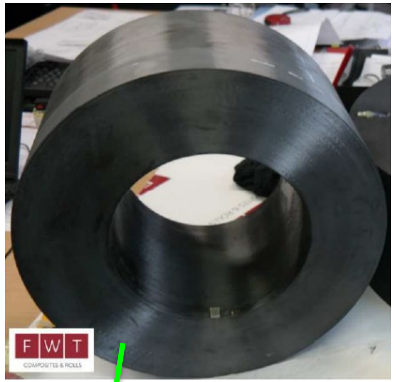
✓ Wet-wound CFRP hoop capabilities by FWT

✓ Steel rotor ordered

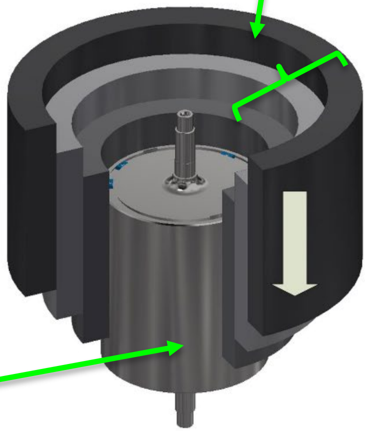


Steel shaft #2 (currently being manufactured @ Fleischer / TUG)

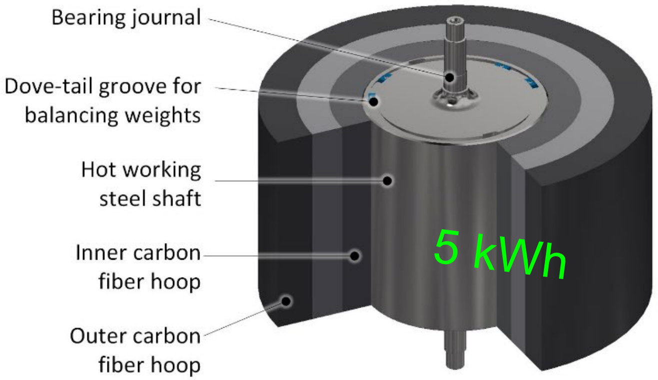
→ Base for Multiring-Composite-rotor



Outlook of manufacturing capability of FWT

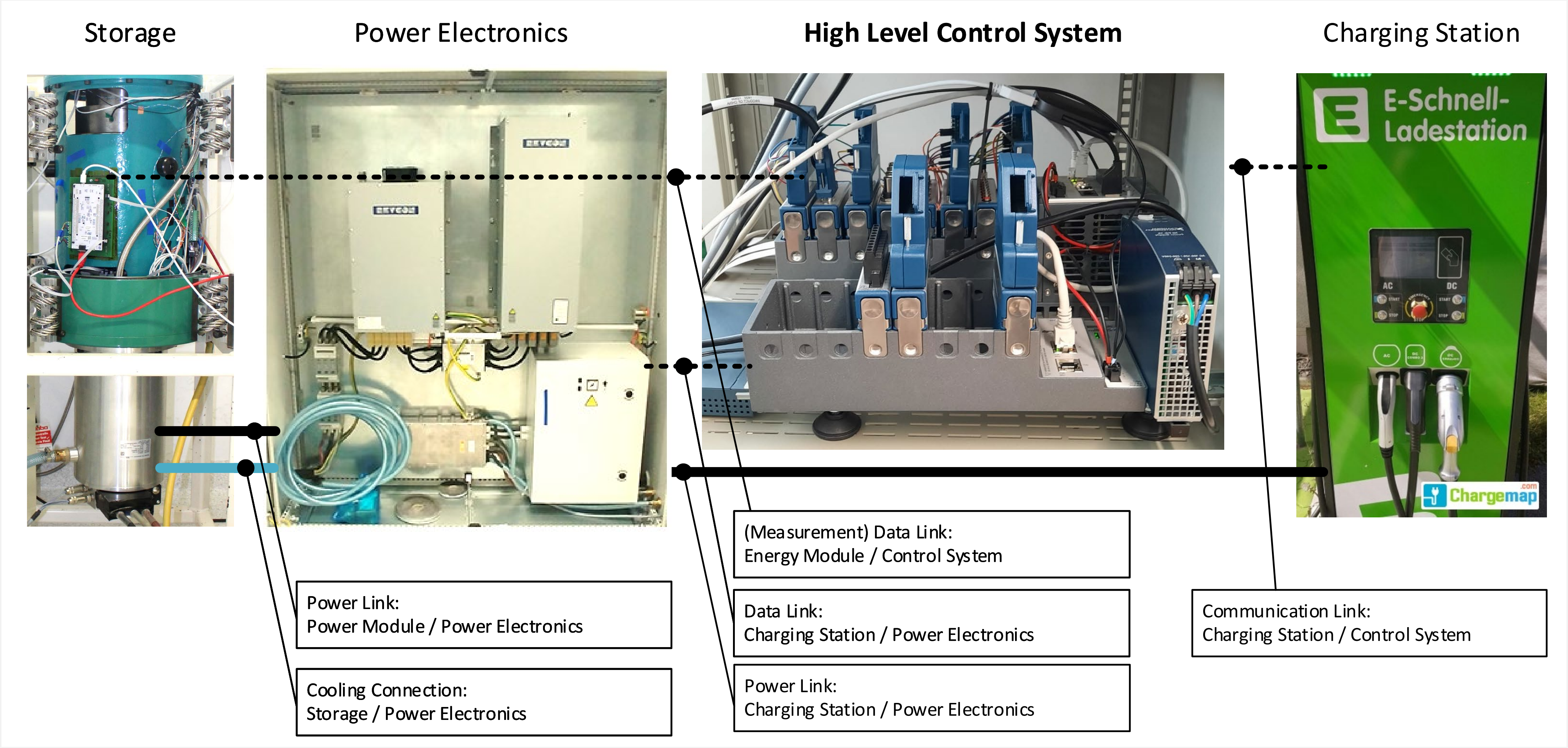


Axial press-fitting



Final multiring rotor

