iFAST 1st Annual Meeting, May 4, 2022

Mike Seidel, PSI/EPFL

WP11 Overview

task 1: **Sustainable Concepts for RIs**: networking, workshops on selected topics
deliverable: report

1) System Efficiency of Accelerator Concepts (N.Catalan Lasheras, CERN)
2) Key Technologies and Components for High Efficiency (C.Martins ESS)
3) Cross Linking Accelerator R&D with Industrial Approaches (P.Spiller GSI)
4) Ecological Concepts (D. Voelker DESY)

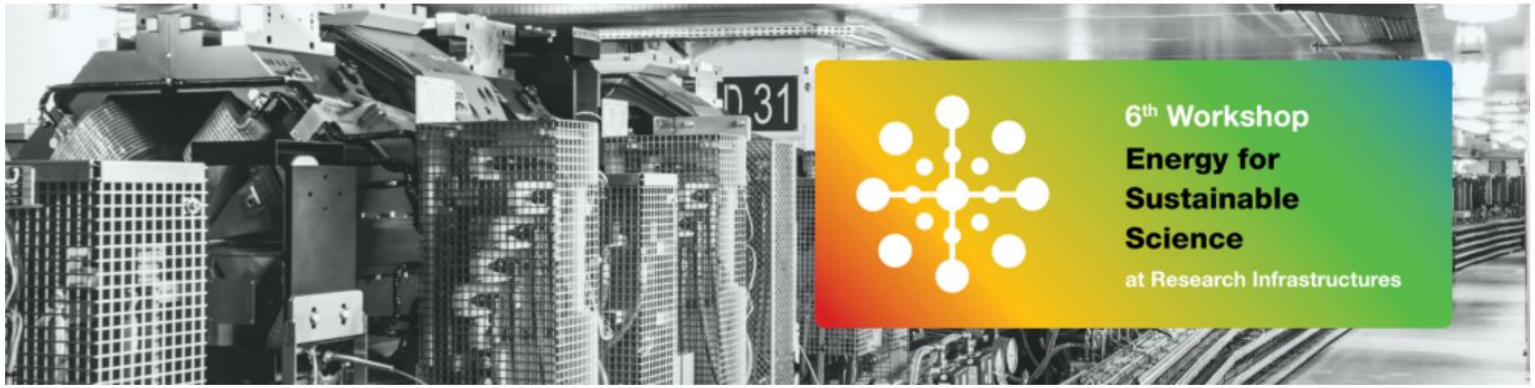
task 2: **High Efficiency Klystron** (O.Brunner CERN, THALES, ULANC)

- deliverable: industrial prototype
- replacing klystrons in LHC

task 3: **Permanent Combined Function Magnets for Light Sources** (B.Shepherd, UKRI, DLS, KYMA, DESY)

- deliverable: magnet prototype, applicable for Diamond upgrade,PETRA-4
- several advantages of permanent magnets, not just power consumption

ESSRI Workshop Grenoble, Sep 29, 2022



29-30 September 2022 REGISTRATION OPENS 1ST MAY
ESRF, Grenoble
Europe/Paris timezone

Enter your search term

- Overview
- Committees
- Timetable
- Registration Instructions PLEASE READ!
- ESRF Registration Form
- Fees & Payment information

Dwindling resources together with rising energy costs and climate change are all challenges faced by the next generation of large-scale research infrastructures. Indeed, the enhanced performance of proposed new facilities often comes with anticipated increased power consumption. Sustainable developments at research infrastructures will rely on mid- and long-term strategies for reliable, affordable and carbon-neutral energy supplies.

The ESRF (European Synchrotron Radiation Facility) is pleased to host the **Sixth Workshop on Energy for Sustainable Science at Research Infrastructures** on **29th and 30th September 2022** in Grenoble, France in collaboration with:

Grenoble: Green Capitol of Europe, 2022

Session Topics:

- energy efficient technologies
- energy management at research infrastructures
- sustainability of equipment, materials and resources
- energy management for projects

International Organising Committee

Carlo Bocchetta - ESS
Frederick Bordry - CERN
Serge Claudet - CERN
Andrew Harrison - ERF
Jean-Luc Revol - ESRF
Mike Seidel - PSI
Denise Voelker - DESY

