# POWER ELECTRONICS AS THE ENABLING TECHNOLOGY FOR BUILDINGS DECARBONIZATION

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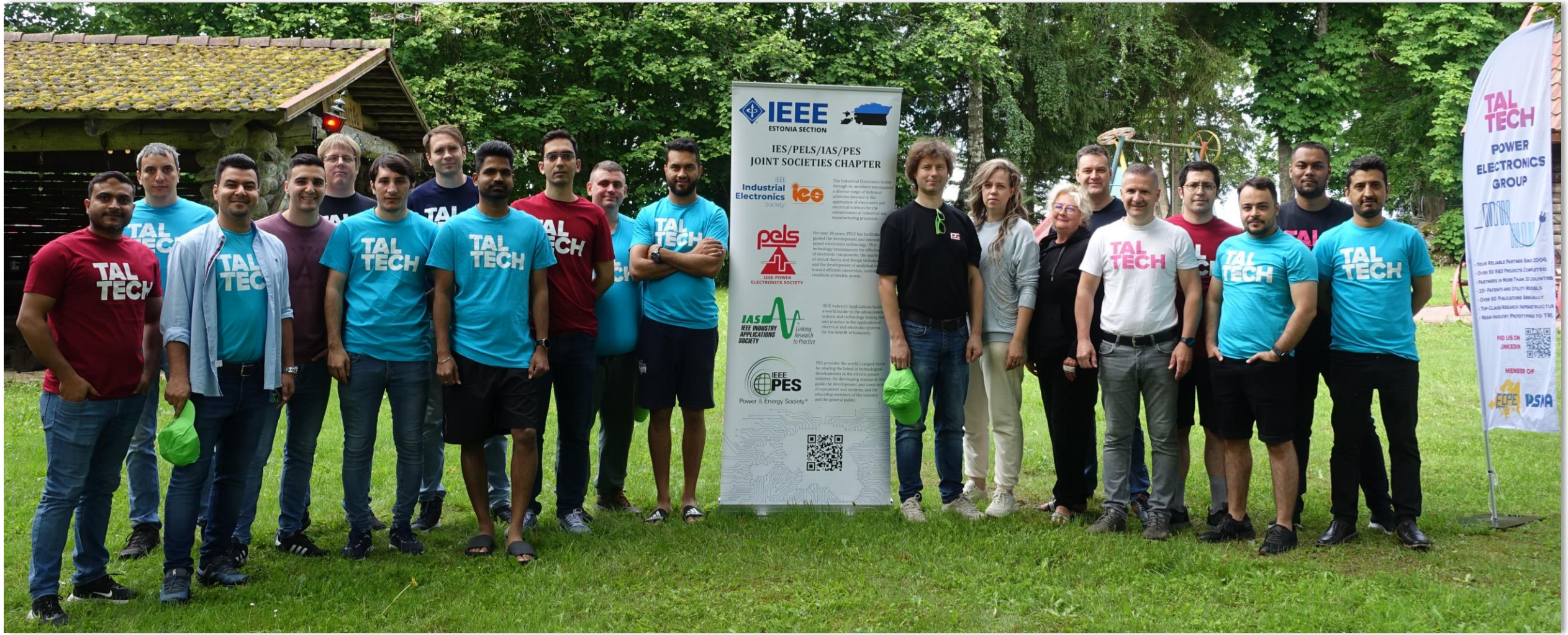
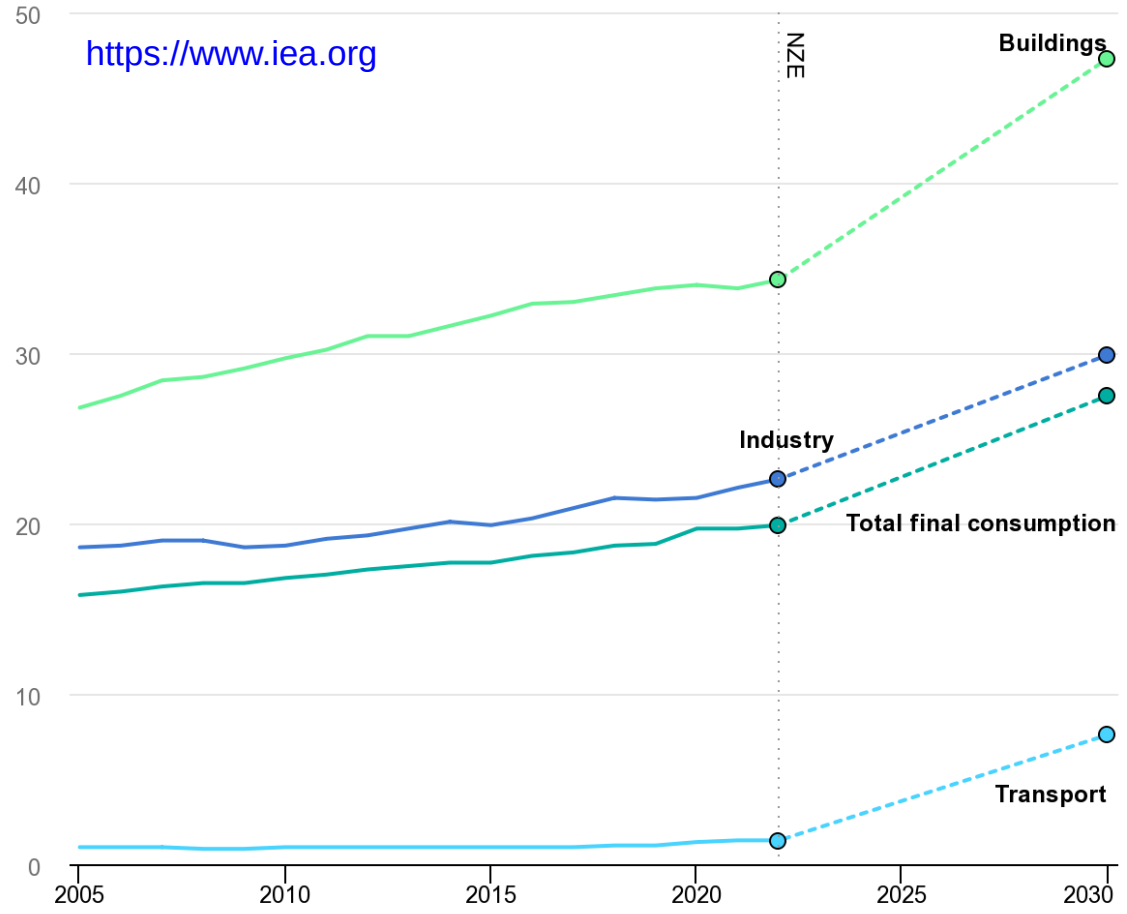
# ESTONIA - A DESTINATION FOR TECH LOVERS