T7.1b: High Level Control System

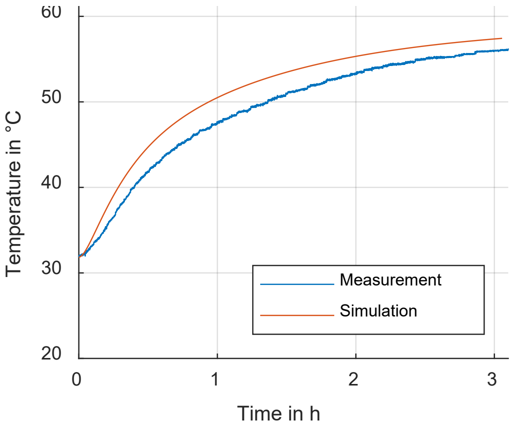


✓ ***High level communication between the charging point, the FlyGrid System and the grid***

WP8: System Verification in Lab Environment

- Successful competition of first full-speed test runs
- Overall FlyGrid power loss during run-out
- Stationary temperature determination at constant speed

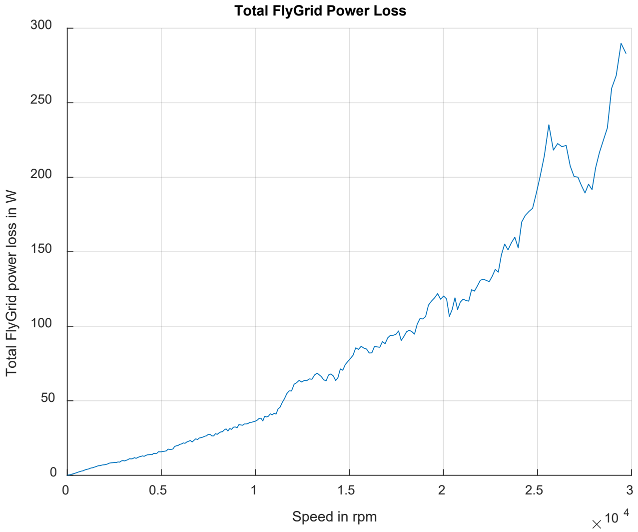
Coupling temperature over time at 20,000 rpm