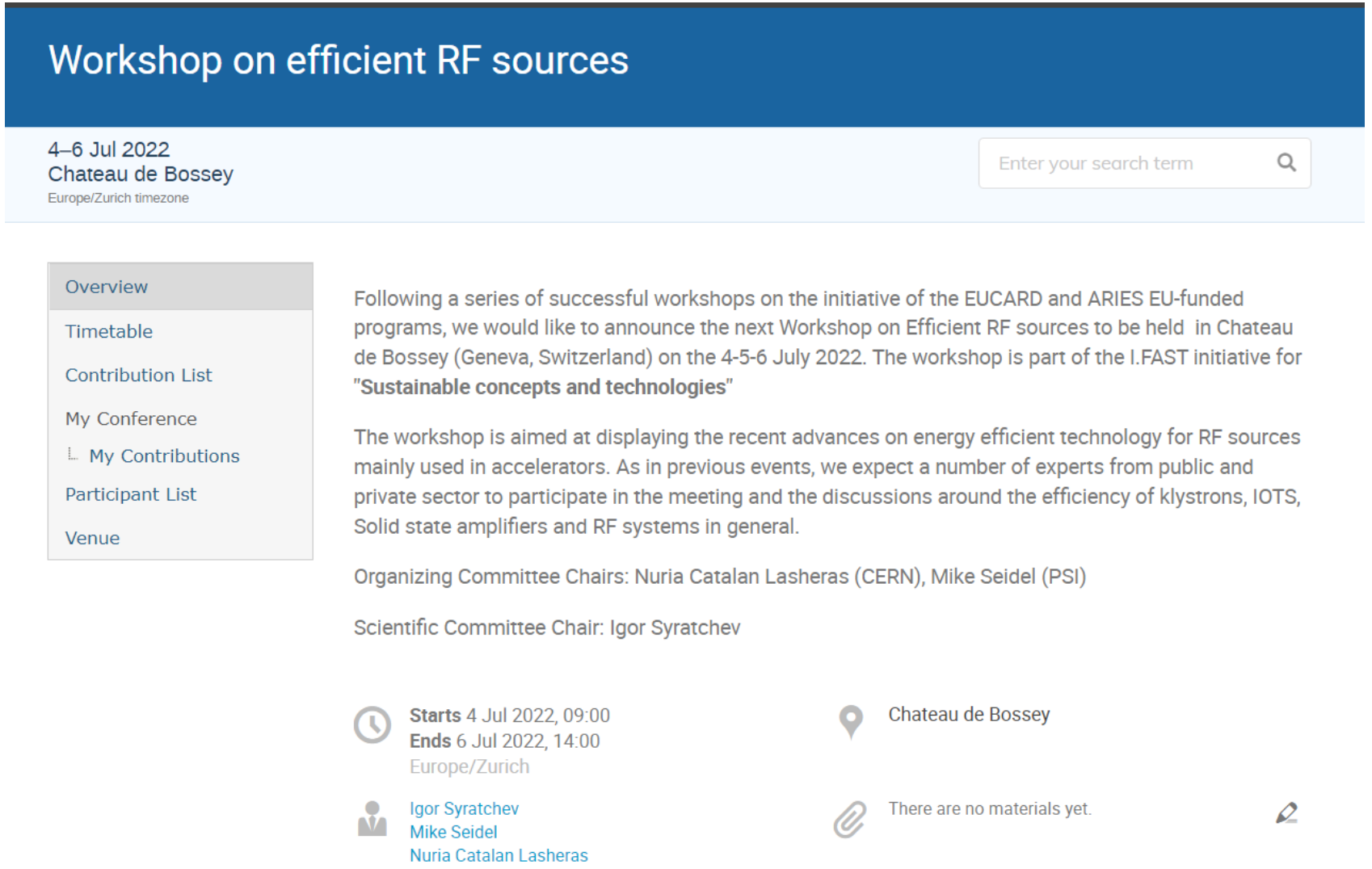
iFAST

https://indico.esrf.fr/event/2/

WP11: Sustainable concepts and technologies. MS51

WP11, 1.1: N.Catalan-Lasheras

- RF efficiency in operational and planned accelerators
- High efficiency klystrons
- Industrial partners contribution
- Magnetrons, IOTs, tetrodes
- Solid State Amplifiers



https://indico.cern.ch/event/1138197/

Registration will open soon!!

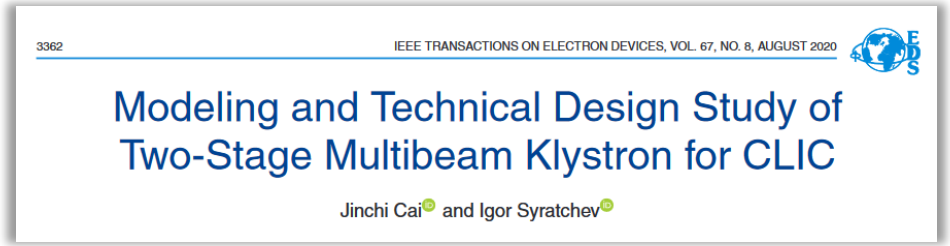
Technology R&D: Efficient RF Power Sources

- **Klystrons**, η>70% within reach
  e.g. CLIC two stage multi-beam klystron, J.Cai, I.Syratchev, IEEE Trans, 2020

- **Magnetron**, R&D at various groups, η=60-80% in reach
  e.g. Wang et al, J-Lab, IPAC 2019; A.Dexter, Lancaster U., LINAC-2014;
  B.Chase, Fermilab, JINST-2015

- **Solid state amplifiers (SSA)** at various groups, η=60-90% depending of freq.

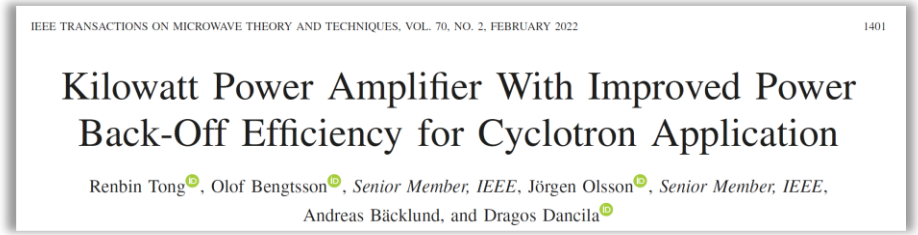
towards 100% means also low heat removal & compact units !