# POWER ELECTRONICS GROUP OF TALTECH



# TOWARDS 2050 NZE PATHWAY (EU GREEN DEAL)

- *By 2050 the EU aims to become the **world's first "climate-neutral bloc"** having an economy with net-zero greenhouse gas emissions (NZE)*
- ***Electrification** is considered one of the key strategies to reach NZE goals*
- *In 2050 the **share of electricity** in the final energy consumption is targeted to be **more than 50%***
- *By 2050, almost **90%** of electricity generation in EU is expected to come **from renewable sources**, with wind and solar PV together accounting for nearly 70%*
- *Much of the NZE need will be met by shifting towards **electric transport** and **electrification of heating/cooling demand of buildings** using heat pumps*
- *In 2050, **electricity will become the dominant energy carrier for the buildings in EU.** The prognosed growth in demand by 2030 is 12% and 35% by 2050*




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

# DECARBONIZATION OF BUILDING STOCK IN EU

- ***Buildings*** *are responsible for approximately* ***40% of EU energy consumption***, ***more than half of EU gas consumption*** *(mainly through heating, cooling and domestic hot water), and 36% of the energy-related greenhouse gas emissions.*
- ***Roughly 75% of buildings*** *in the EU are not energy efficient, yet 85–95% of today's buildings will still be in use in 2050*
- *To* ***boost decarbonization*** *the EU requires all new buildings from 2021 to be nearly zero-energy buildings (nZEB)*
- ***nZEB (or class A building)*** *means a building with a very high energy performance where the very low amount of energy should be covered to a* ***very significant extent by energy from the renewable sources***
- *Recently, the EU proposed to move from the current nZEB to zero-emission buildings (****ZEB, A+ or $A_0$****) from January 1, 2030. In ZEB the very low amount of energy still required must be* ***fully covered by energy from the renewable sources and without on-site carbon emissions from fossil fuels***
- *In practice,* ***nZEB consumes up to 4 times less energy*** *than the traditional „old school" building, ZEB will consume even less*