Steady state coupling temperature

Idle speed	Coupling temperature
10,000 rpm	50.5 °C
20,000 rpm	57.8 °C

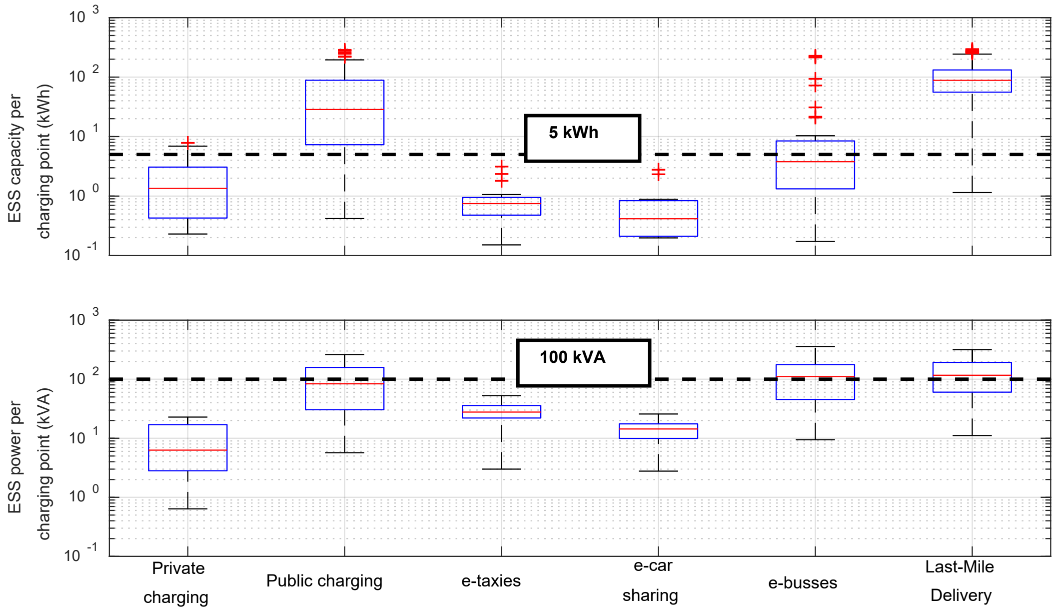
Rotor start temperature of 32 °C due to previous long term FESS testing.