3362 IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 67, NO. 8, AUGUST 2020

Modeling and Technical Design Study of Two-Stage Multibeam Klystron for CLIC

Jinchi Cai and Igor Syratchev

Example: study 1GHz for CLIC drive beam; 6 cavities, 30 beamlets; 25+140kV; η_{sat}=82%


IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 70, NO. 2, FEBRUARY 2022 1401

Kilowatt Power Amplifier With Improved Power Back-Off Efficiency for Cyclotron Application

Renbin Tong, Olof Bengtsson, *Senior Member, IEEE*, Jörgen Olsson, *Senior Member, IEEE*, Andreas Bäcklund, and Dragos Dancila

Example: SSA for Isotope production Cyclotron, 98.5MHz, 12x1kW units, η_D=93% (90% with regulation overhead)
Uppsala group, WP in I.FAST program

WU#1 – Powering accelerators from local PV renewable energy

1.2: C.Martins et al, ESS

Concept:

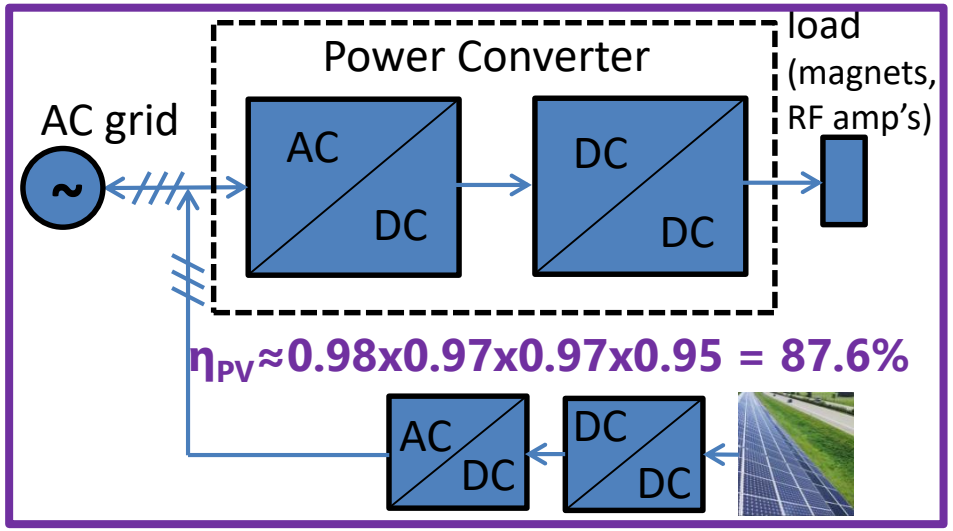
- Install PV panels near accelerators' "wasted land";
- Connect PV to the main power converters supplying accelerator magnets / RF amplifiers, using high efficiency DC/DC converters
- AFE's can redirect the PV energy back to the AC grid when accelerator not running;
- Up to 15-20% renewable energy utilization possible with no transmission losses and high conversion efficiency;
- Lower capital cost & lower payback time;

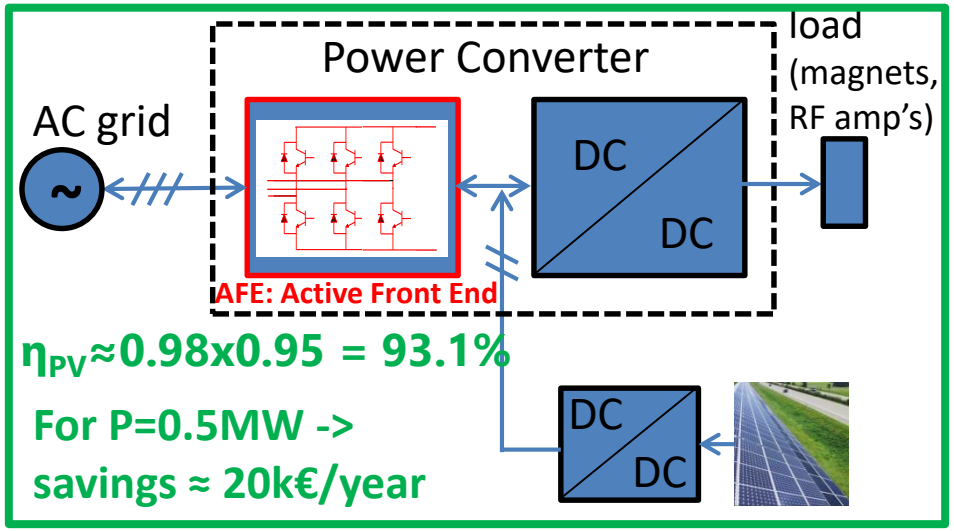
Objectives:

- Feasibility study for ESS case: up-to 2MW installed PV injected into the Linac RF klystron modulators;
- MSc thesis with Lund University (starting Feb. 2022);

Conventional:

PV injected into the AC grid (4 stages)





New scheme: PV injected into power converters (2 stages)

WU#1 – Powering accelerators from local PV renewable energy

How much does that PV energy represent wrt ESS accelerator annual consumption?

