

POWER ELECTRONICS AS THE ENABLING TECHNOLOGY FOR BUILDINGS DECARBONIZATION

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Centre of Excellence in Energy Efficiency

IEEE Industrial Electronics Society


TALLINN → BOLOGNA
St. Olaf's Church
Old Town walls
TALLINN · TLL
ESTONIA
TALLINN, ESTONIA
≈1,890 km
Straight-line air distance
Two Towers
San Petronio Basilica
BOLOGNA · BLQ
ITALY
BOLOGNA, ITALY
Illustrated map • Actual flight routes may vary


ESPRESSO MACCHIATO
TALLINN
TOMMY CASH
TOMMY-SIZE

WHERE I AM FROM

ESTONIA - A Destination for Tech Lovers
TALLINN - The Best-Preserved Medieval City in Northern Europe





- *Population:1.35 million*
- *Currency: Euro*
- *World's most digitally advanced society*
- *Estonia leads Europe in startups, unicorns, and investments per capita*

skype Bolt wise skeleton

- *Population: 456.000*
- *Historic Centre (Old Town) of Tallinn is UNESCO world heritage site*
- *Annually welcoming over 3.2 million foreign visitors*

TALTECH – TALLINN UNIVERSITY OF TECHNOLOGY

LEADER IN ESTONIAN TECHNOLOGY AND IT EDUCATION, RESEARCH AND INNOVATION



TAL TECH

POWER ELECTRONICS GROUP OF TALTECH

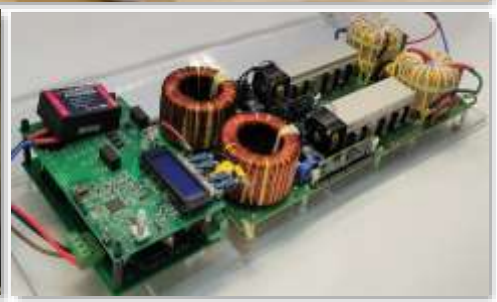
LARGEST RESEARCH CENTER FOR APPLIED POWER ELECTRONICS IN BALTIC STATES











OUR CORE RESEARCH AND INNOVATION ACTIVITY

ENHANCEMENT OF ENERGY PERFORMANCE OF BUILDINGS

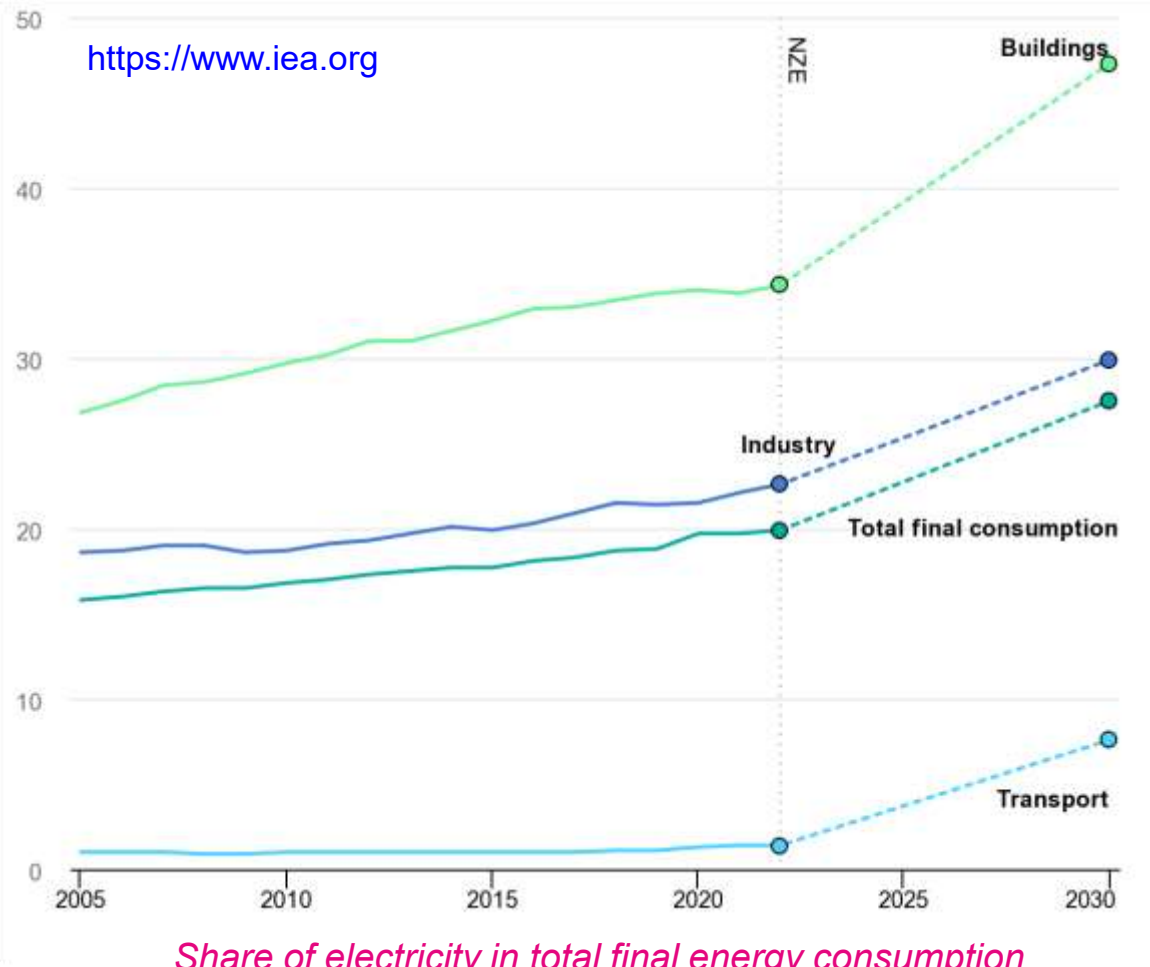


Centre of Excellence in Energy Efficiency

MOTIVATION: TOWARDS EU GREEN DEAL TARGETS

- *By 2050 the EU aims to become the **world's first "climate-neutral bloc"** with net-zero greenhouse gas emissions (NZE)*
- ***Electrification** is considered one of the key strategies to reach NZE goals*
- *Main priorities are **electrification of transport** and **heating/cooling demand of buildings** using heat pumps*
- *In 2050, **electricity will become the dominant energy carrier for the buildings in EU***





Share of electricity in total final energy consumption in the NZE scenario (2005-2030)

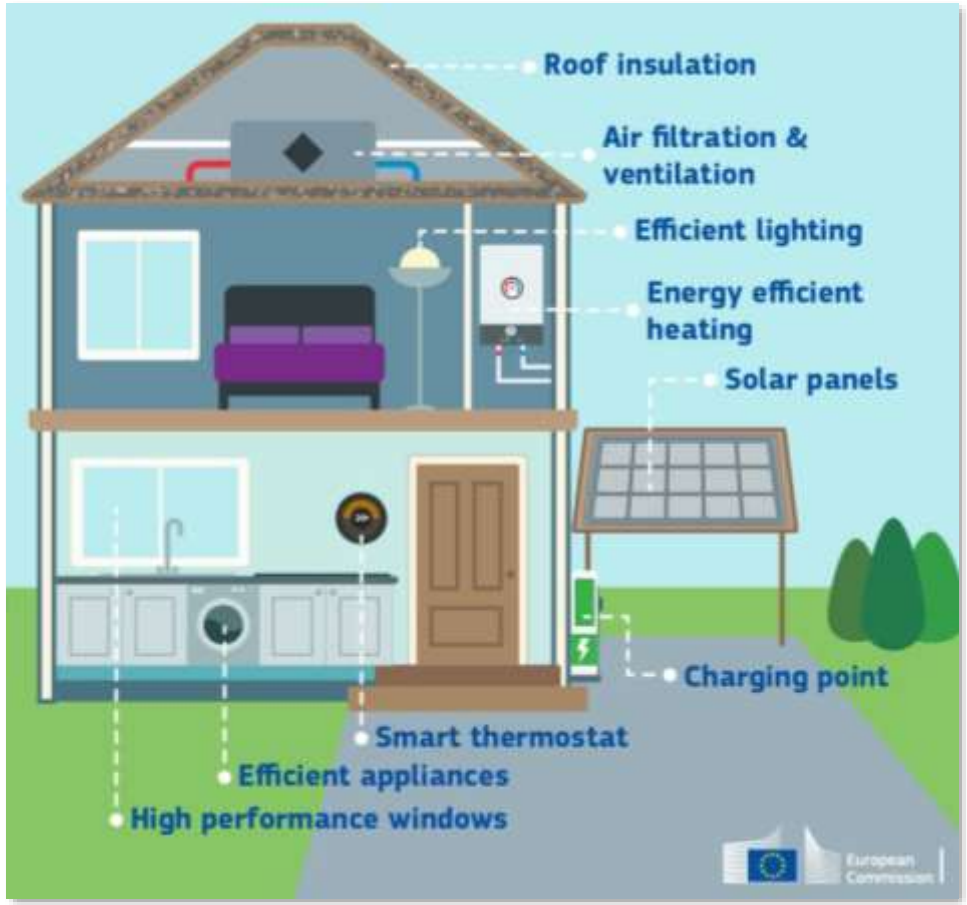
DECARBONIZATION OF BUILDING STOCK IN EU

- *In 2002, the EU began implementing the **Energy Performance of Buildings Directive (EPBD)**, which is a framework to reduce energy consumption and boost decarbonization of buildings*
- *The EPBD requires all new buildings from **2021 to be nearly zero-energy buildings (nZEB or class A)**, i.e. must have a high energy performance and very low energy needs, covered largely by onsite or nearby renewable energy sources*
- *From **January 2030** the EPBD requires all new buildings to be **zero-emission buildings (ZEB, A+ or A_0)**, i.e. without on-site carbon emissions from fossil fuels*
- *EPBD demands the installation of **EV charging points** in new and significantly renovated non-residential buildings with more than 5 parking spaces, and in residential buildings with more than ten parking spaces*
- *EPBD introduced „Smart Readiness Indicator“ to assess the technological readiness of the building to **interact with their occupants and adapt to signals from the grid (for ex., energy flexibility)***



ZEB: WHAT IT MEANS IN PRACTICE

- ***ZEB = HIGH ENERGY PERFORMANCE + LOCAL RENEWABLE ENERGY GENERATION + "ALL-ELECTRIC" LIFESTYLE***
- ***"Must have" attributes of ZEB:*** *PV installation (ideally backed up with energy storage), heat pump, heat recovery ventilation, energy-efficient lighting and appliances, smart control of loads*
- *In result, ZEB consumes **up to 4 times less energy** than the traditional „old school" non-renovated building (class F)*
- *Most of the energy saving technologies used in ZEB are **power electronics based***




Shutterstock


Image: Enphase


Image: SMA


Image: SMA

CLASSICAL EXAMPLES OF DECARBONIZATION





BAPV vs BIPV- RENEWABLE ENERGY SHOULDN'T COME AT THE COST OF AESTHETICS !

Building-Attached Photovoltaics (BAPV) *lacks full integration into the building, adds additional load, with limited contributions to aesthetics and structural integrity*



Building-Integrated Photovoltaics (BIPV) *is revolutionizing the solar industry by bridging the gap between electricity generation and building design*





THERE'S MORE OPTIONS THAN THE ROOFTOP PV!