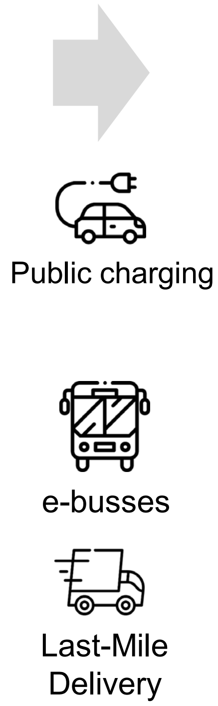


3. Analysis of potential grid-relieving measures

Design of energy storage systems for supplying various use cases

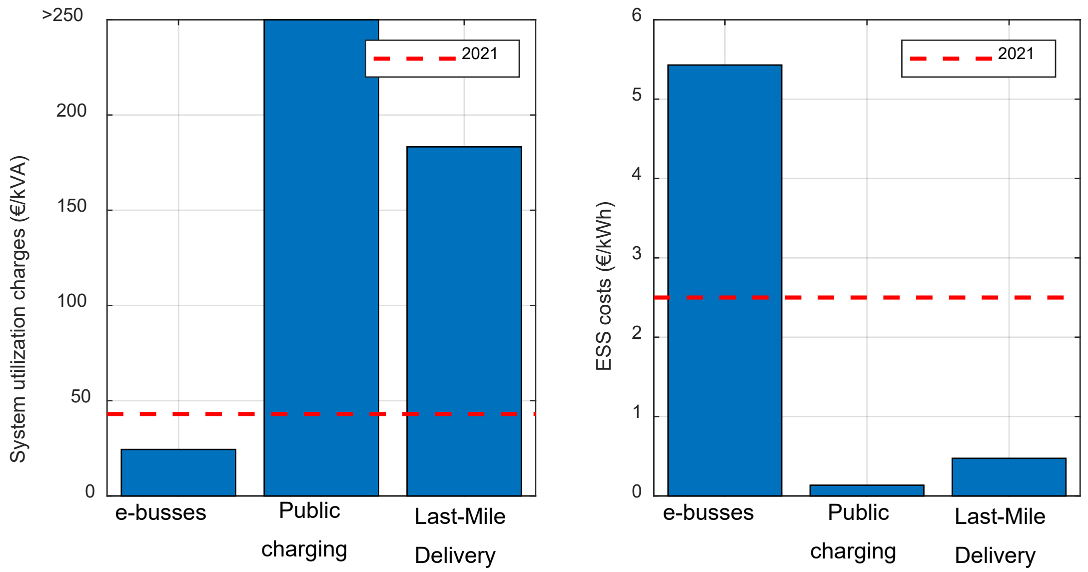
Grid Loads and EV Charging





Techno-economic assessment:

How can energy storages provide cost benefits compared to classic grid reinforcements?



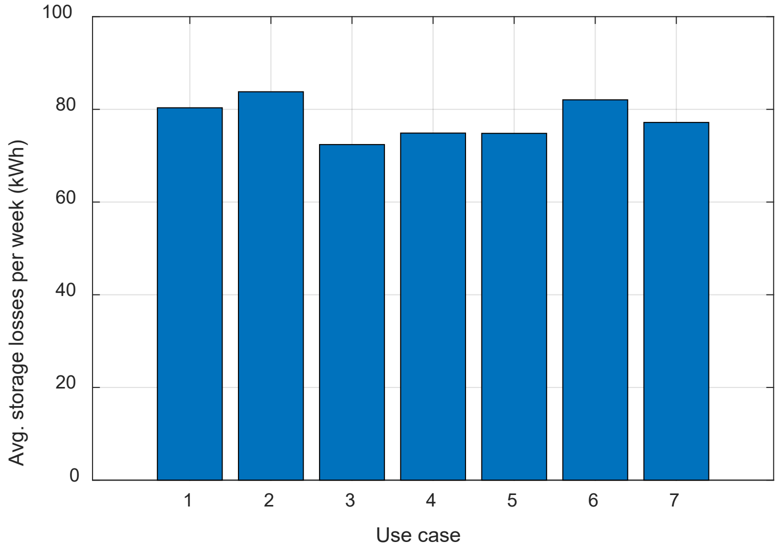
Even energy storages with low capacity units allow significant grid relief

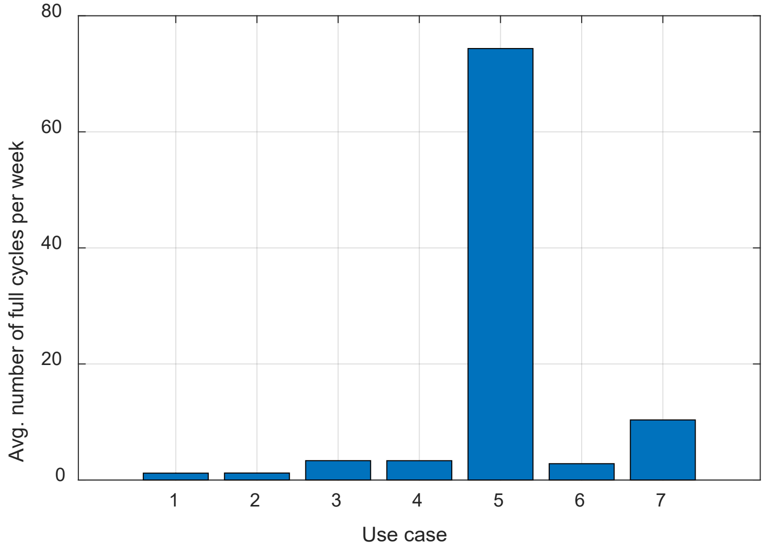
Electric busses already allow for an optimal and cost-efficient operation of energy storages

Methodology to Determine FESS Properties

Suitability of the investigated use-cases for FESS application:

- **Battery electric busses** and fast charging at **shopping centers or highway stations** allow **lowest FESS idling losses** during operation due to high level of utilization
- **Battery electric busses** require **highest number of daily charge/discharge cycles** resulting in optimal exploitation of the FESS's specific properties