**Table 2.** Estonian energy labels for the three categories of detached houses D1, D2, and D3; EPC (kWh/(m²a)).

| En. Label | D1 (EPC) | D2 (EPC) | D3 (EPC) |
|---|---|---|---|
| A | ≤145 | ≤120 | ≤100 |
| B | 146–165 | 121–140 | 101–120 |
| C | 166–185 | 141–160 | 121–140 |
| D | 186–235 | 161–210 | 141–200 |
| E | 236–285 | 211–260 | 201–250 |
| F | 286–350 | 261–330 | 251–320 |
| G | 351–420 | 331–400 | 321–390 |
| H | ≥421 | ≥401 | ≥391 |

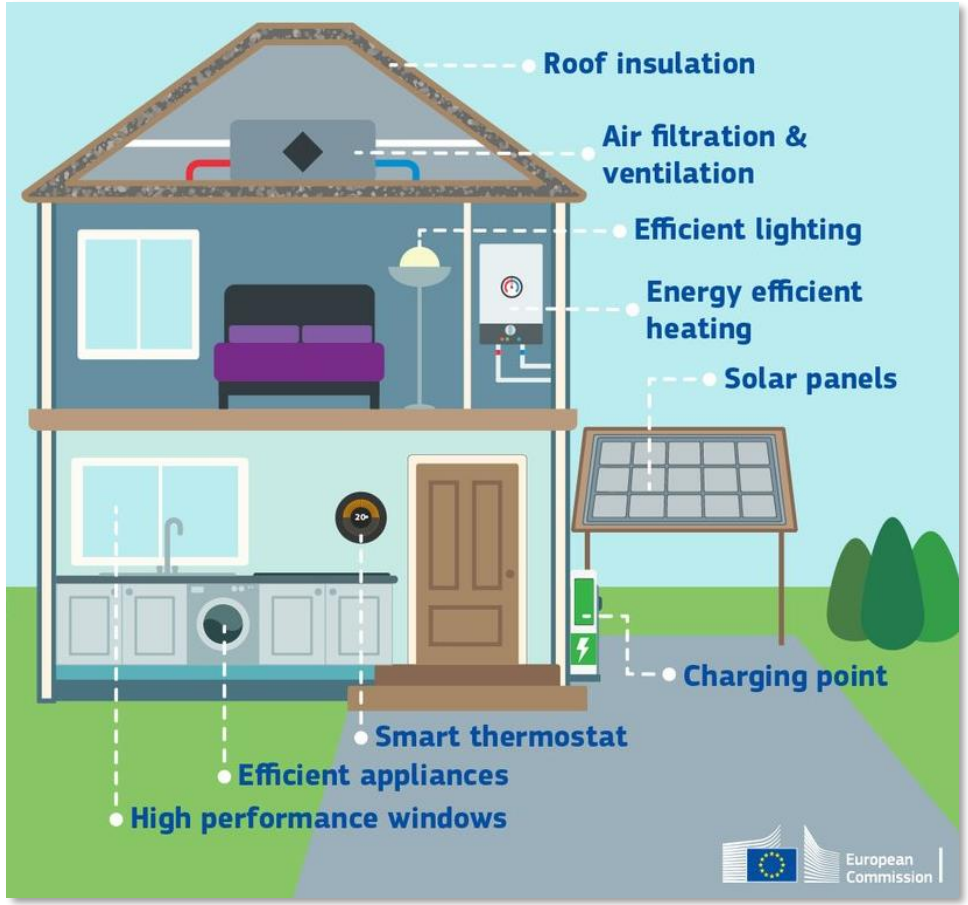

D1, <120 m²
D2, 120–220 m²
D3, >220 m²

https://energy.ec.europa.eu

# ZEB AND POWER ELECTRONICS

## IT IS ALL ABOUT EFFICIENCY AND ENERGY SAVING

- ***ZEB*** *= high energy performance + local renewable energy generation + all-electric lifestyle*
- ***Energy efficiency is the main feature of ZEB*** *- PV installation (backed up with energy storage), heat pump, heat recovery ventilation, energy-efficient appliances and lighting, smart control of loads, energy arbitrage*
- *Most of the energy saving technologies used in ZEB are* ***power electronics based***