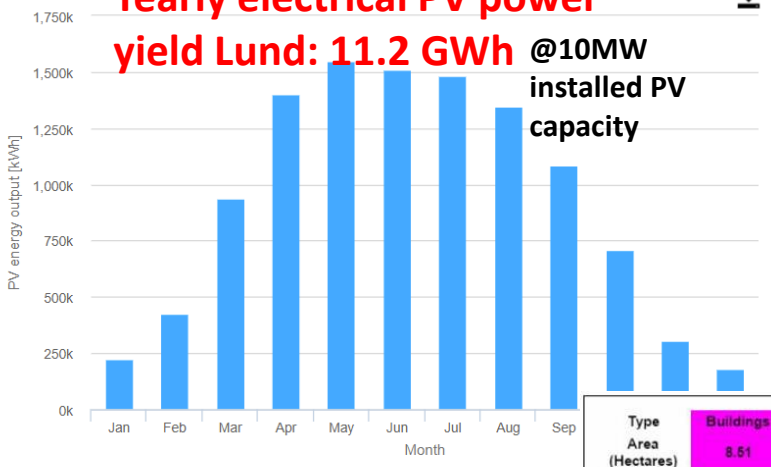
PERFORMANCE OF GRID-CONNECTED PV: RESULTS — PV output

Summary

Provided inputs:	
Location [Lat/Lon]:	55.735,13.253
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed [kWp]:	10000
System loss [%]:	5

Simulation outputs:	
Slope angle [°]:	40 (opt)
Azimuth angle [°]:	2 (opt)
Yearly PV energy production [kWh]:	11162309.12
Yearly in-plane irradiation [kWh/m²]:	1251.02
Year-to-year variability [kWh]:	488195.41
Changes in output due to:	
Angle of incidence [%]:	-3.02
Spectral effects [%]:	1.51
Temperature and low irradiance [%]:	-4.59
Total loss [%]:	-10.77

Monthly energy output from fix-angle PV system

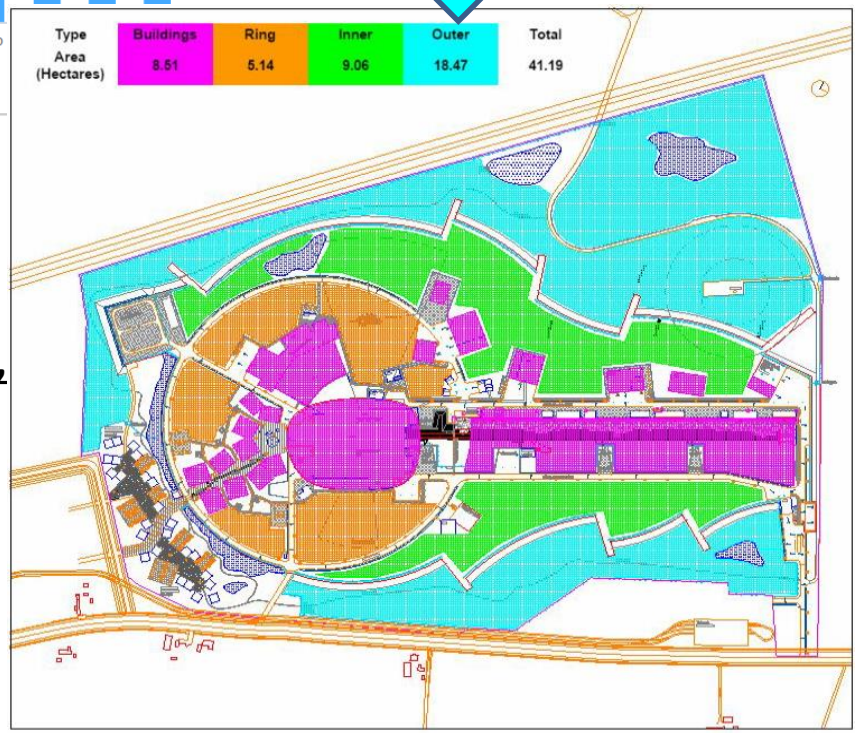


Yearly electrical PV power yield Lund: 11.2 GWh @10MW installed PV capacity

10MW installed PV capacity
- Land area: ~18 hectares

Areas in **"blue"**
(i.e. outer area of ESS site):
~ 18.5 hectares

1.2: C.Martins et al, ESS



- By its completion, the ESS accelerator yearly consumption is: ~12MW*5'500h = 66GWh;

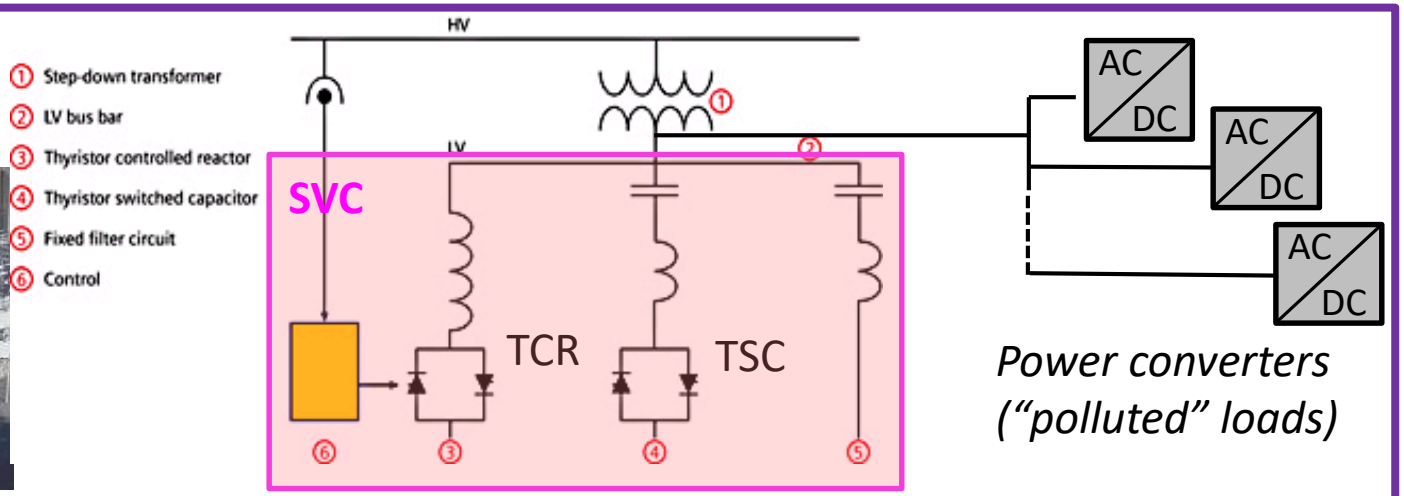
- **<u>CONCLUSION: With 10MW PV installed capacity, the ESS accelerator can be powered up-to 17% from local PV renewable energy</u>**