	EV Use Case
1	Charging at public parking lots
2	EV car sharing
3	Highway fast charging
4	Public charging at shopping centers
5	Electrified busses
6	Electrified taxies
7	Electrified last-mile delivery trucks

Intermediate Summary: FlyGrid Grid Simulation Part

Conclusions

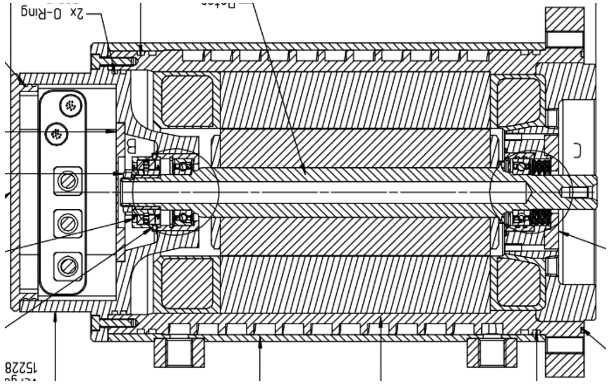
- Peak-load shaving by ESS allow grid-friendly integration of future e-mobility into present-day power grids
- Required ESS specifications strongly depend on the considered EV use case and charging power
- The majority of future charging demands can be supplied by small ESSs (e.g., 5kWh and 100 kVA)
- Electric busses represent optimum application of flyhweel ESS due to frequent and constant energy demands and high charging power

Outlook

- Combination with other flexibility options
- (Cost-)comparison with classic grid reinforcement measures

FlyGrid
Energy Storage for Vehicle Fast Charging and Grid Integration

WP 7: Testing of Motor/Generator-System



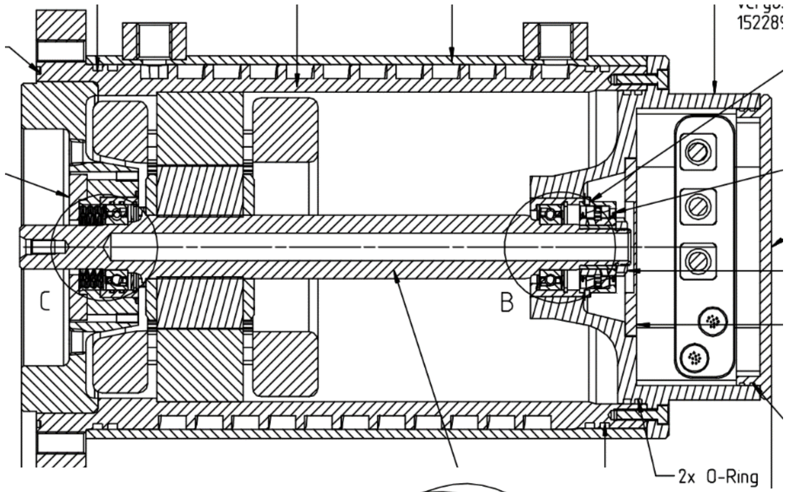
Due to the tests with test motor 2 the winding design with maximum torque per ampere and full field weakening functions was chosen.

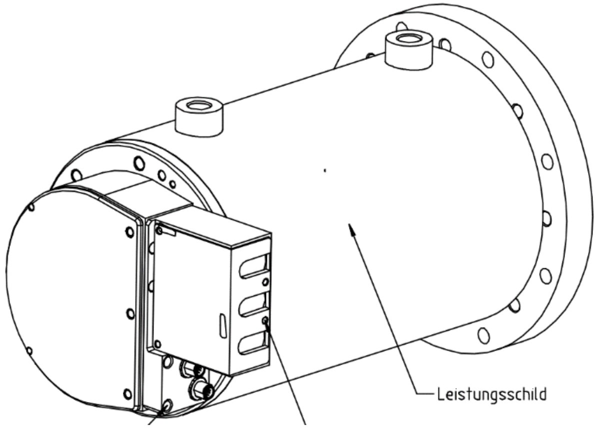
The demonstrator is running in the test-field at THIEN eDrives with semicron-inverter.

The basic and in the beginning foreseen Ld-/Lq-control strategy can be used, which is the less complicated and therefore the fastest possibility to control the motor.