# EXAMPLES OF BUILDING STOCK DECARBONIZATION


https://greensunnj.com/solar-hall-of-shame/

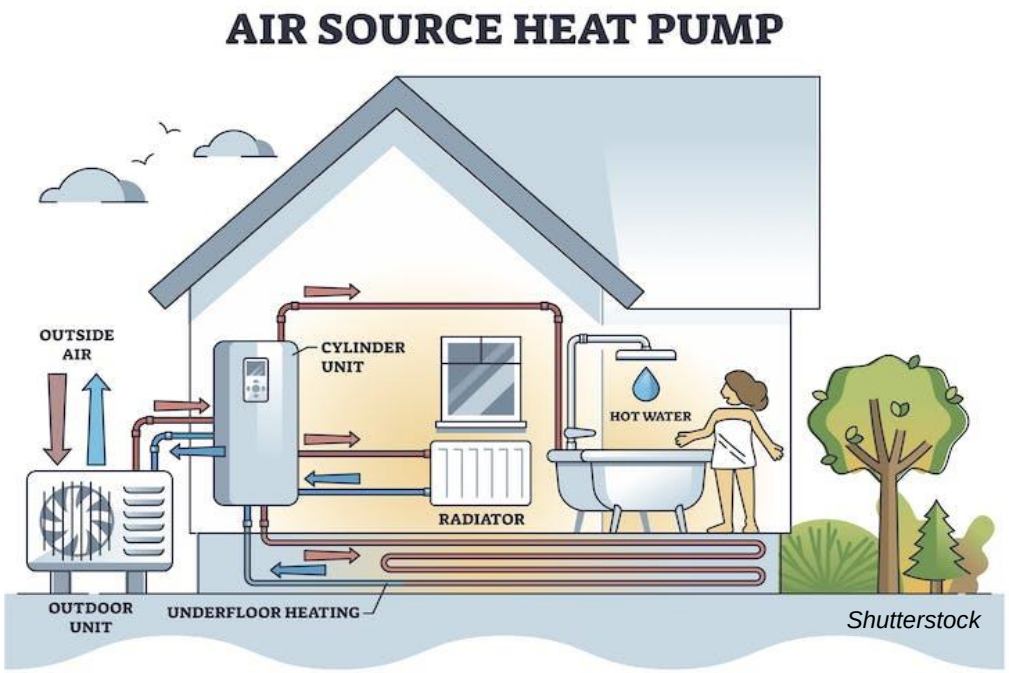
# BAPV vs BIPV- RENEWABLE ENERGY SHOULDN'T COME AT THE COST OF AESTHETICS !

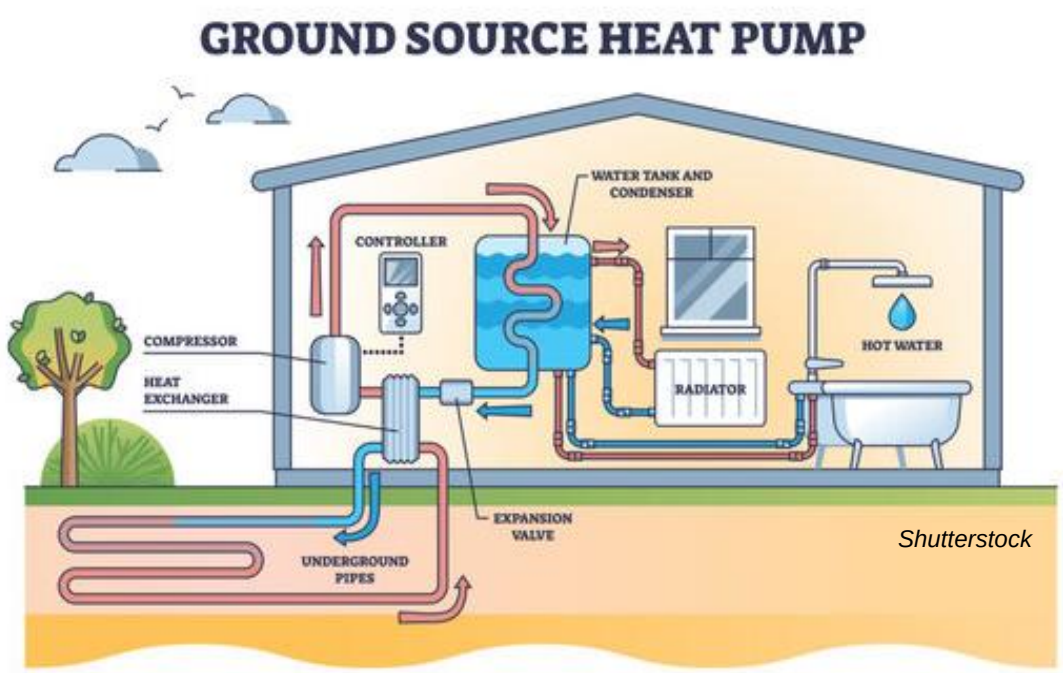
***Building-Attached Photovoltaics (BAPV)*** *lacks full integration into the building, adds additional load, with limited contributions to aesthetics and structural integrity*