Note: The AFE's of the klystron modulators can operate ~8'500h/year, i.e. injecting PV power back into the AC line when the accelerator is shutdown (i.e. for ~3'000 h/year);

WU#2 – Grid friendly accelerator power converters

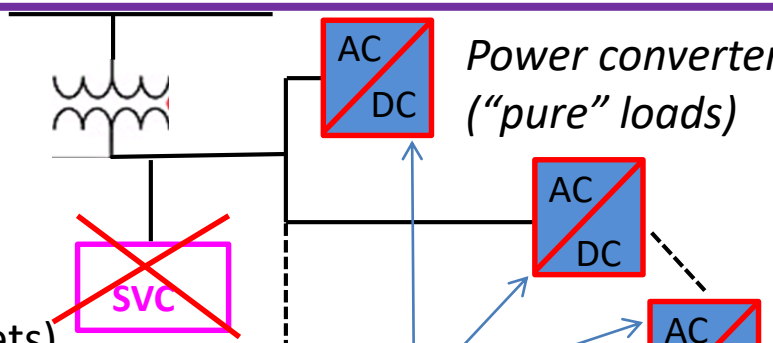
Conventional scheme: centralized power quality compensators

- Expensive;
- Limited performance



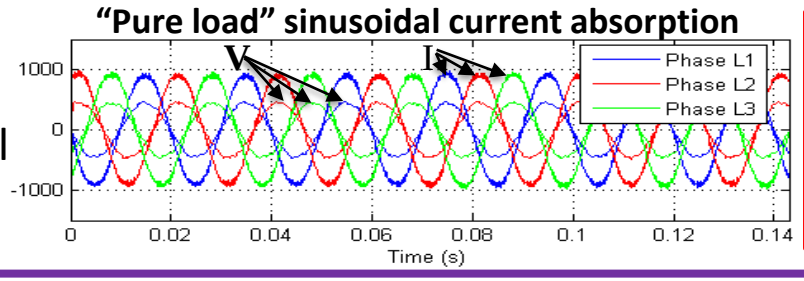
New scheme: active compensators (AFE's) integrated within the power converters

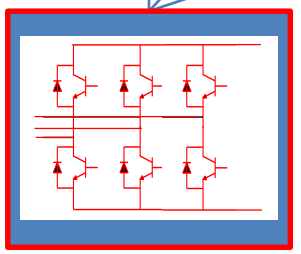
- No external SVC's required: cost savings;
- Excellent performance (unitary power factor, very low current harmonic distortion: <3%);
- Higher efficiency (no harmonics in the power line between loads and compensators);
- Power reversal capability (superconducting magnets)



Objectives:

- Comparative study between conventional & new compensators





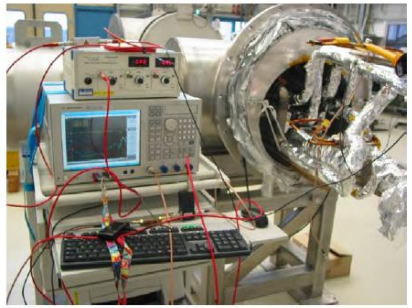
AC/DC: Active Front End (AFE)

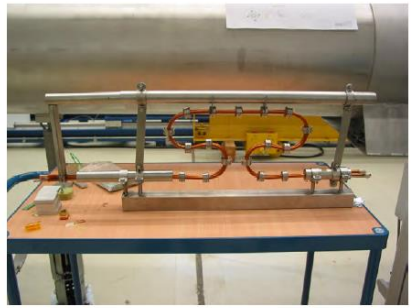
GSI Technology Transfer: Fault Detection in Cables

Detection of Defects in Cables by means of

1: Synthetic Time Domain Reflectometry (sTDR)
2: Breakdown Detection with „Time of Flight“ (ToF)

Developed to detect faults in superconducting bus bar systems.