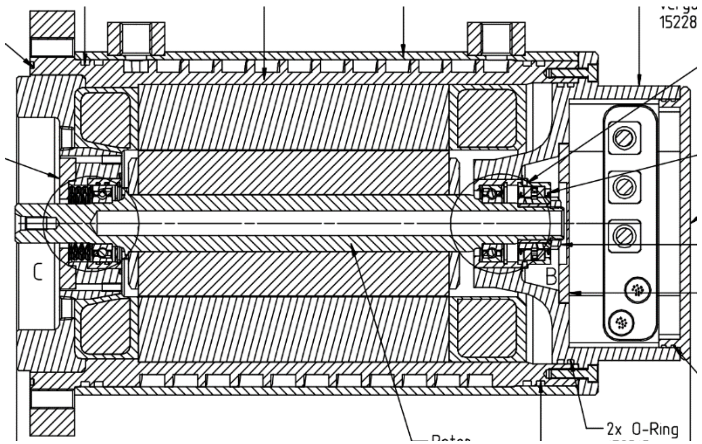
WP4: Motor-/Generator Design

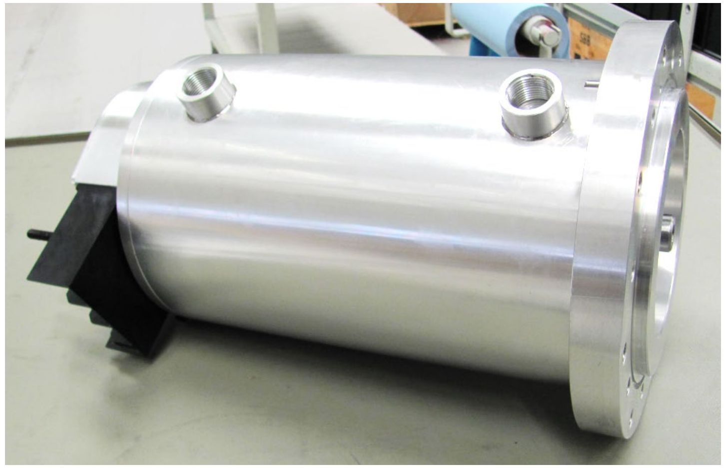
Test Motor 2



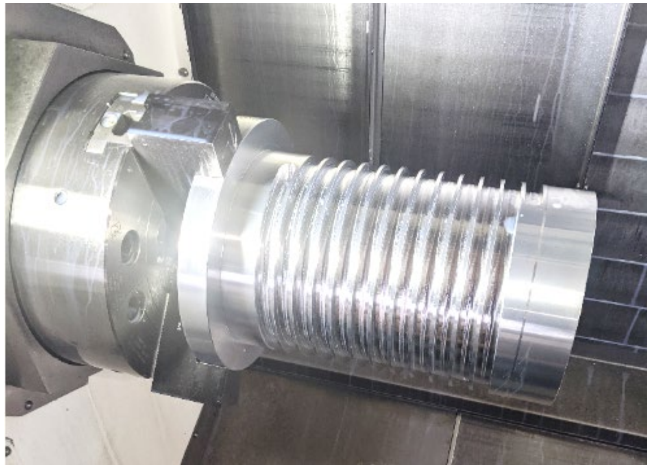


Demonstrator





WP 5: Manufacturing of Motor/generator

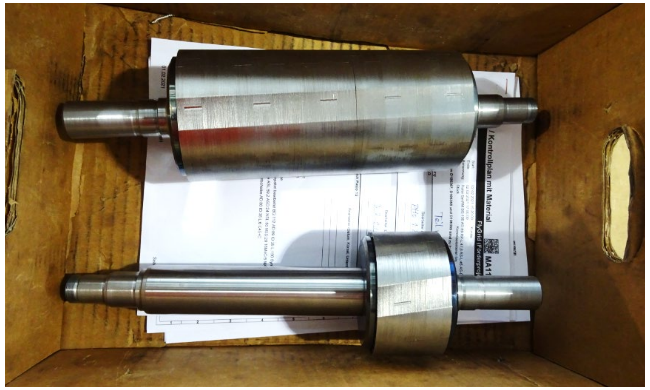


Housing production

End-shield

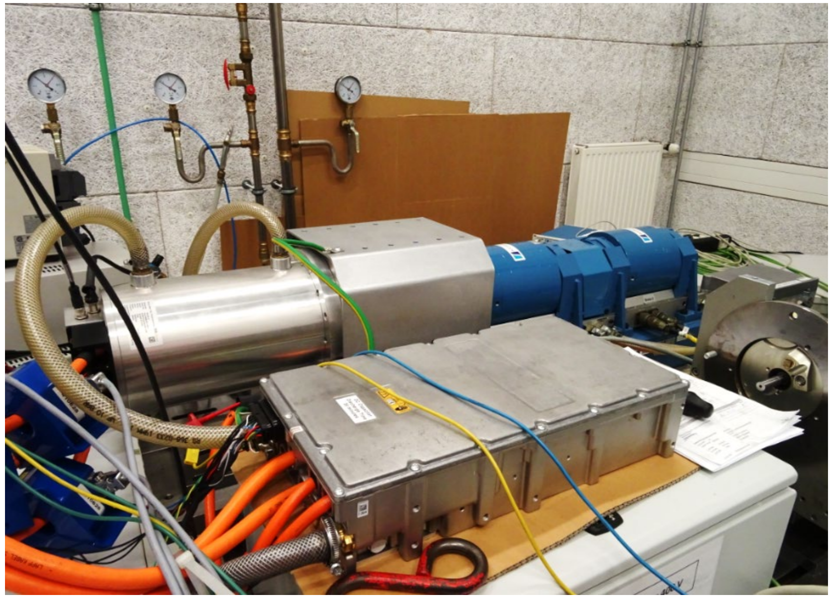
Stator of test motor with z_n=6

rotors of test-motor and demonstrator



WP 5: Testing of Motor/Generator

(updated comp. to intermediate report Nr 3)