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


# ADVANTAGES OF HEAT PUMPS

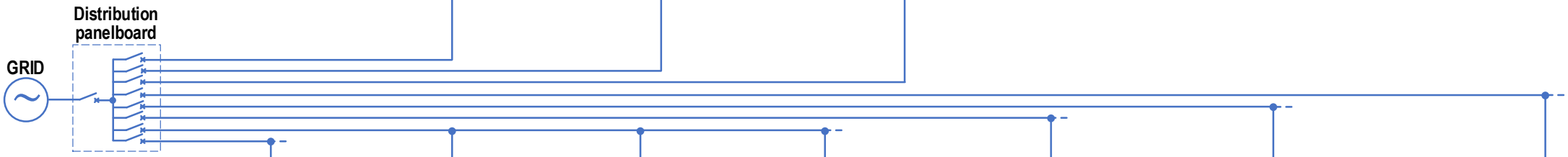
- *There are **two main types of heat pumps** – air source and ground source (geothermal)*
- ***Excellent energy efficiency**: can deliver up to 5 times more heat energy to a home than the electrical energy it consumes (see COP – Coefficient of Performance or SCOP – Seasonal Coefficient of Performance )*
- *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***



# AC-BASED ELECTRICAL SYSTEM OF ZEB TODAY

## WE GAIN THE BENEFITS OF AN ALL-ELECTRIC LIFESTYLE!





*Look at the **energy label** when buying heat pumps, induction cooktops and other appliances!*