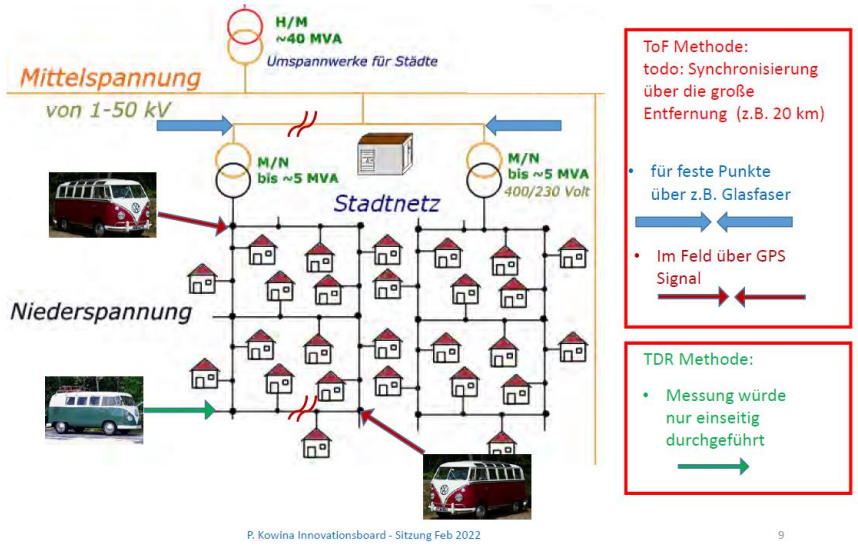




1.3: P.Spiller, J.Stadlmann et al, GSI

Application to cables with limited access (high precision in position determination about 2 cm)

a) Underground power cable (test with E-Net AG)
b) Power cable of critical infrastructure (servers, computer centers, internet hubs and nodes)
a) Underwater sea cable



TT Support: Funding of over time work.

HTS Cables for Fast Ramped Synchrotrons

1.3: P.Spiller,
J.Stadlmann et al, GSI

Application Study in Energy Systems

- Explore different applications for different HTS ReBCO cable types
  - Split applications into two categories – “Conductors” and “Magnets” based on field exposure in the application
  - Further distinguish applications by time constants (aka dynamic behaviour of application)
  - Evaluate market potential for different applications
- Goal is to identify synergies between I.FAST cable development in WP8.6 and further industrial applications in stustainable energy systems

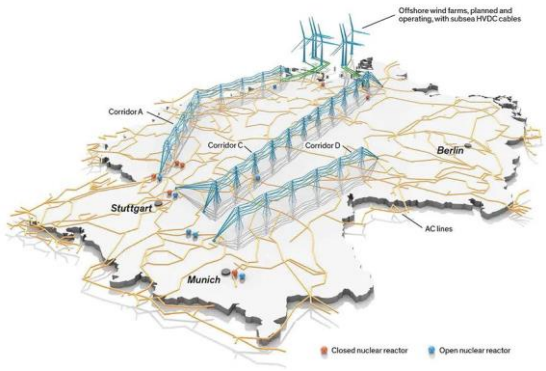
HTS Cables for Fast Ramped Synchrotrons

1.3: P.Spiller,
J.Stadlmann et al, GSI

HTS Energy Applications

- Evaluated cable options
  - Stacked tapes cable (ST)
  - Roebel cable (Roe)
  - CORC/CORT (CR)
- FCL has been studied for CORC/CORT type cable
  - Advantages:
    - Easily adjustable transport capacity by varying coolant temperature
    - Parallel paths in CORT makes tapes requirements less stict
    - Round shape gives flexibitly for winding

Application	Application field	Cable concepts tested	Cable concept established
Current Leads/Magnet Feeders	Science/Energy	ST, CR	ST
Fault Current Limiters	Energy	Single tape, ST	-
High Field Magnets	Science/Energy	Single tape	Single tape
Fusion	Industry/Energy	ST, CR	-
Induction Billet Heaters/ Magnetic Separation	Industry/Energy	Single tape	-
Magnetic Energy Storage	Energy	Single tape, CR	-
Particle Accelerators/ Particle Therapy	Science, Medicine	ST, Roe, CR	-
Power transmission cables	Energy	CR	CR
Energy, Transport	Energy, Transport	Single tape	-
Transformers	Energy	Single tape, ST, Roe	-
Wireless Energy Transfer	Transport/Energy	Single tape	-
MRI	Science/Medicine	Single tape	-
NMR	Science/Medicine	Single tape	Single tape



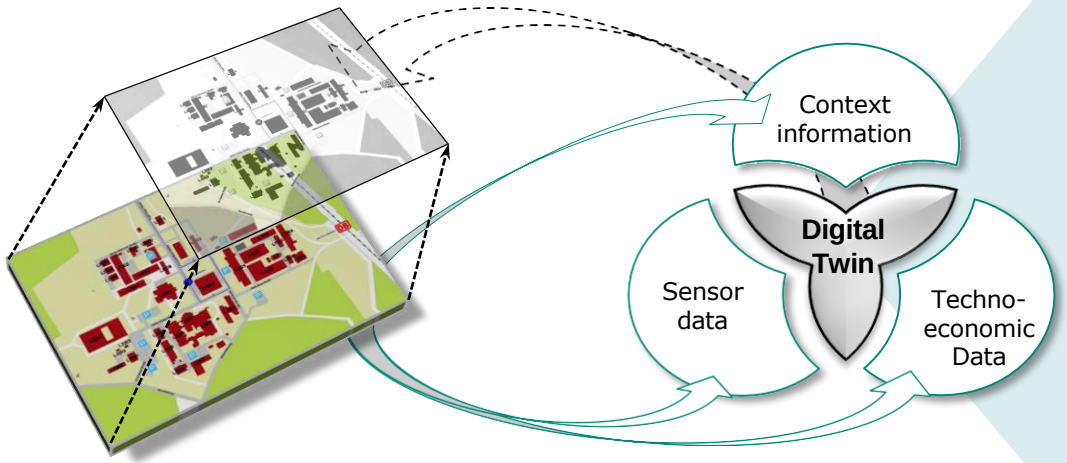
Implementation of a Digital Twin for a Multi Energy System

Part of the EnEff Campus Lichtwiese project at TU Darmstadt

TECHNISCHE UNIVERSITÄT DARMSTADT

A Digital Twin is...