SOLAR PV FENCES



SOLAR WINDOWS



SOLAR PANEL WINDOW BLINDS



SOLAR BALCONIES



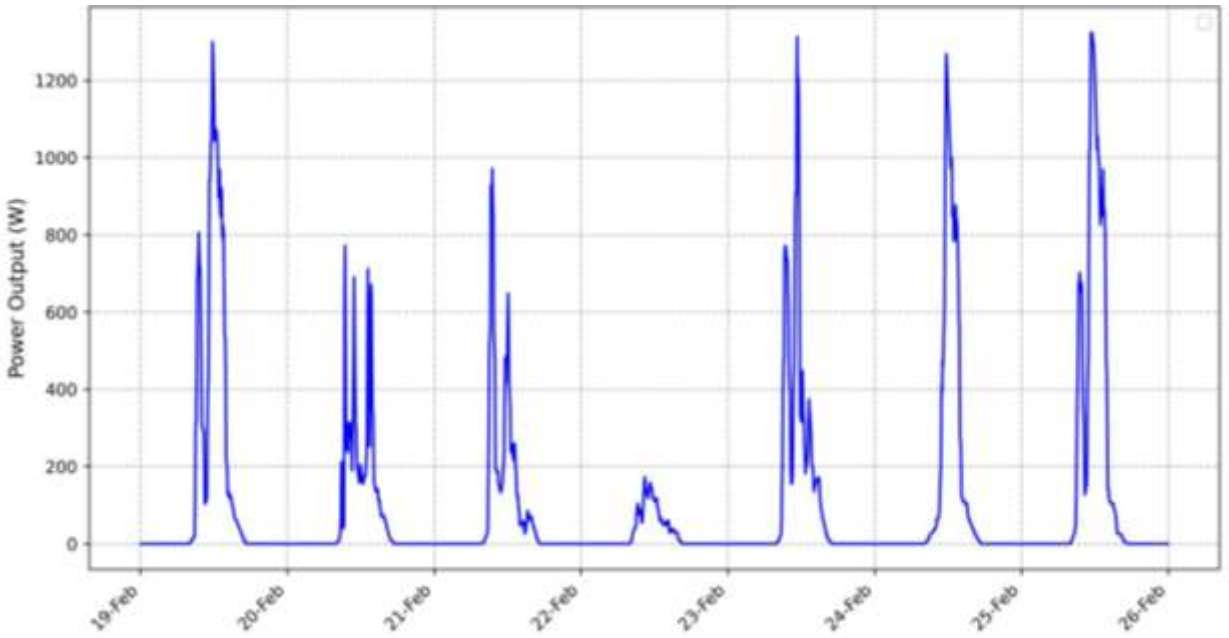
SOLAR FAÇADES



SOLAR FAÇADE – GENERATE WHEN OTHER DO NOT

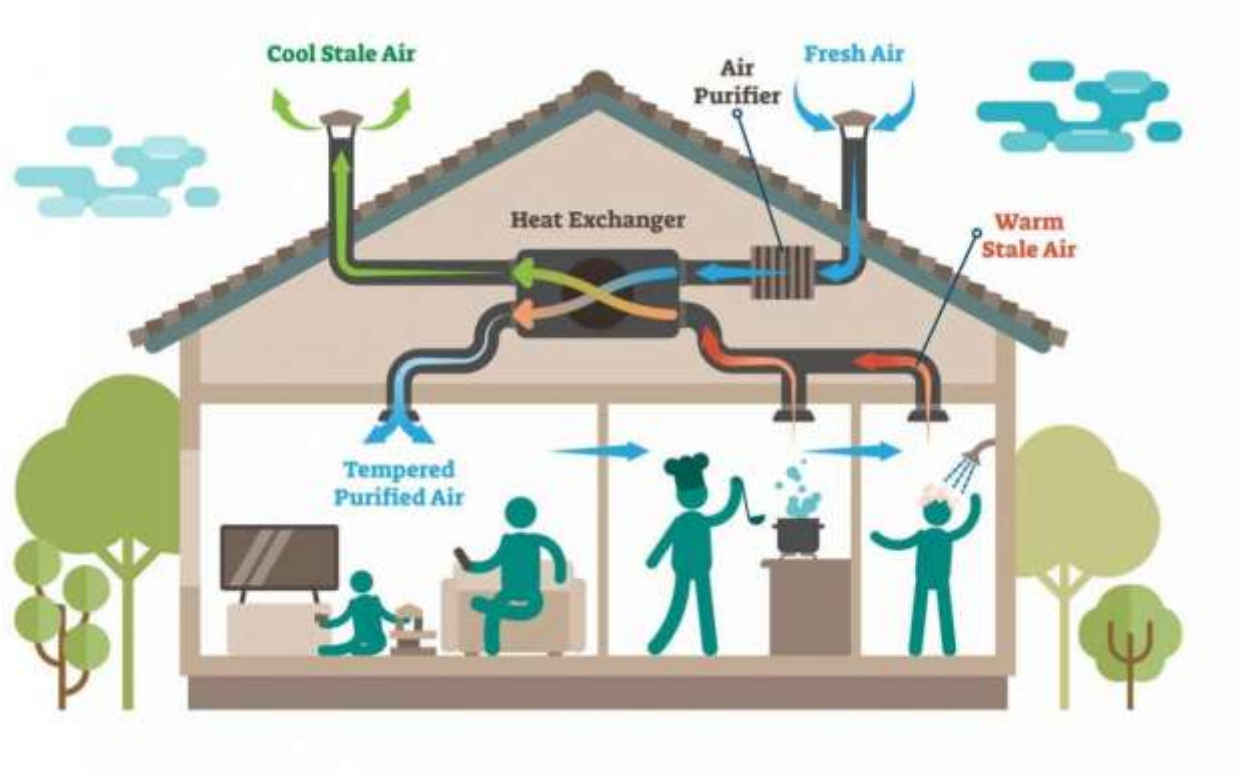
- ***In Northern EU,*** *snow covers the PV panels on the roof for long time, but they cannot generate much even without snow as sun ray's incident angle is highly unfavorable (sun rays nearly horizontal)*
- ***Solar façades*** *are never covered by snow, while sun incident angle is nearly ideal in winter*
- ***TalTech Residential DC Innovation Hub*** *has 5 PV modules of 144 half-cut cells rated for 360 W*
- *Test data from February 2026 show that the solar façade produced* ***17.9 kWh vs. 0 kWh*** *from the roof*





HEAT RECOVERY VENTILATION SYSTEMS

- ***Improved energy efficiency**: reduces heating demand of the buidling by **recovering up to 60–90% of the heat** from exhaust air; lowers energy bills*
- ***Better indoor air quality**: reduces buildup of carbon dioxide and radon levels, removes pollutants such as VOCs (from paints, furniture), allergens, and odors; maintains balanced indoor humidity levels.*
- ***Power electronics enabled smart control** and **easily pairing with PV** installation*



Temperature efficiency

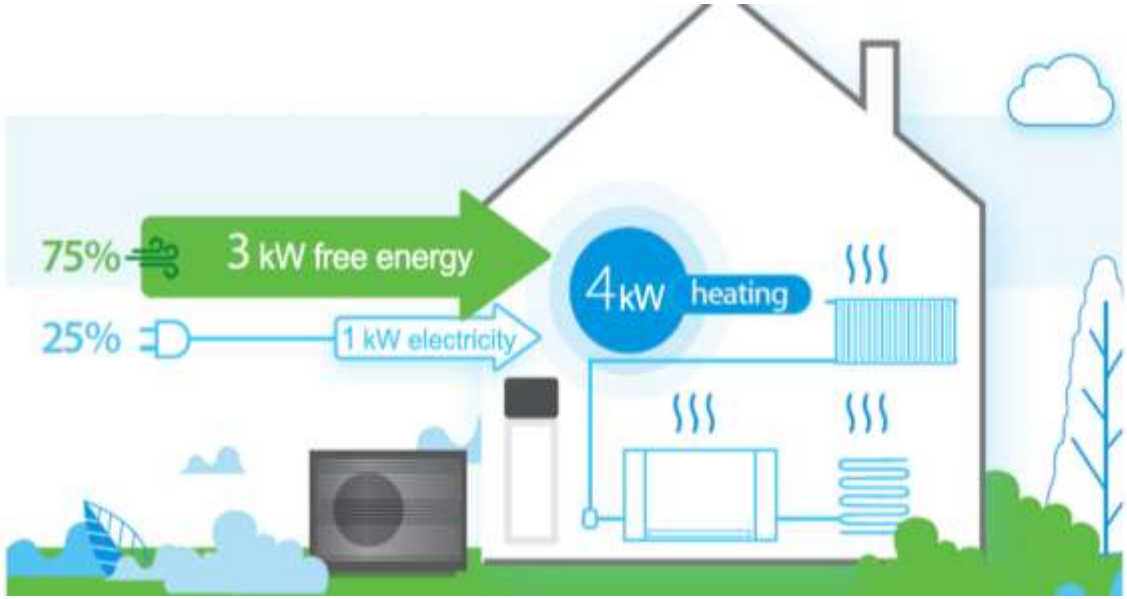
	Winter				
Outdoor temperature, °C	-23	-15	-10	-5	0
After heat exchanger, °C	15,6	16,7	17,4	18,1	18,9

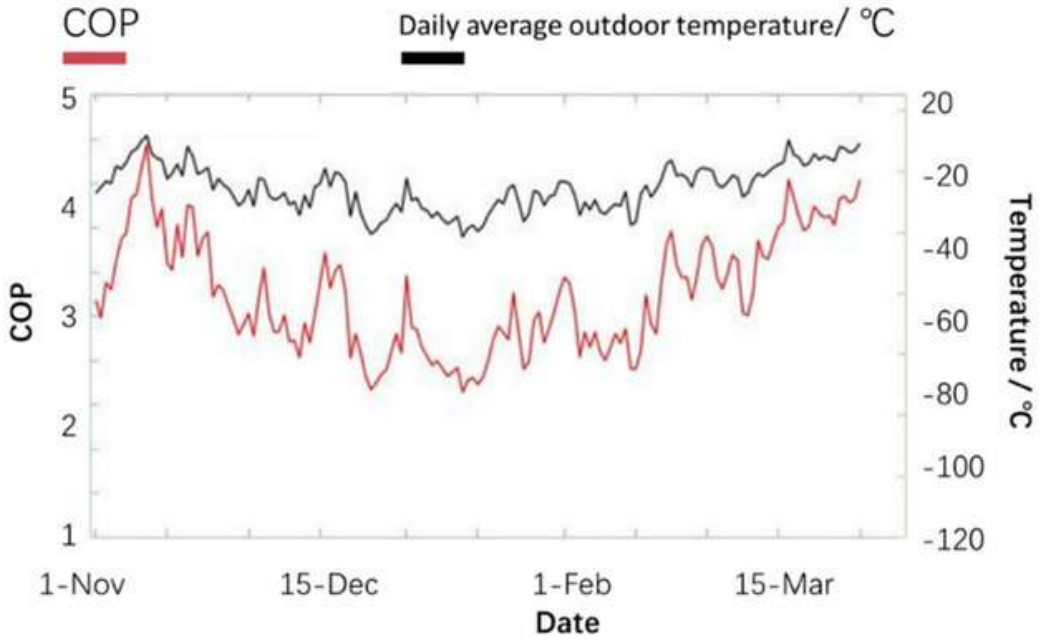
Indoor +22 °C, 20 % RH



ELECTRIFICATION OF HEATING WITH HEAT PUMPS

- ***Excellent energy efficiency**: can deliver up to 5 times more heat energy to a home than the electrical energy it consumes (see COP – Coefficient of Performance or SCOP – Seasonal Coefficient of Performance)*
- *Used for **space heating/cooling** and providing **domestic hot water** for showers and sinks*
- *Can be **easily paired with PV** installation*
- ***Power electronics enabled smart control** – heat pump can be operated as a **flexible and grid-responsive resource***



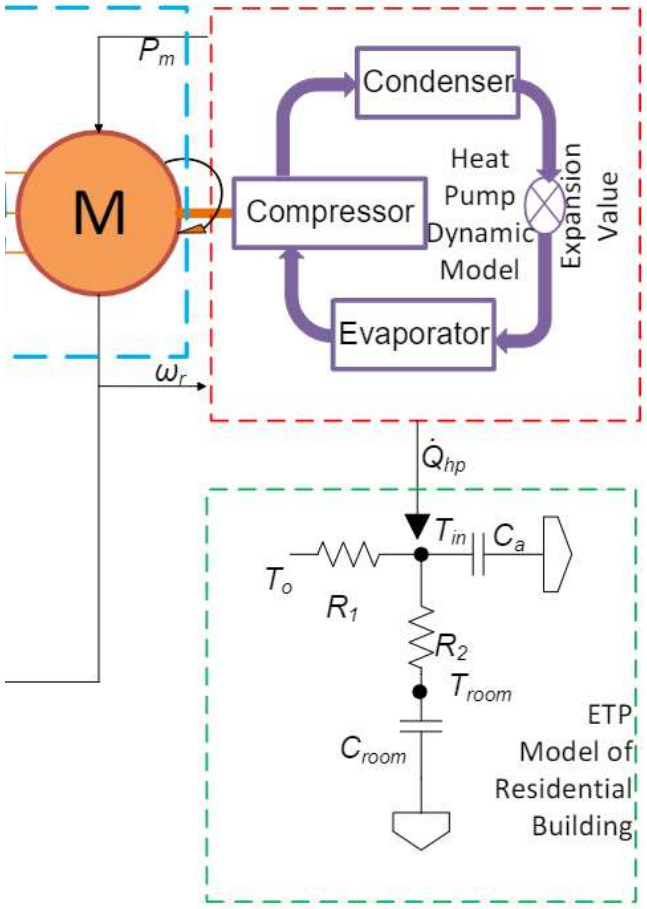


- Source: daikin.ie

HEAT PUMPS USE POWER ELECTRONICS



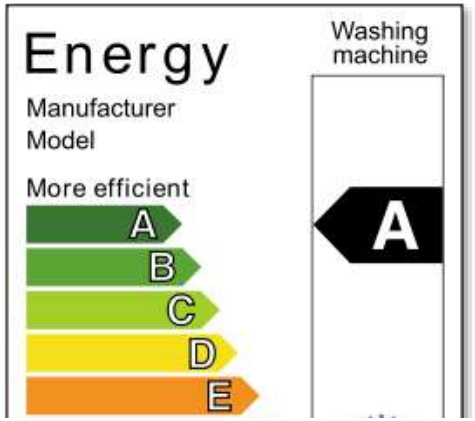
- Source: daikin.ie





CLASS-A ENERGY-EFFICIENT APPLIANCES

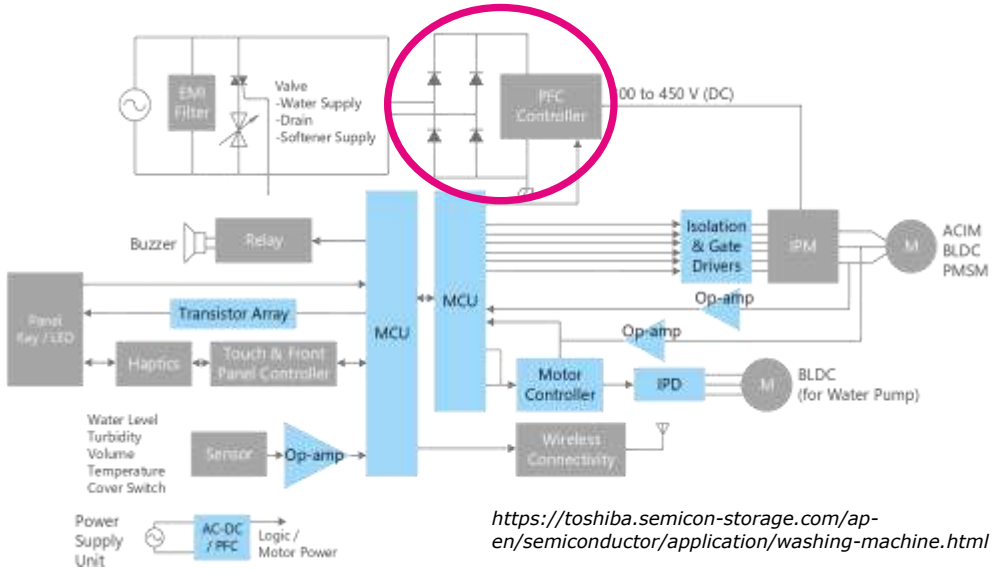
WASHING MACHINES, REFRIGERATORS, INDUCTION COOKTOPS, HEAT PUMPS, ETC.