Test motor 2 is running in test-field at TeD with *Semicron*-inverter.

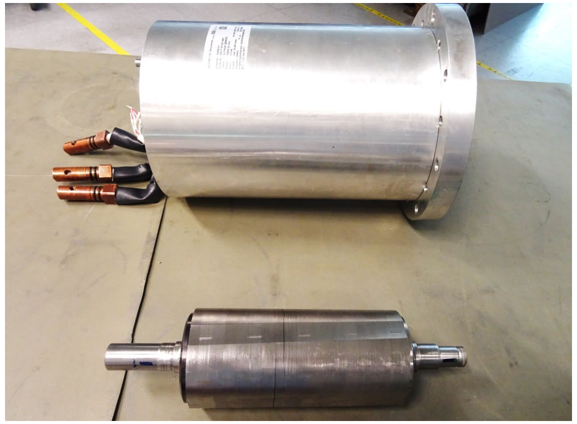
Foreseen control strategy for high dynamic control is implemented, which is based on differential L_d/L_q-parameters

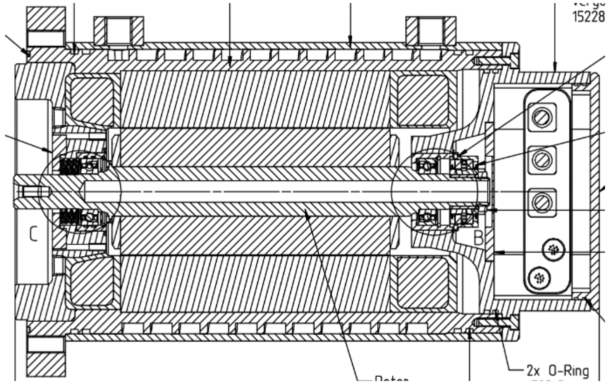
Control parameters are working properly; point of best torque per ampere like predicted

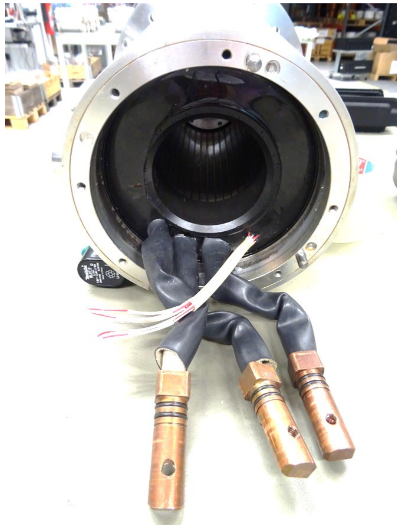
Differences in predicted torque consumption: 200 A measured instead of 160 A calculated