Digital twin provides target state



Real system provides actual state

...a virtual representation of a real world system.

Web: www.eins.tu-darmstadt.de
Mail: christopher.ripp@eins.tu-darmstadt.de

CH.Ripp, TUD/GSI

Objective: Optimization of the Systems Performance (Cost and Emission minimal)

Operational Optimization: Two staged cost and emission optimization

Input

- Demand Time series D(t)
- Technology parameters $\eta, u_p, \bar{P}$
- Price Time series $c_{var}(t)$
- CO2 Intensity $CO\_2I(c,t)$

Cost $min \sum_t c_{var}(t) u_{cp} P\ (c_{in}, cp, c_{out}, t)$

CO_2 $min \sum_t P\ (c_{in}, cp, c_{out}, t)\ CO_2I(c,t)$

s.t. $P(c_{in}, cp, c_{out}, t) \leq u_{cp}(t)\bar{P}(cp)$

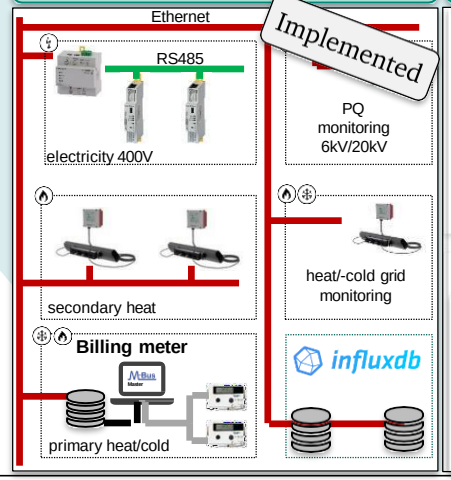
$u_{cp} \in \{0,1\}$

- Energy balance
- Consistent storage operation
- Co-generation efficiency
- ...

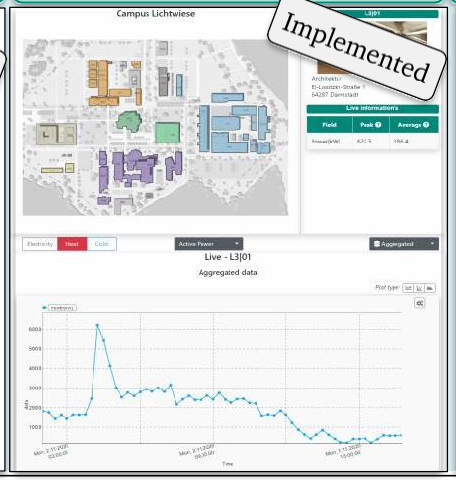
Output

- Dispatch P(j,t,y)
- Costs €
- Emissions CO2

High-Res Energy Monitoring



Web-based energy platform



Machine Learning Forecasts

- Automatized data validation
- Probabilistic forecast for electricity, heat, and cold
- Operational parameter estimation, e.g., efficiency rates, power gradients

Task 1.4: Ecological Concepts (DESY, Denise Voelker)

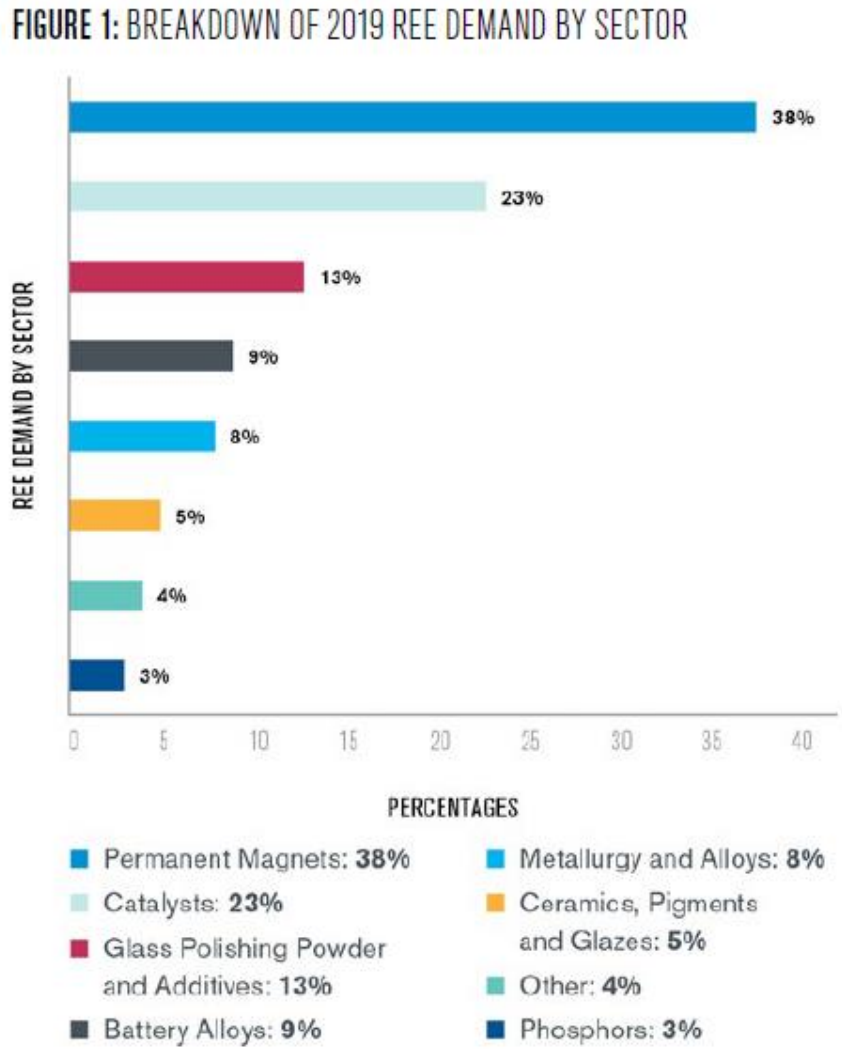
Focus 1: Rare earths for permanent magnets