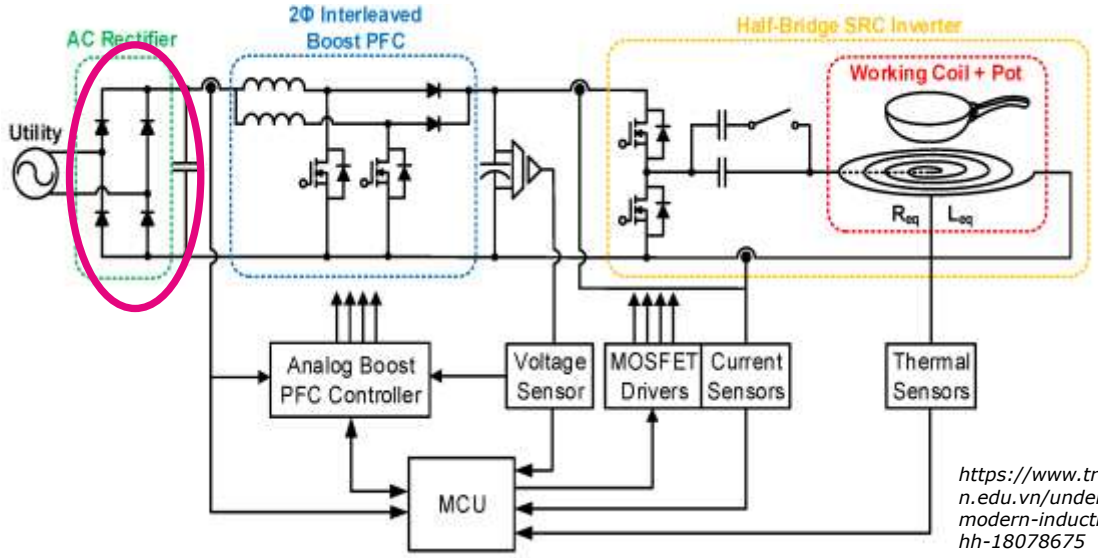




THEY ALL USE DIRECT CURRENT (DC) FOR OPERATION !!!



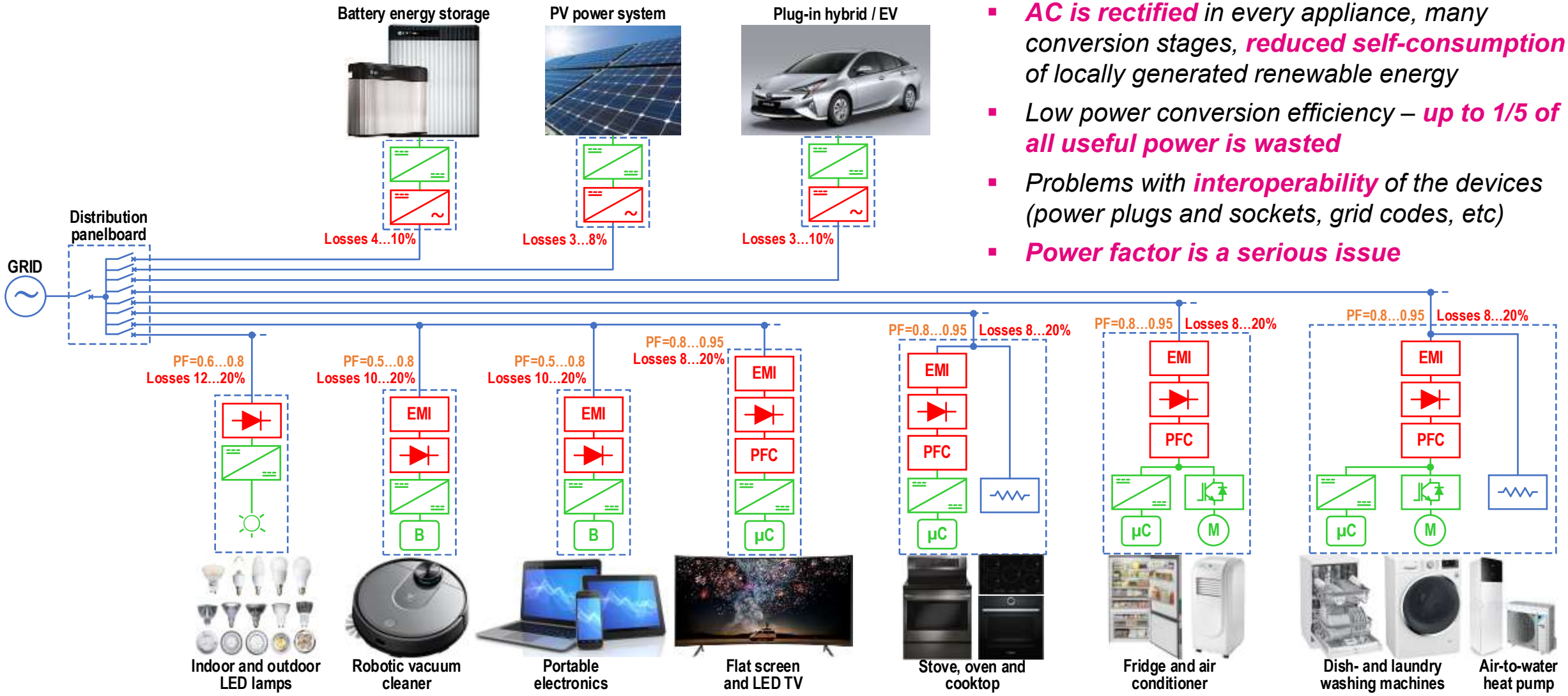
https://toshiba.semicon-storage.com/ap-en/semiconductor/application/washing-machine.html



https://www.truongquoctesaigon.edu.vn/understanding-how-modern-induction-cooker-work-hh-18078675

AC-BASED ELECTRICAL SYSTEM OF A ZEB TODAY

WE ARE LIVING IN A DC WORLD WITHOUT FULLY REALIZING ITS TRUE POTENTIAL !



- *AC is rectified in every appliance, many conversion stages, **reduced self-consumption** of locally generated renewable energy*
- *Low power conversion efficiency – **up to 1/5 of all useful power is wasted***
- *Problems with **interoperability** of the devices (power plugs and sockets, grid codes, etc)*
- ***Power factor is a serious issue***

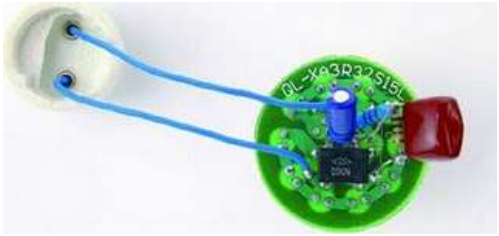
FULL-ELECTRIC LIFESTYLE WITH AC

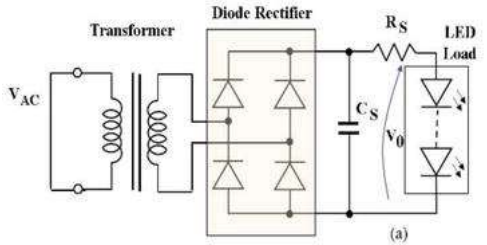
A CLOSER LOOK AT THE POWER FACTOR ISSUE

PFC stage is required only above 75W - energy efficiency is additionally affected by the non-unity power factor

GU10 LED bulb (4.3 W)





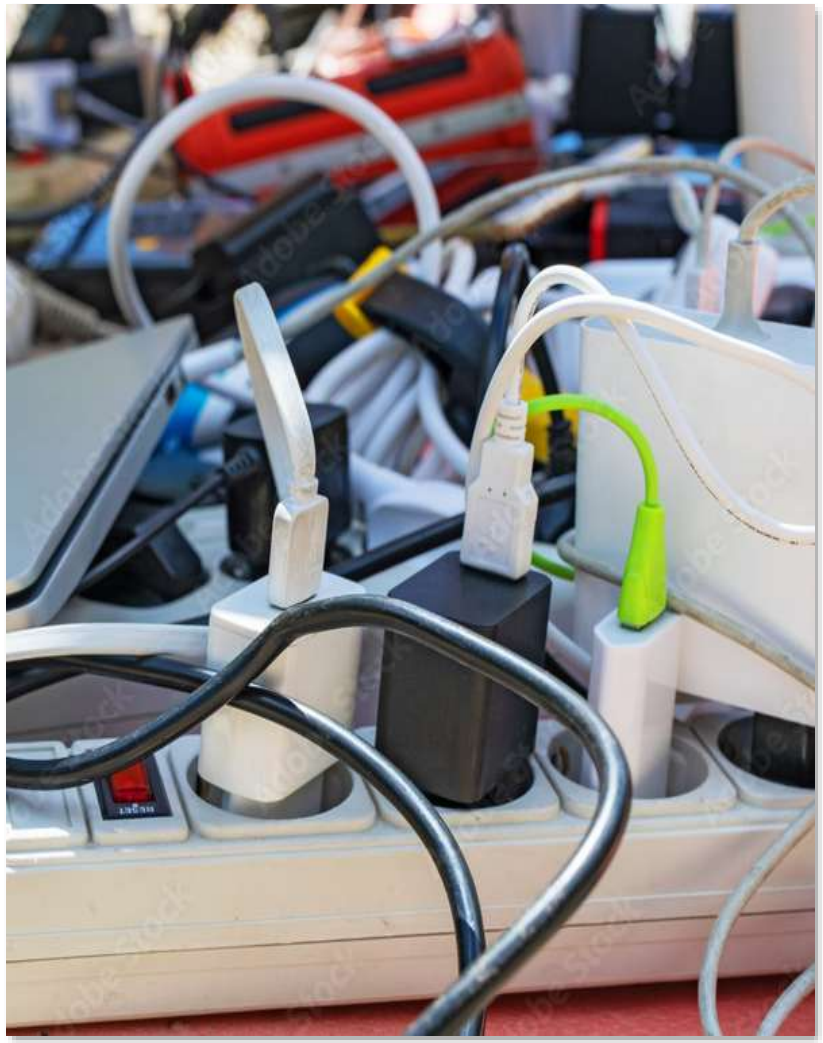


1	Urms	1	—	232.40	V
2	Irms	1	—	0.0337	A
3	P	1	—	4.33	W
4	S	1	—	7.83	VA
5	Q	1	—	6.52	var
6	Uthd	1	—	0.964	%
7	Ithd	1	—	74.420	%
8	PF	1	—	0.5534	

Laptop/Phone chargers (65 W)



No.	Function	Data	Units
1	Urms	232.37	V
2	Irms	0.5766	A
3	P	65.09	W
4	S	133.99	VA
5	Q	117.12	var
6	Uthd	1.122	%
7	Ithd	86.841	%
8	PF	0.4858	
9	Udc	19.243	V
10	Idc	-3.022	A
11	P	-58.16	W