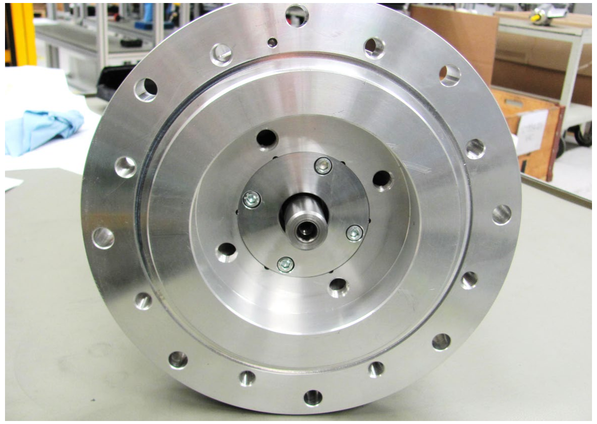
- R1: mechanical tolerances; if taken into account as measured, difference is 188 A vs. 200 A
- R2: to be verified: heat influence zone from laser cutting process

WP4: Motor-/Generator Design

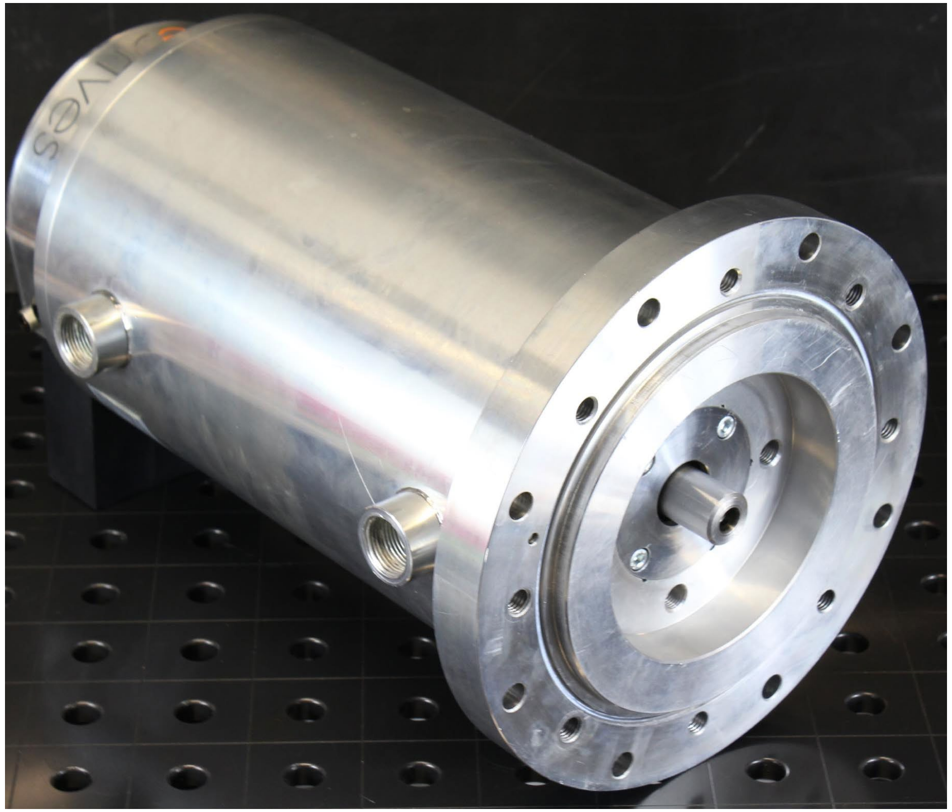








✓ The demonstrator was finished in November 2021



WP 7: Development of Power Electronics and System

- After demo facility planning was done, the control cabinet, containing frequency inverter, power feedback unit, filters, fuses, capacitor cabinet, and water and air cooling of the components was finished.
- The pictures show the control cabinet made ready for transport to TU Graz.
- Currently undergoing lab testing