- Huge energy savings versus destructive mining and processing
- At PETRA IV up to 100 PM
- In 2019 38% of rare earth elements demand was for PM
- Other player/fields concerned with rare earths (and therefore possible partners):
  - wind power stations, battery producers etc.
  - Producers of loudspeakers, hard drives etc.
  - Space technology
  - Formula 1
- Currently no alternative sources or certified mining and processing available

→ investigation on social and environmental impacts of mining and processing for PM will be presented soon

→ Next step: approach industry

→ Workshop planned for Jan 2023



Source:
https://kleinmanenergy.upenn.edu/research/publications/rare-earth-elements-a-resource-constraint-of-the-energy-transition/

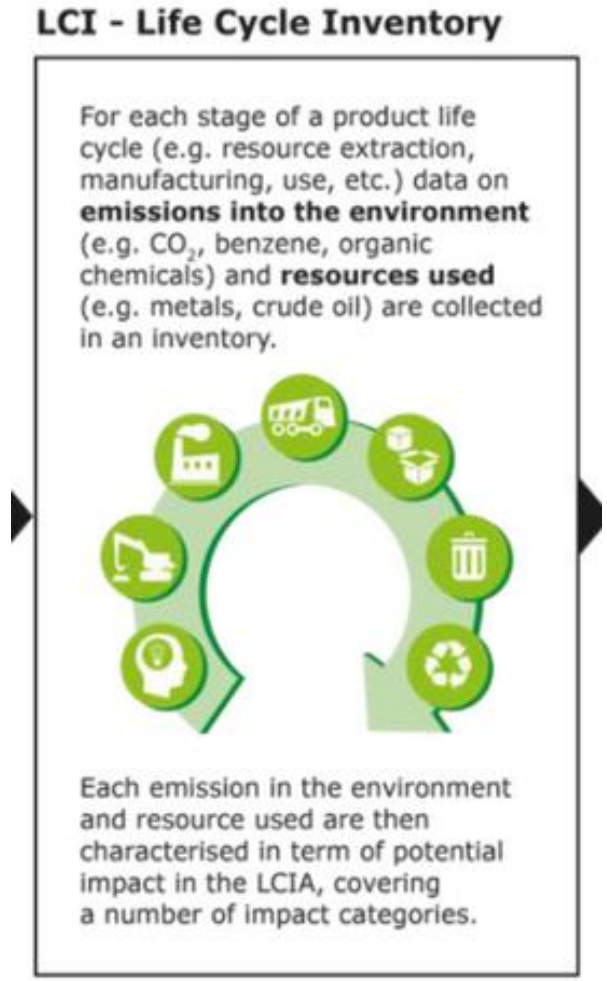
Task 1.4: Ecological Concepts (DESY, Denise Voelker)

Focus 2: Life cycle assessment (LCA) of technological components

- Consider entire life cycle of machines and components meaning construction – running – deconstruction
- LCA contains:
  - Life Cycle Inventory (LCI)
  - Life Cycle Impact Assessment (LCIA)
  - Life Cycle Interpretation phase
  - Cost analysis (invest versus operation versus decommissioning
- Goal: implement life cycle management already in planning phase of new RIs

→ Currently identification and contact of experts on technical life cycle thinking

→ Workshop planned for Jan 2023



Example: Content of a Life Cycle Inventory

Source: https://eplca.jrc.ec.europa.eu/lifecycleassessment.html

Appendix: Milestones & Deliverables

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification	
MS50	Workshop on energy for sustainable science at research infrastructures, at ESRF	41 - PSI	6	Web site (task 11.1)	**ESSRI Grenoble, J.P. Revol et al, prep ongoing! September , 2022; [Link, reserve the date]**
MS51	Workshop on efficient RF sources	1 - CERN	13	Web site (task 11.1)	July 2022
MS52	Workshop on efficient magnet- and RF power supplies	2 - ESS	22	Web site (task 11.1)	April 2023
MS53	Workshop on sustainable materials and lifecycle management for accelerators	12 - DESY	18	Web site (task 11.1)	December 2022
MS54	Workshop on industrial approaches for sustainable accelerators	13 - GSI	42	Web site (task 11.1)	December 2024
MS55	Design review	1 - CERN	12	Web site (task 11.2)	June 2022
MS56	Magnets constructed and tested	25 - KYMA	25	Magnetic measurements completed (task 11.3)	July 2023

Deliverables related to WP11	
D11.1: Sustainable Accelerators Report. *Report on strategies to improve sustainability and reduce environmental impact of accelerators.*	M45
D11.2: Klystron prototype completed and validated. *Report on the construction of the klystron prototype and on the test results.*	M36
D11.3: Prototype adjustable PM quadrupole and combined function magnets. *Two prototype PM-based magnets one quadrupole and one combined-function magnet designed, built and measured.*	M28