FULL-ELECTRIC LIFESTYLE WITH AC

A CLOSER LOOK AT THE POWER FACTOR ISSUE

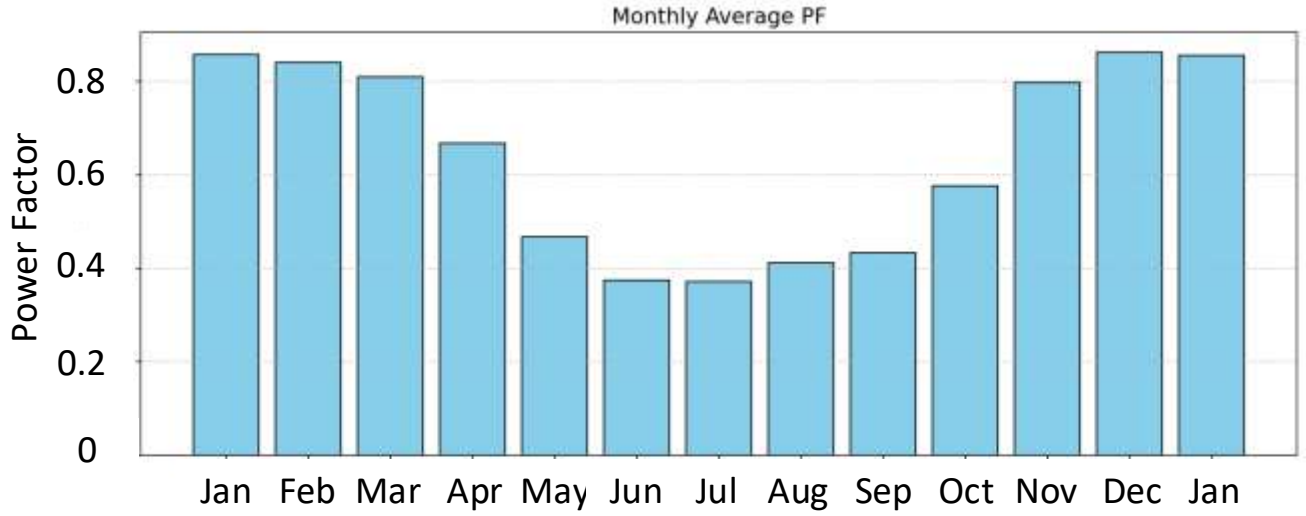
176.7 m² single-family detached home

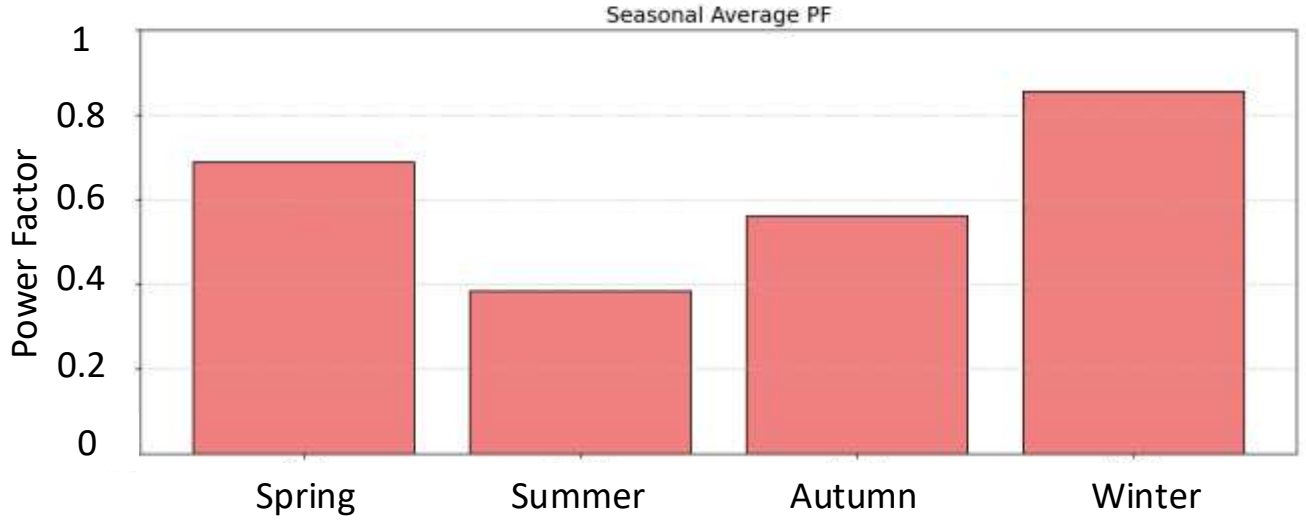






Location	*Estonia, Tallinn*
Total power of PV	*5 kWp*
Model of HP	*Thermia Atec HP 11*
Electric car	*BMW i3*
COP of HP	*COP 3.8 (+7/+45 °C)*
Habitants	*4*



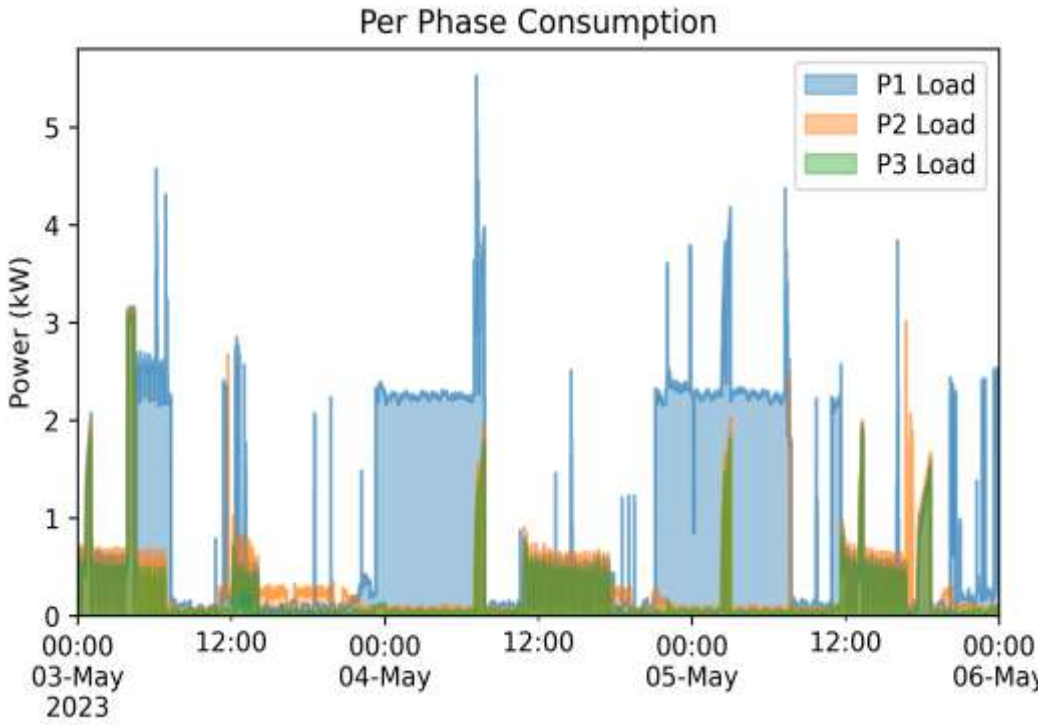


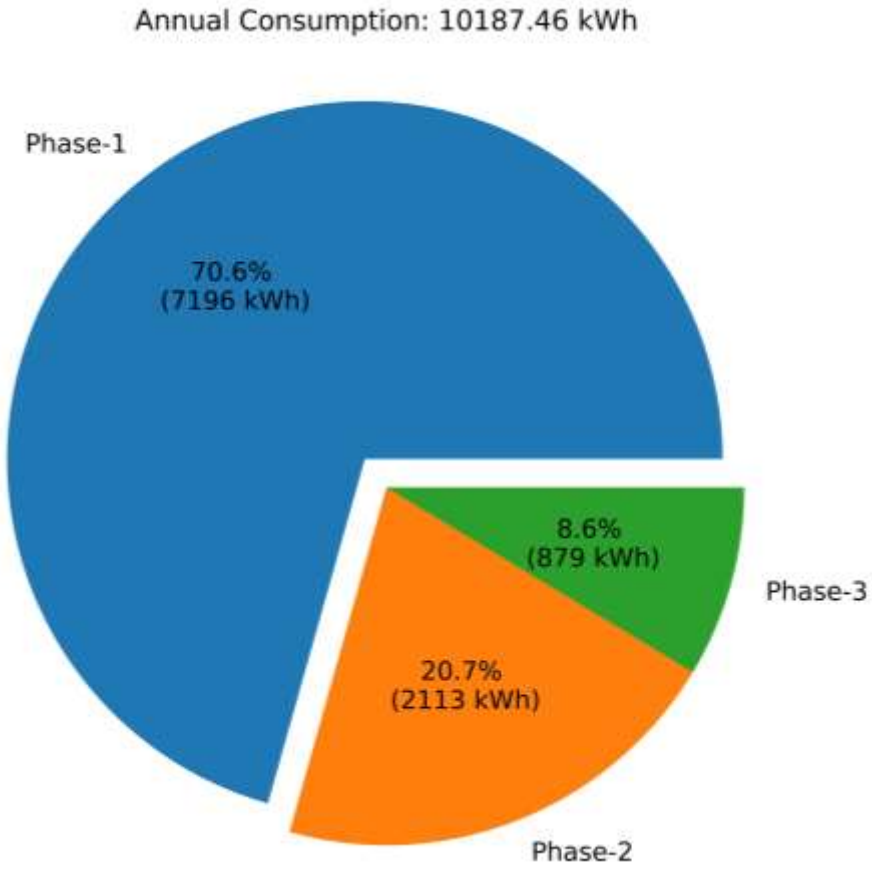
FULL-ELECTRIC LIFESTYLE WITH AC

A CLOSER LOOK AT THE PHASE LOAD IMBALANCE

Many residential (home) EV chargers have a single-phase grid connection with resulting negative impact on distribution transformers



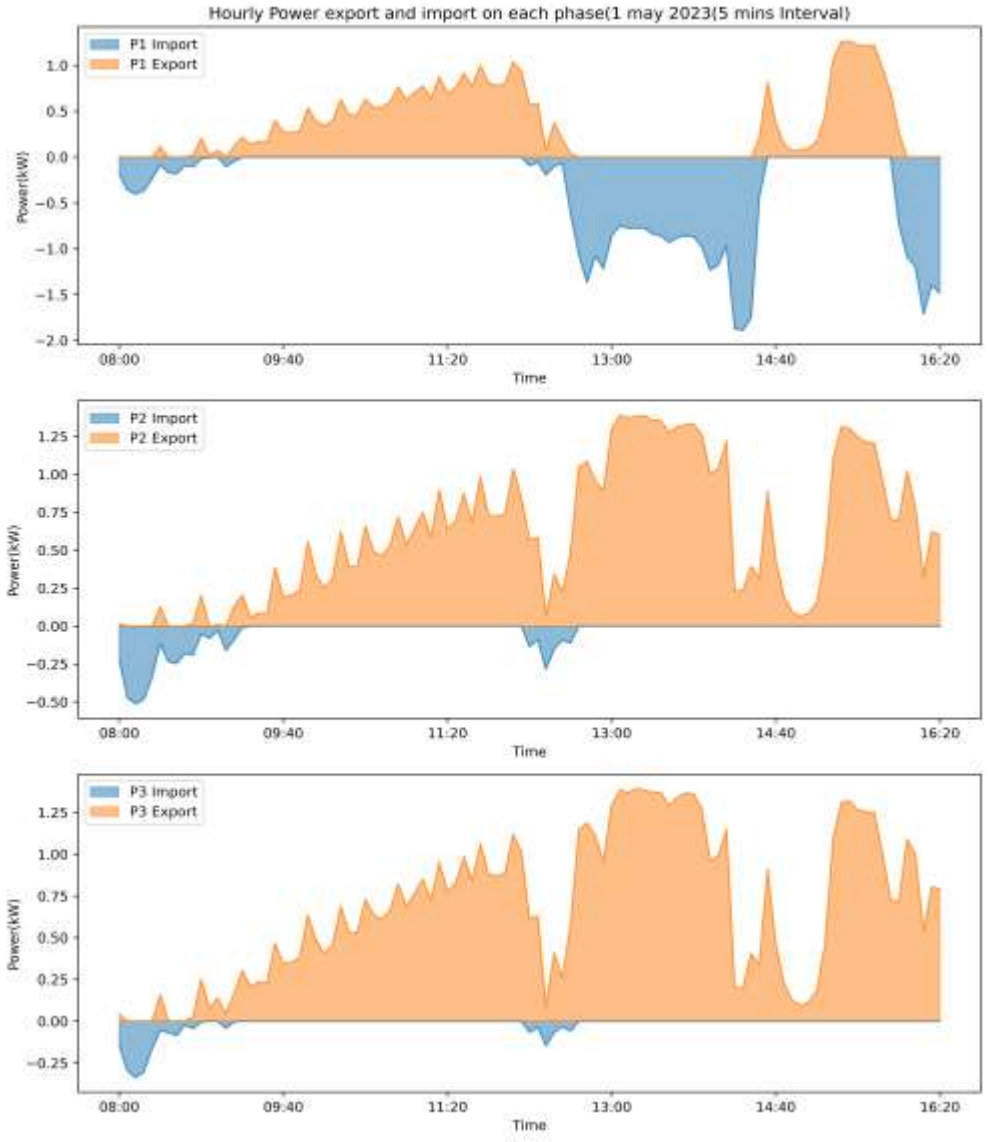


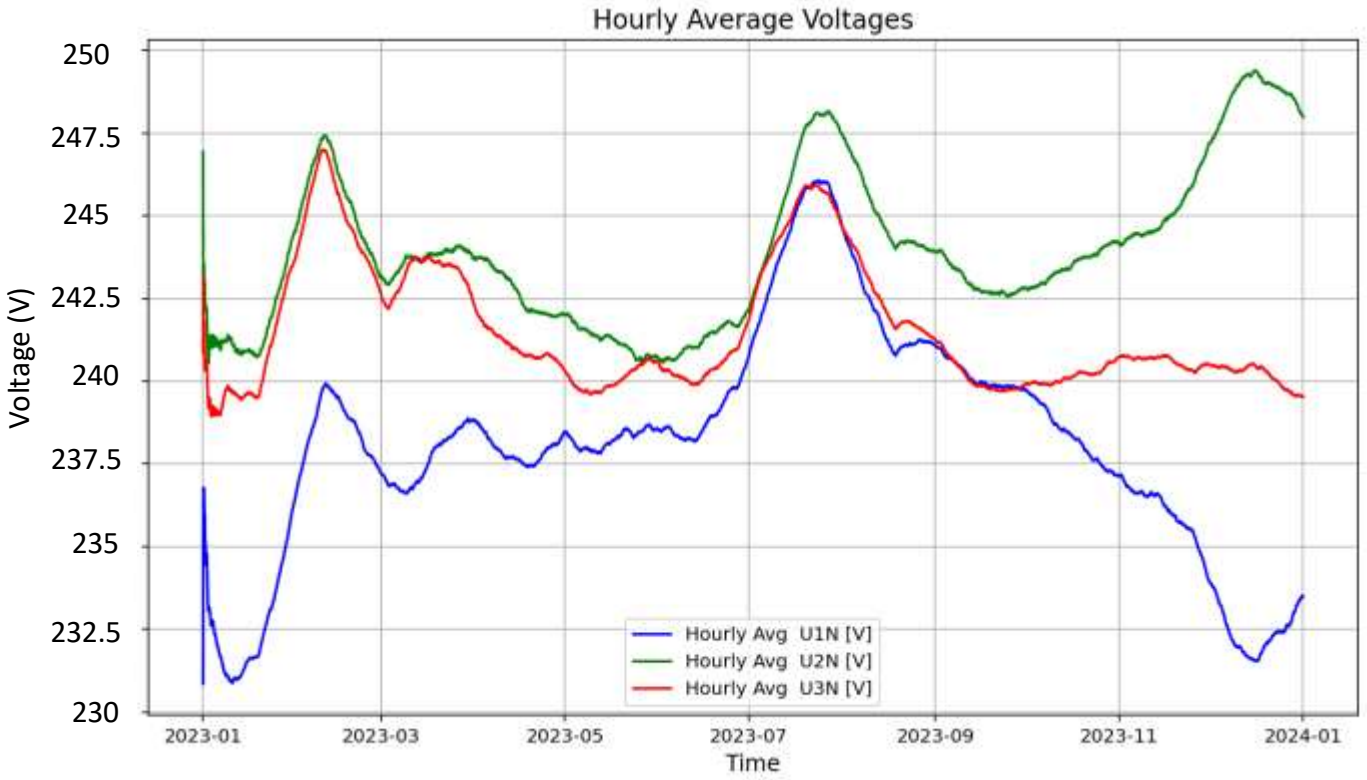


Hasan, S.; Blinov, A.; Chub, A.; Vinnikov, D. "PV Generation and Consumption Dataset of an Estonian Residential Dwelling", Dataset; DOI:10.48726/6hayh-x0h25 [Online]:https://data.taltech.ee/records/6hayh-x0h25