Indoor and outdoor LED lamps


Robotic vacuum cleaner


Portable electronics


Flat screen and LED TV


Stove, oven and cooktop


Fridge and air conditioner

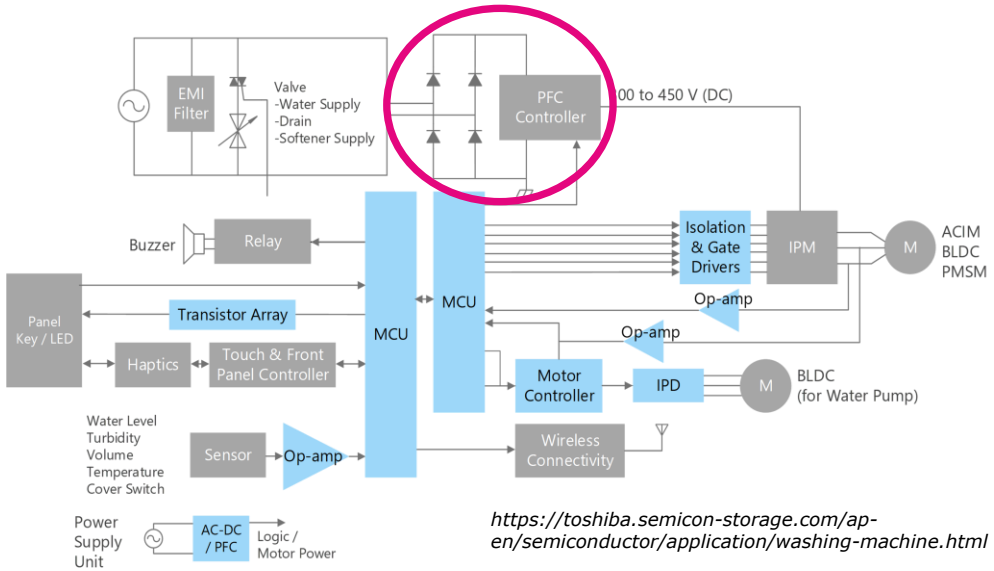

Dish- and laundry washing machines


Air-to-water heat pump

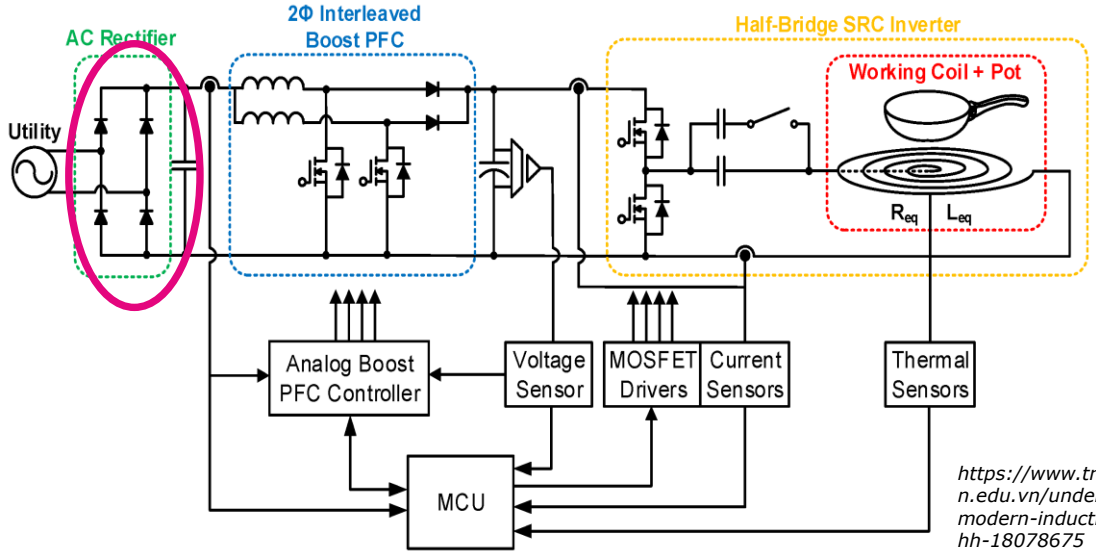
# CLASS-A ENERGY-EFFICIENT APPLIANCES

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

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



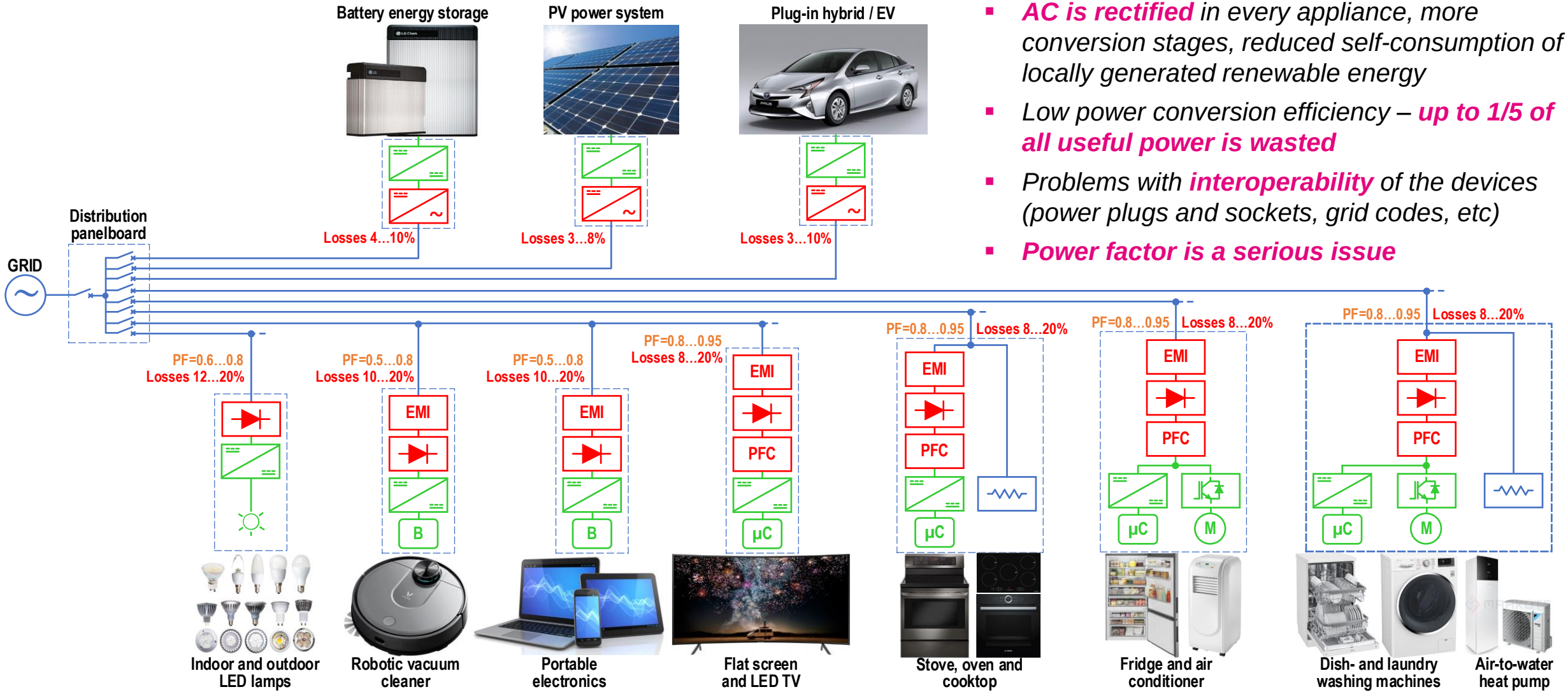