FULL-ELECTRIC LIFESTYLE WITH AC

ENERGY EXPORT/IMPORT BALANCE and VOLTAGE IMBALANCE ISSUES





Hasan, S.; Blinov, A.; Chub, A.; Vinnikov, D. "PV Generation and Consumption Dataset of an Estonian Residential Dwelling", Dataset; DOI:10.48726/6hayh-x0h25 [Online]:https://data.taltech.ee/records/6hayh-x0h25

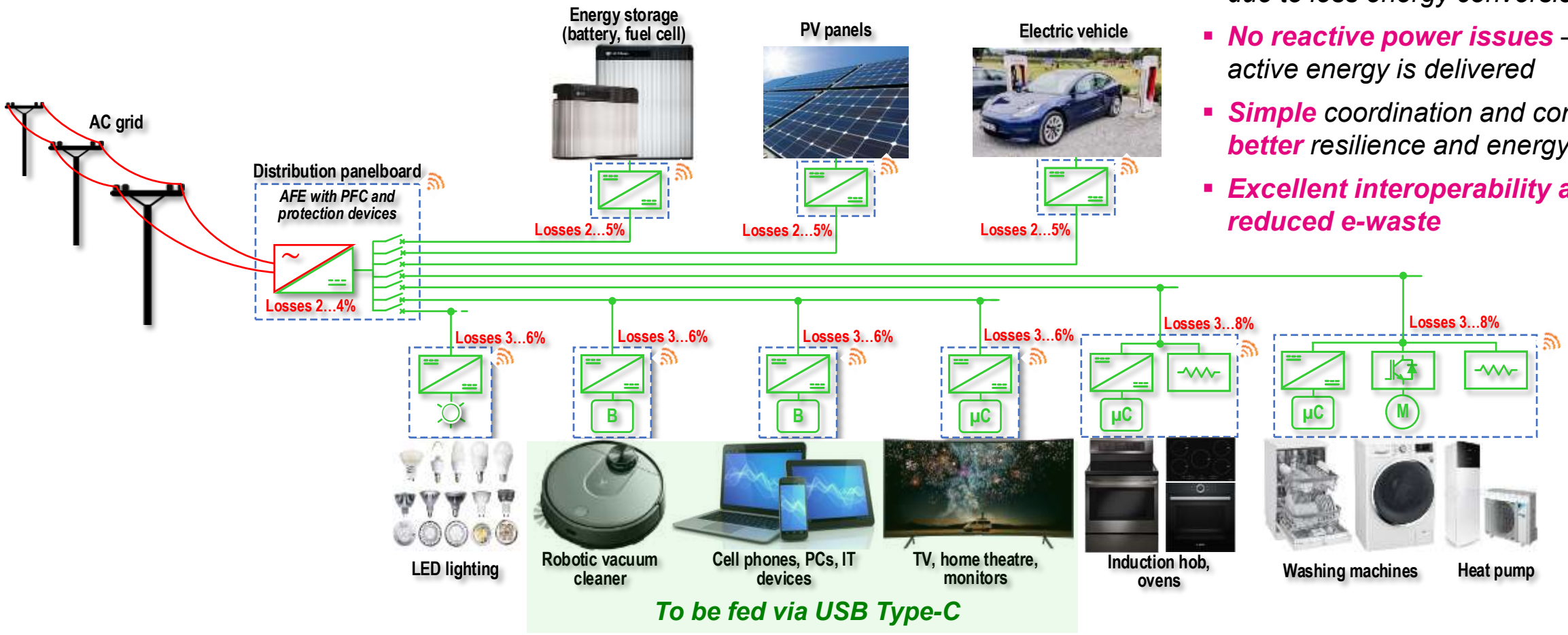
FULL-ELECTRIC LIFESTYLE WITH AC




Every problem has a solution😀😀

NEXT-GEN ELECTRICAL SYSTEM OF A ZEB

DC POWER DISTRIBUTION AND DC-FED APPLIANCES



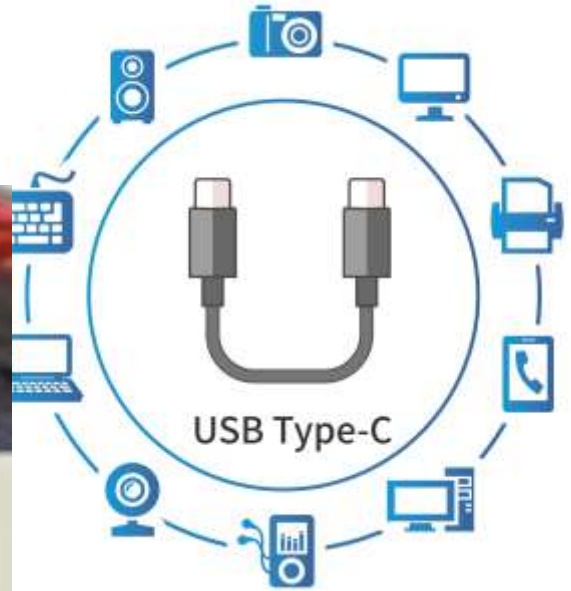
- ***Increased*** *efficiency and* ***maximized*** *self-consumption of renewable energy due to less energy conversion stages*
- ***No reactive power issues*** *– only active energy is delivered*
- ***Simple*** *coordination and control,* ***better*** *resilience and energy security*
- ***Excellent interoperability and reduced e-waste***

TAL TECH

USB TYPE-C IS THE FIRST STEP TOWARD ENERGY-EFFICIENT AND INTEROPERABLE DC POWER DISTRIBUTION

*Starting from 2025 the **USB Type-C became the common charging standard for small electronic devices in the EU**. Laptops will have to be equipped with a USB Type-C port by 28 April 2026.*

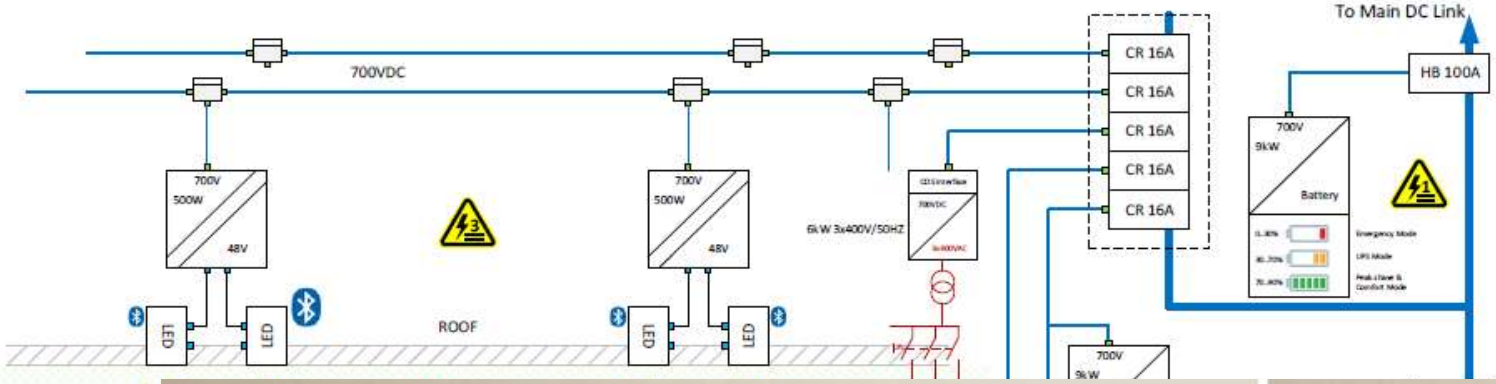


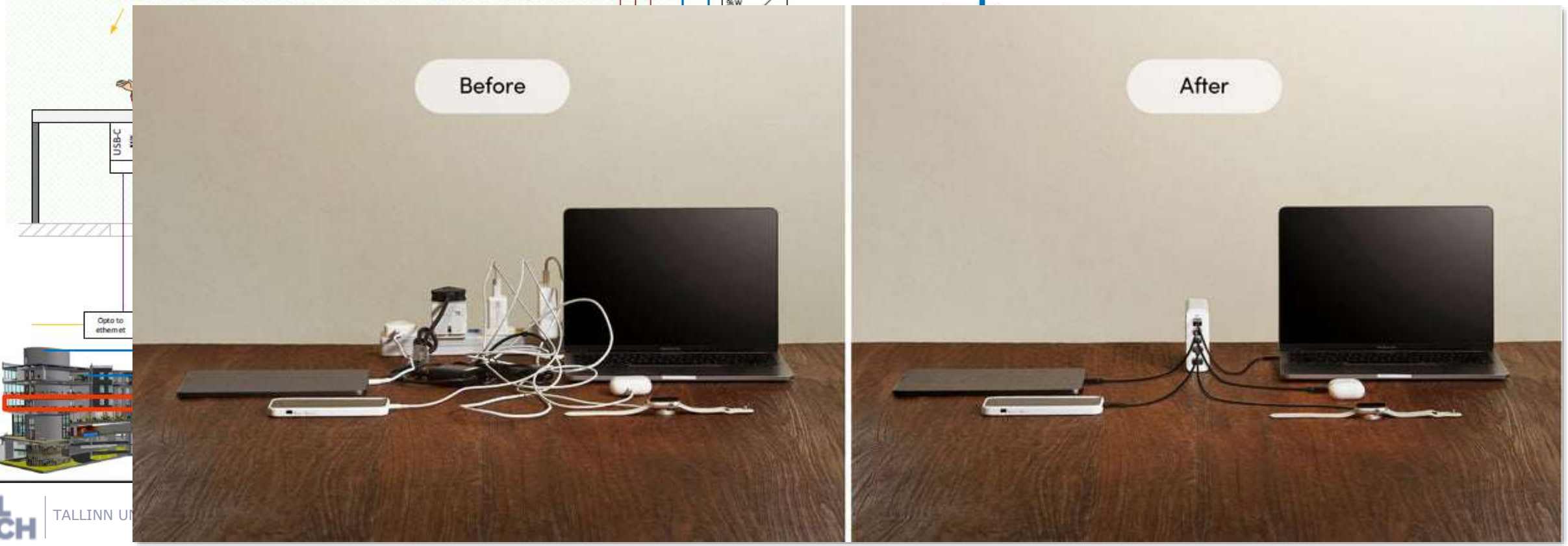




ENERGY NEUTRAL DC WORKSPACE







HISTORICAL CHOICE: FROM 230 VAC TO 350 VDC

- *The **LVDC** power distribution concept was proposed by **DC Systems** and implemented in Dutch standardization in **2018** (NPR9090 - Dutch Practical Guideline for the installations up to 1500 V DC)*
- *Starting **from 2021** the concept is continuously developed, improved and showcased by **Current/OS Foundation***
- ***350 VDC** is considered as a substitute for 230 VAC and **700 VDC** for 3x400 VAC**
- *Residential DC installations can be realized either with a **unipolar** or **bipolar architectures***
- ***Droop control** based power management, where voltage is used as a shared signal that reflects the power availability. The installation is **self-regulating** featuring excellent **resilience*****
- *Residential DC installations require ultrafast **solid-state circuit breakers (SSCB)** with tripping times less than **10 µs**. In combination with **residual current detection** and **arc fault mitigation** the SSCBs help eliminating safety concerns associated with DC and ensure **ultimate safety** of residents and property*

* https://currentos.org/technical-rules/

** Current/OS Distributed Electrical System: Droop Control Explained (https://www.youtube.com/@Current-OS)

BENEFITS OF DC OVER AC IN HOUSEHOLDS*

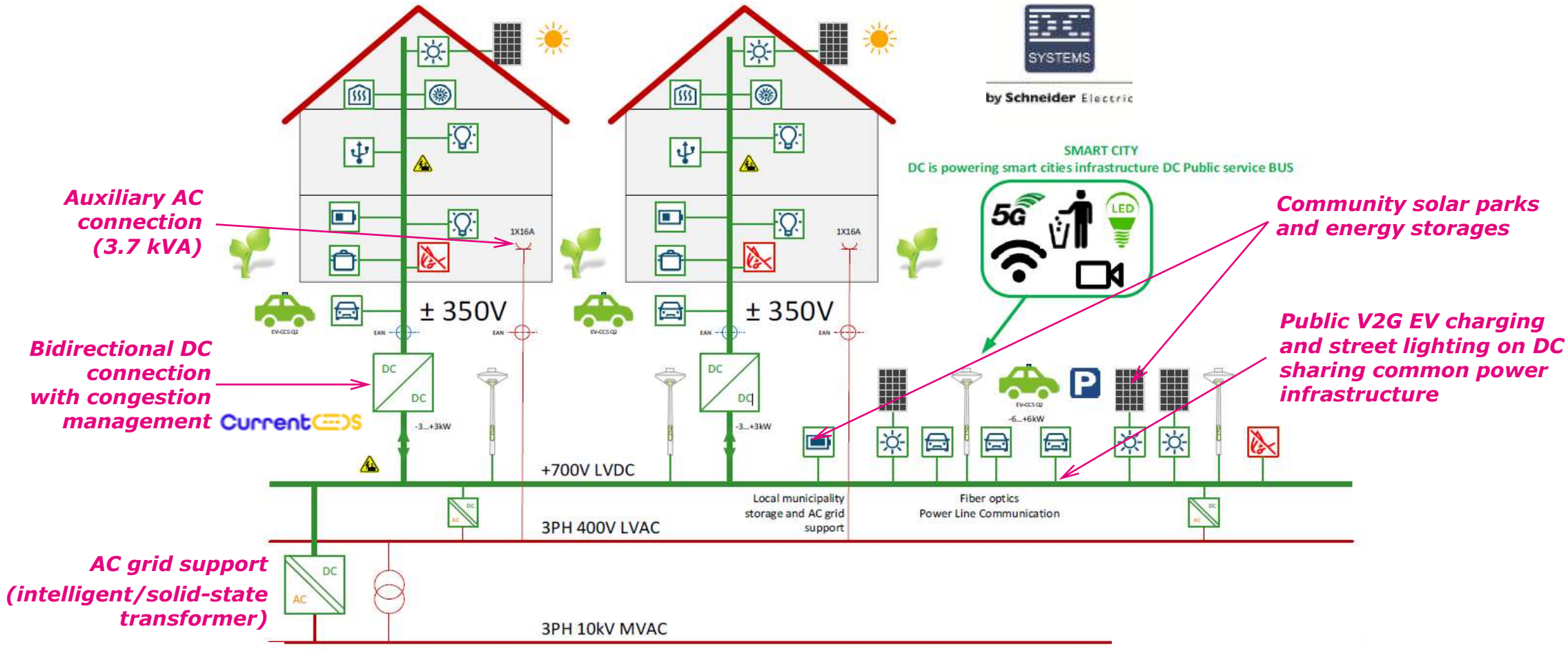
DC OPENS A NEW DIMENSION IN ENERGY PERFORMANCE OF BUILDINGS

- ***100% power electronics enabled*** *technology with ultimate control flexibility, efficiency, power density and reliability*
- *Up to* ***35% power loss reduction*** *due to more efficient power conversion and distribution and better utilization of the local renewable energy (solar photovoltaics, battery energy storage and heat pump)*
- *Up to* ***55% reduction*** *in distribution cabling mass (copper or aluminum)*
- *Up to* ***85% reduction*** *in the required connection capacity to the AC distribution grid*
- *Up to* ***20% reduction*** *in lifecycle costs when a building is fully converted to DC*
- *Easy implementation of* ***Vehicle-to-Home (V2H)*** *and* ***Vehicle-to-Grid (V2G)*** *technologies*
- ***Resilient*** *power supply during blackouts with possibility to support grid stability (power consumption curtailment, phase balancing, etc.)*

** EU Strategic Energy Technology Plan (implementation working group on DC technologies, subgroup on LVDC), September 12, 2024*

DC ELECTRIFICATION OF NEIGHBOURHOODS

DC enables new revenue streams *for homeowners from participation in energy services and collective initiatives (EaaS, VPPaaS, energy communities, energy hubs, etc.)*



MAIN CHALLENGES OF DC TODAY

- *Lack of international standardization and certification schemes*
- *Lack of market-ready power electronic systems and appliances*
- *Lack of public awareness and technology demonstration*

General Motors EV1 (1996)



Tesla Model S (2012)



CurrentOS

Defining Standards for DC Microgrids

- **Global DC partnership**
- **Member of IEC SyC LVDC**
- **100+ partners** to date, more joining every month
- **25 countries represented in**
  - North America
  - Europe
  - Asia
- **Universities join for free**
- **https://currentos.org**

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Universities

inesc id lisboa, JUNIA, Northeastern University, Politecnico Milano 1863, RWTH Aachen University, TAL TECH, TU Delft, Technische Universität Ilmenau, UNINOVA, Université de La Réunion, University of Strathclyde Glasgow, Universität Stuttgart

Certification

DAMSTRALAB, DEKRA, INESCTEC, intertek, NMi

Trade Goups

BSRIA, DG4SC, Merge Alliance, europacable, GIMELEC, VOLTA, Stichting Gelijkspanning Nederland

350 VDC TECHNOLOGY IS VERY FAST DEVELOPING

RECENTLY IS A TECHNOLOGY VALIDATION AND DEMONSTRATION PHASE (2020-2030)

- *Big players (Schneider Electric, EATON, ABB, etc.) strongly support the technology development and innovation*
- *Solid state circuit breakers (DC Systems B.V., Blixt, DC Opportunities B.V.)*
- *USB-C PD (power delivery) 100 W wall socket outlet (DC Systems B.V.)*
- *Public light LED drivers (DC Systems B.V., Tridonic)*
- *Induction cooktop (ATAG Benelux)*
- *Hood fan (ATAG Benelux)*
- *Refrigerator (ATAG Benelux)*
- *Heat pumps (NRGtec)*
- *Under development: coffee machine, oven, microwave, washing machines, etc.*



DC TECHNOLOGY DEMONSTRATION FACILITIES (1)

DIRECT CURRENT EXPERIENCE CENTER (AALSMEER, NL)

SYSTEMS

by Schneider Electric

- DC-powered office setups;
- Energy recovering industrial automation equipment,
- Solar technology;
- EV charging and more.











Book your visit via email: experience.center@dc.systems

DC TECHNOLOGY DEMONSTRATION FACILITIES (2)

DC OPPORTUNITIES DEMO FACILITY IN GREEN VILLAGE (DELFT, NL)







DCpportunities

https://dc-opportunities.com/dcmicrogrids/meshed-350-700v-dc-microgrid-at-the-green-village/

DC TECHNOLOGY DEMONSTRATION FACILITIES (3)

TALTECH RESIDENTIAL DC INNOVATION HUB (TALLINN, ESTONIA)

TAL TECH

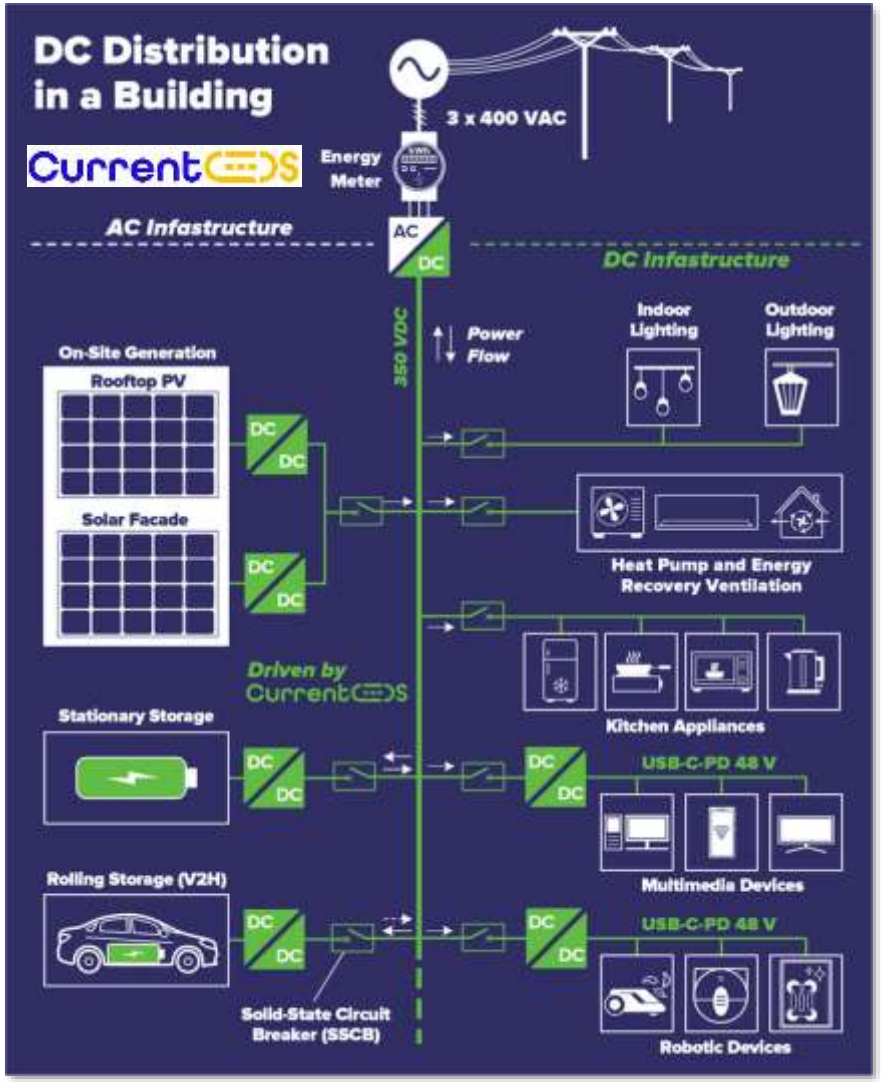
OFFICIAL PARTNER

Shift2DC

SmartGY SUM

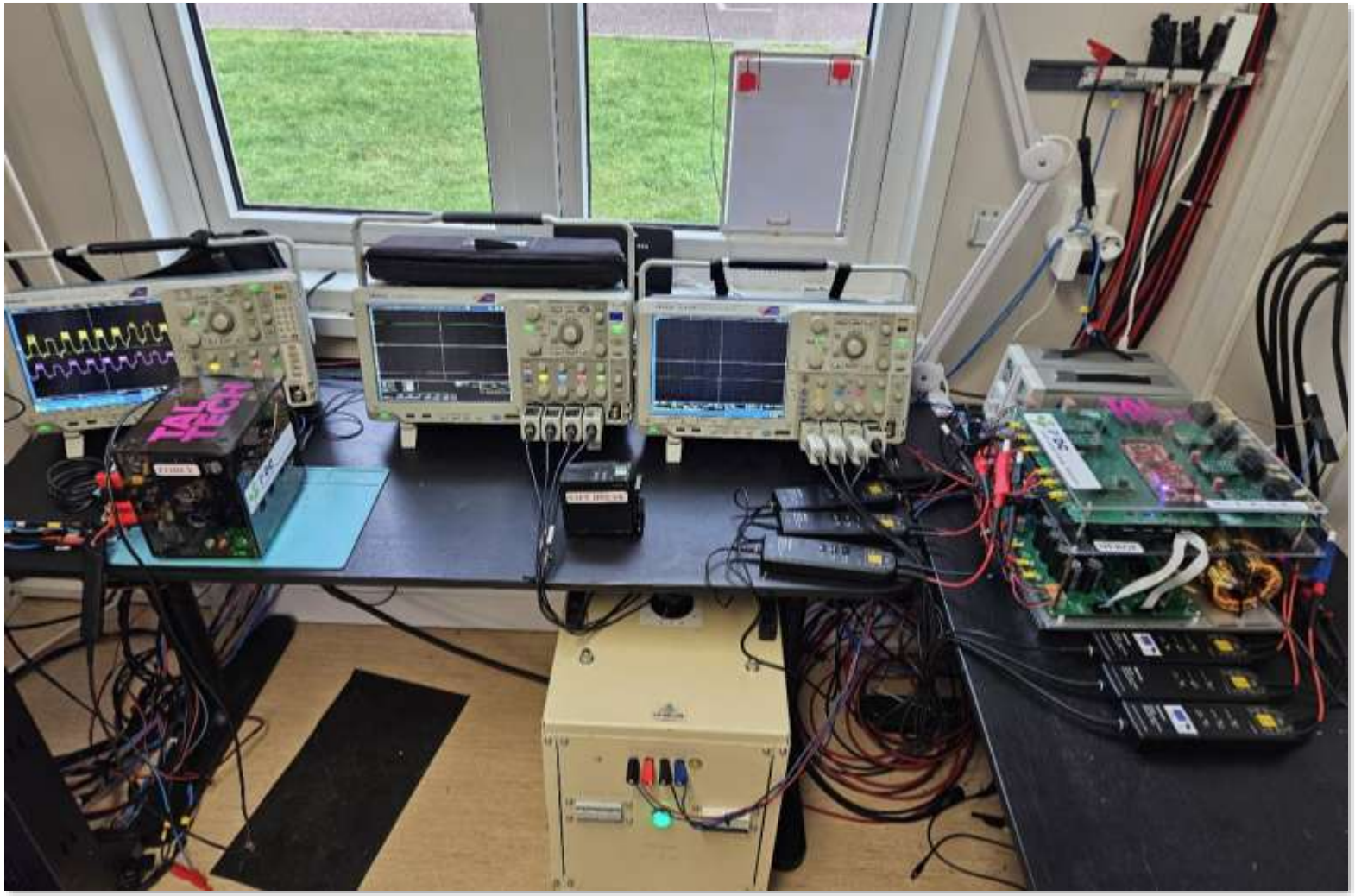






Book your visit via email at: i3dc@taltech.ee

OUR NOVEL TECHNOLOGIES UNDER TEST IN DC INNOHUB





SAFEBREAK



MERGE



FORCE



FlexiVerter

2025-27: EXPANSION, NEW PARTNERS AND R&D TOPICS





SOLARSTONE AIROBOT

DAIKIN TRIDONIC CAFA

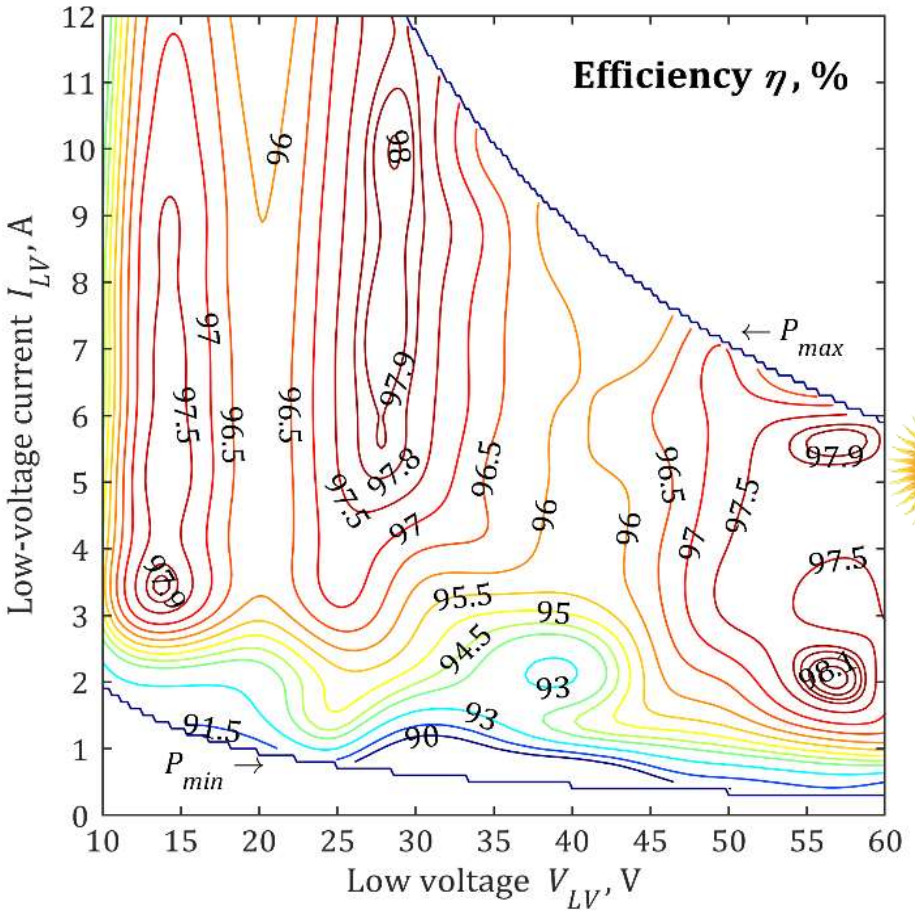


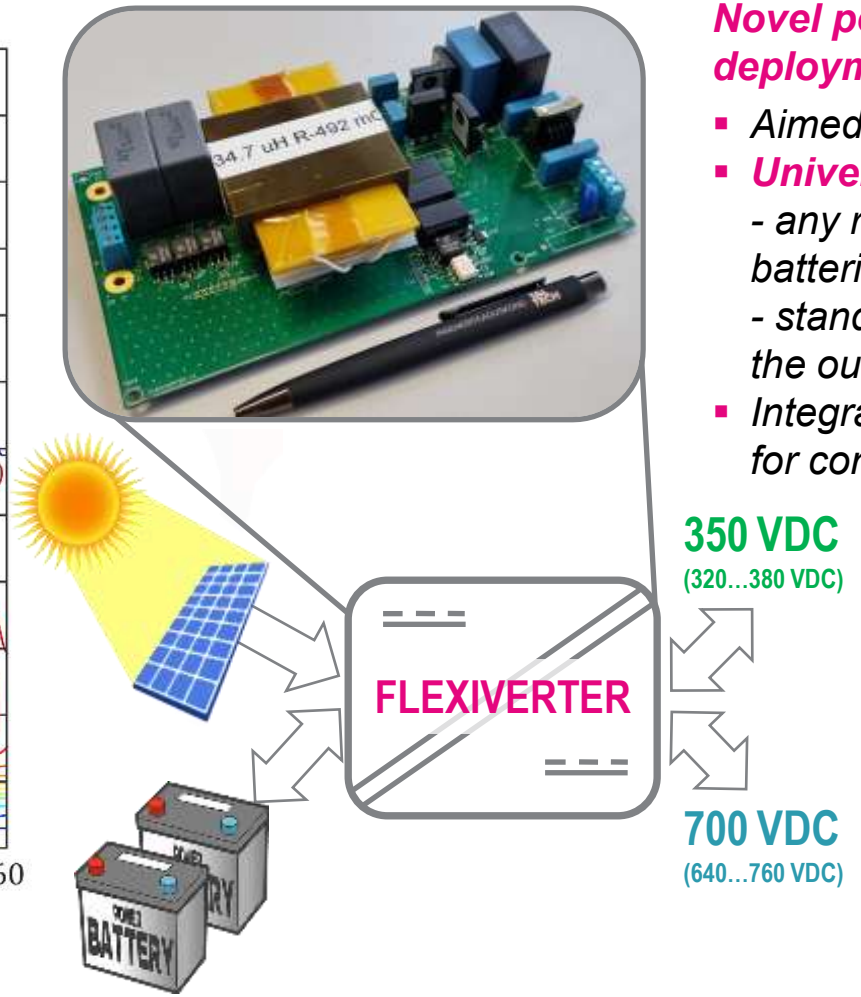
NEW R&D DIRECTIONS AND DC DEMOS

- *Droop-controlled residential DC HVAC systems*
- *Droop-controlled DC appliances and lighting systems*
- *DC neighbourhoods*
- *Urban DC infrastructure, incl. DC streetlighting microgrids*
- *Use of DC in defence-tech and disaster relief applications*

FLEXIVERTER – FLEXIble conVERTER

Power electronics "LEGO" for DC prosumer homes





Novel power electronic building block for fast deployment of residential DC microgrids:

- *Aimed at nano-producers (<800W)*
- ***Universal compatibility:***
  - any residential PV module and 24V or 48V batteries at the input
  - standard 350±30V or 700±60V microgrid at the output
- *Integrated soft-start and solid-state protection for compatibility with **CurrentOS** protocol*

Features:

- *Peak efficiency **>98%***
- *Input source type **identification***
- *DC microgrid ready – **droop control** for battery and **power clipping** for PV*
- ***Global** maximum power point tracking verified*
- ***Integrated** design*
- *Generic **off-the-shelf components** used*

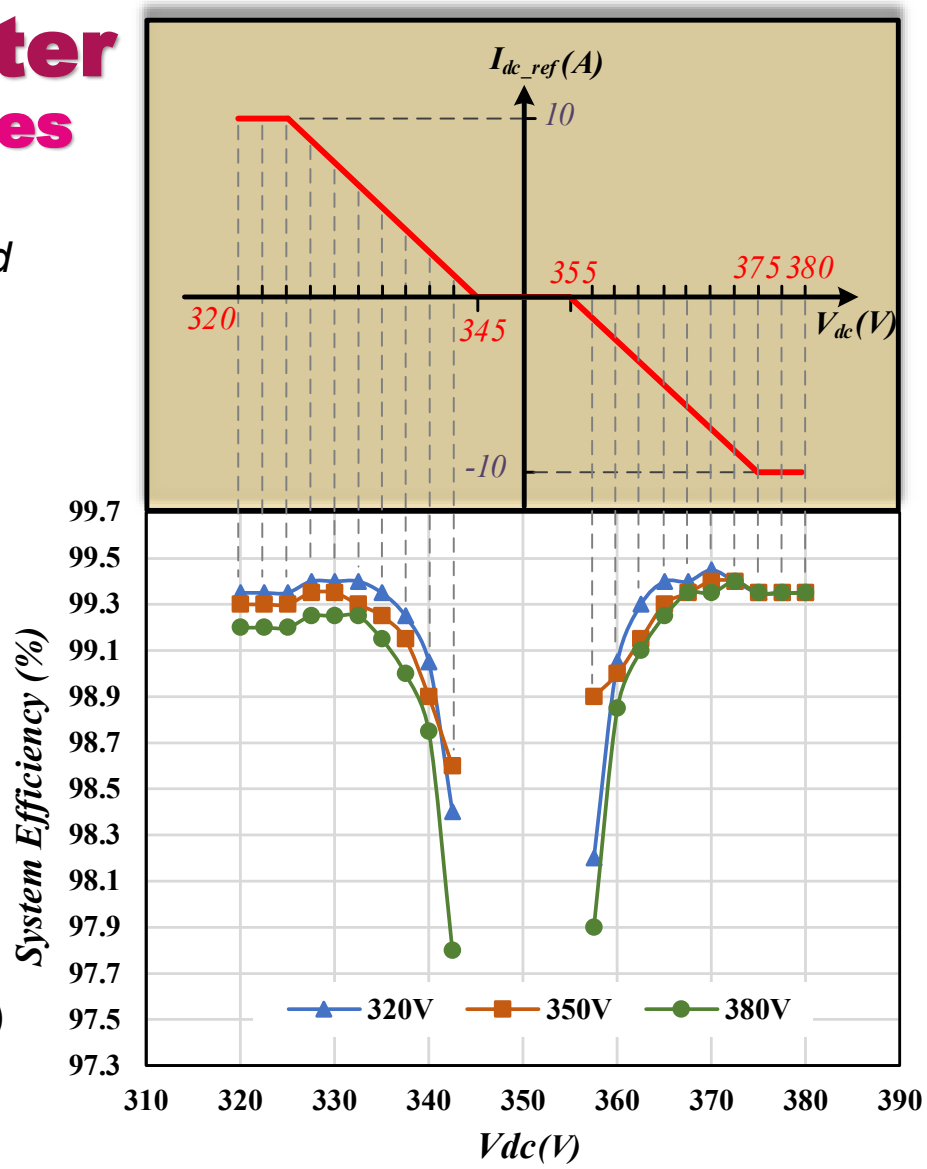
V. Sidorov, A. Chub, D. Vinnikov and A. Lindvest, "Novel Universal Power Electronic Interface for Integration of PV Modules and Battery Energy Storages in Residential DC Microgrids," in IEEE Access, vol. 11, pp. 30845-30858, 2023.

FORCE – Fractional pOweR ConvErter

For efficient integration of second-life batteries



- *Ultra-efficient – **over 99%** for 25%+ load*
- *Optimized for **350±30V** residential DC microgrids*
- *Designed for **second-life** LFP battery stack of 109 cells, approx. capacity ~8 kWh (depends on degradation)*
- ***Patented control** with soft-switching in the entire range*
- ***Soft-start** and embedded solid-state **protection** for compatibility with **CurrentOS** DC microgrid protocol*
- ***Low stress** on components*
- *Ready for emerging bidirectional **monolithic GaN switches** (by Infineon)*

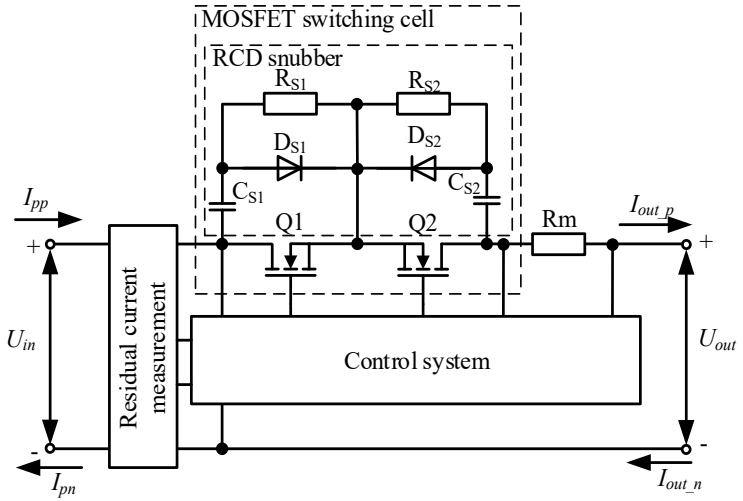


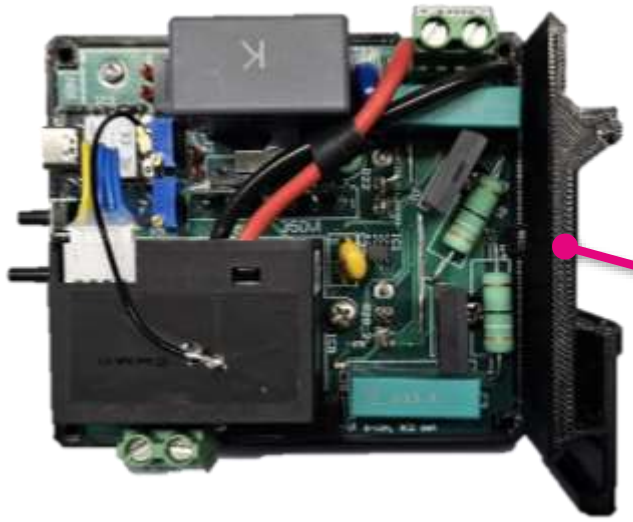
N. Hassanpour, A. Chub, A. Blinov and D. Vinnikov, "Soft-Switching Bidirectional Step-Up/Down Partial Power Converter with Reduced Components Stress," in IEEE Transactions on Power Electronics, vol. 38, no. 11, pp. 14166-14177, Nov. 2023.

SAFEBREAK – SAfe and Fast DC Electronic BREAKer

Multifunctional SSCB for residential prosumer DC nanogrids

- *Optimized for **350 VDC/16A** residential applications*
- *Utilizes SiC JFETs for **low R_{DSon}**, efficiency **99.8% @ 16A***
- ***Fast speed** – short circuit detected within 10 µs*
- *Min. voltage: 100 VDC*
- *Max. input voltage: 440 VDC (overvoltage protection at 380 VDC)*
- *Contains **residual current sensor** for ultimate safety*
- *Max. allowed residual current: 6 mA*
- ***Bidirectional operation** (prosumer-ready)*
- ***Connectivity**: WiFi, USB. **Telemetry**: current, voltage, faults*
- *MQTT smart connection to **Energy Management System***







DEVELOPMENTS IN PROGRESS

MERGE: Smart energy gateway for integration of DC homes to AC grid

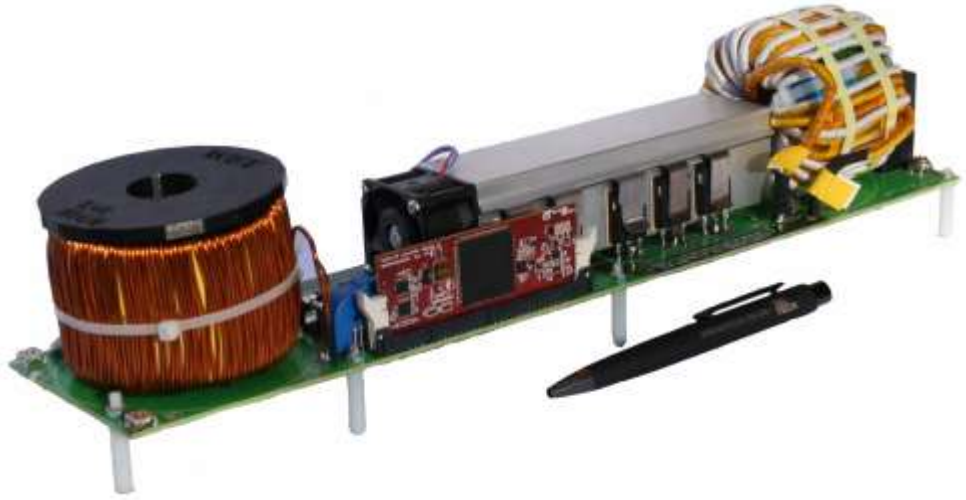
- *Bidirectional power router for prosumer DC buildings*
- *High-frequency galvanic isolation*
- *Input 230/400 VAC, output 350 VDC, 5…10 kW*
- *Droop control according to Current/OS*
- *Efficiency curve optimized for part-load operation based on statistical data (>97 %)*
- *Possible multi-port configuration with USB-PD output*



E. L. Carvalho et al. "Design Considerations of Dual-Active Bridge DC Grid-Forming Converter for DC Buildings," in IEEE Trans. on Ind. Electronics, vol. 71, no. 9, pp. 10601-10611, Sept. 2024

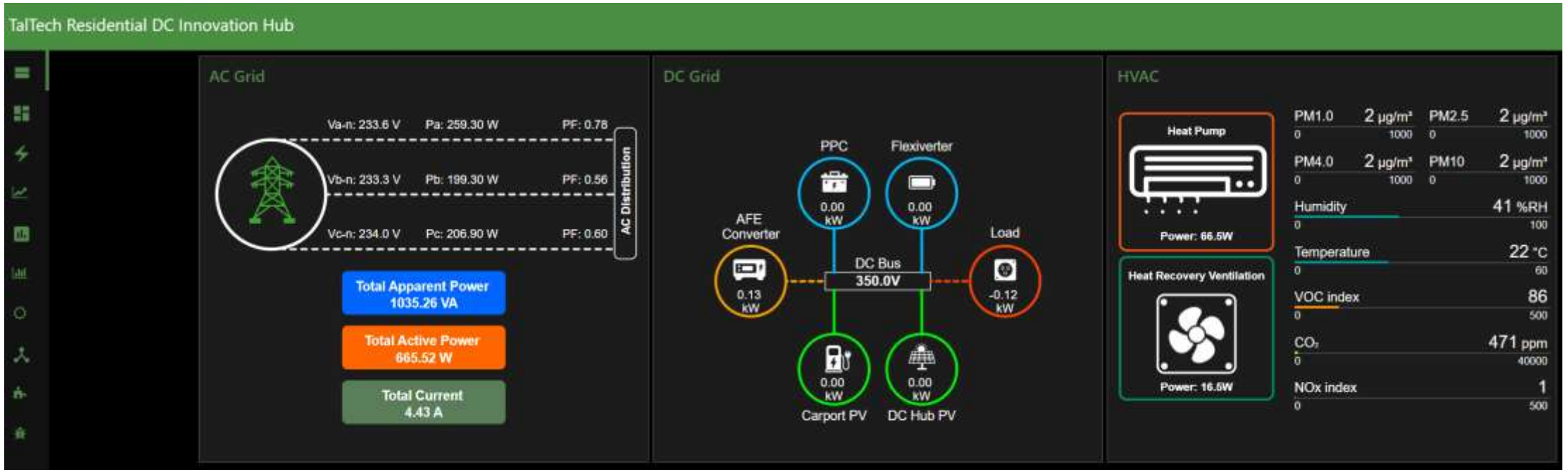
UbiCharge: Ubiquitous low-power EV opportunity Charger

- *Charges EV and employs energy stored in it for the emergency backup power supply of ZEB*
- *High-frequency galvanic isolation*
- *Power 3…7.4 kVA, universal EV-side range of 100…1000 VDC*
- *Droop controlled according to Current/OS (in emergency bands)*
- *High weighted efficiency of >97%*
- *Low-cost single-stage design*



D. Zinchenko et al. "High-Efficiency Single-Stage On-Board Charger for Electrical Vehicles," in IEEE Transactions on Vehicular Technology, vol. 70, no. 12, pp. 12581-12592, Dec. 2021

LIVE TELEMETRY: HTTPS://DCINNOHUB.COM/



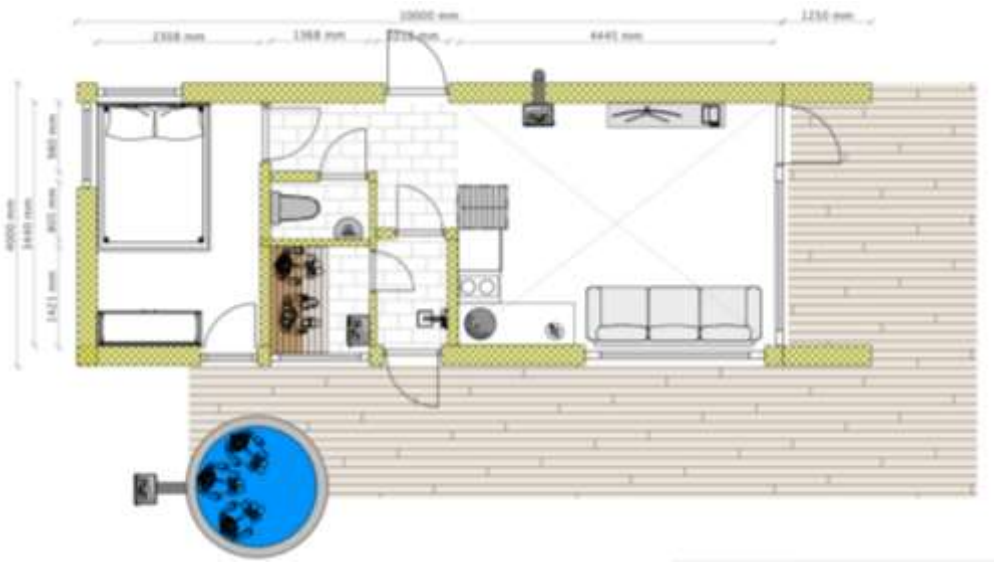




OUR UPCOMING DC TECHNOLOGY SHOWCASE (2030)

A+ GRID-INTERACTIVE PREFAB DC HOUSE







i³ DC Accelerates Energy Transition

CurrentDS

TRIDONIC Green Cube

DAIKIN AIROBOT SOLARSTONE

TAL TECH | TALLINN UNIVERSITY OF TECHNOLOGY

OUR UPCOMING DC TECHNOLOGY SHOWCASE (2030)

A+ GRID-INTERACTIVE PREFAB DC HOUSE





i³ DC Accelerates Energy Transition

CurrentC

TAL TECH | TALLINN UNIVERSITY OF TECHNOLOGY

i^3 DC INITIATIVE: *i*nform *i*nspire & *i*nnovate



The 7th Estonian DC Innovation workshop will take place in TalTech on December 3, 2026. Stay tuned!!!



TALTECH STUDENT DC CLUB (Est. 2025)

- *An initiative connecting TalTech BSc and MSc students interested in developing and commercialization of future-proof droop-controlled residential power electronic systems and appliances*
- ***2026:** 3 BSc, 5 MSc, 2 PhD students+ mentorid*
- *Developed and showcased in June 2026: residential SSCB, residential DC energy storage system based on second-life EV battery (SecondSpark), universal LED driver (AdaLED) etc.*



TALTECH STUDENT DC CLUB (Est. 2025)

- *Organization of TalTech DC Experience Day (beginning of June) and DC Picnic with showcasing of latest developments and innovations*





USB-C PD Hub



Smart DC SSCB (SafeBreak)



DC Kettle

TALTECH STUDENT DC CLUB: SECONDSPARK





PEMC 2026 IN TALLINN – BE PART OF IT!

THE 22ND IEEE POWER ELECTRONICS AND MOTION CONTROL CONFERENCE (PEMC2026) – September 23-25, 2026

CO-SPONSORED BY THE IEEE IES and IAS

Features:

- *Highly relevant program on power electronics, controls, electrical drives, robotics and their industrial applications*
- *230 registered attendees, 160 papers to be presented in 25 oral sessions*
- *Keynotes from world-renown experts: J. Kolar, M. Malinowski, F. Blaabjerg, A. Rathore, etc.*
- *Conference venue next to the Tallinn's Old Town – a UNESCO World Heritage Site*
- *Entertaining social events for attendees, special events for students and WiE members*
- *TalTech PEG expo booth with showcasing of the latest developments*



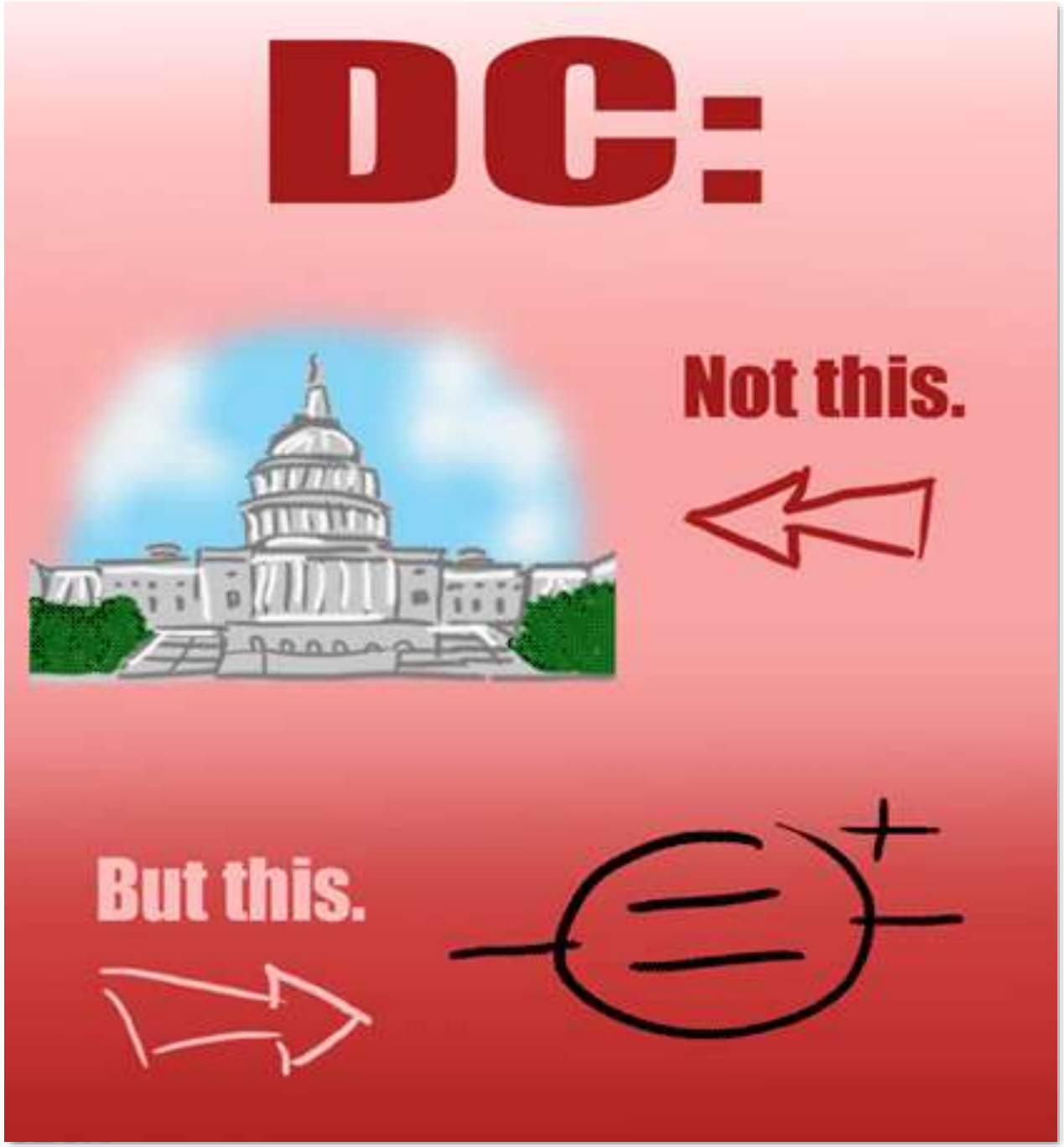
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The most recent news and activities you will find in our LinkedIn groups

Power Electronics Group

i³ DC
Accelerates Energy Transition

- *https://taltech.ee/en/power-electronics-research-group (to be updated)*
- *https://taltech.ee/en/i3dc-initiative*



CALL FOR COLLABORATION!!!

We will welcome
collaboration on DC buildings
with interested partners
all over the World!

Feel free to contact us at
i3dc@taltech.ee

Centre of Excellence in Energy Efficiency

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QUESTIONS



– POWER ELECTRONICS GROUP –

Your Reliable Partner in Power Electronics

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