*https://toshiba.semicon-storage.com/ap-en/semiconductor/application/washing-machine.html*




*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, more 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

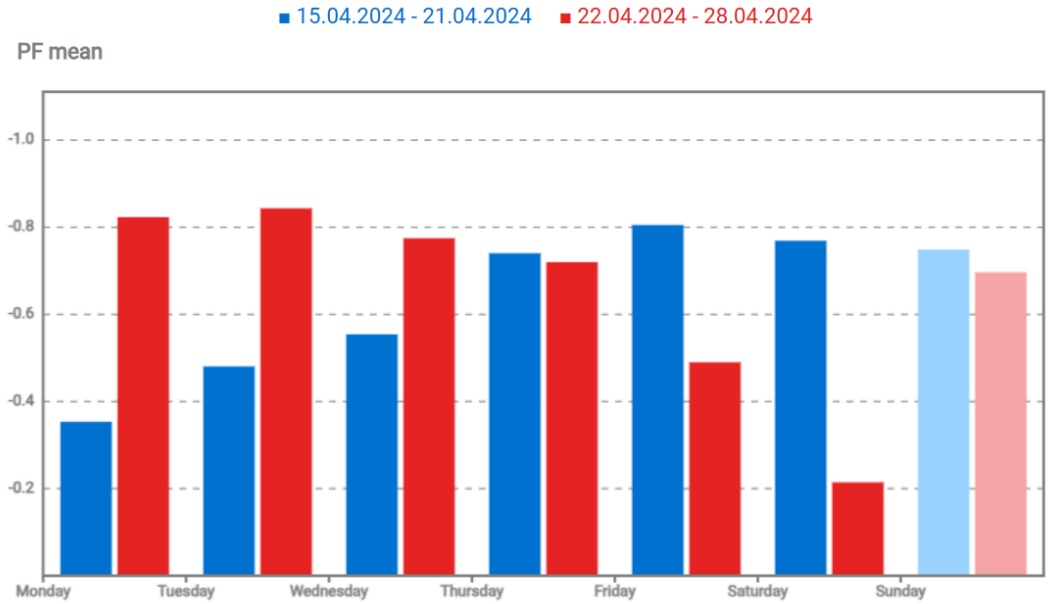
*GU10 LED bulb (4.3 W)*

| | | | | | |
|---|---|---|---|---|---|
| 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 charger (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 |

*176.7 m² private house*




| | |
|---|---|
| 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 |

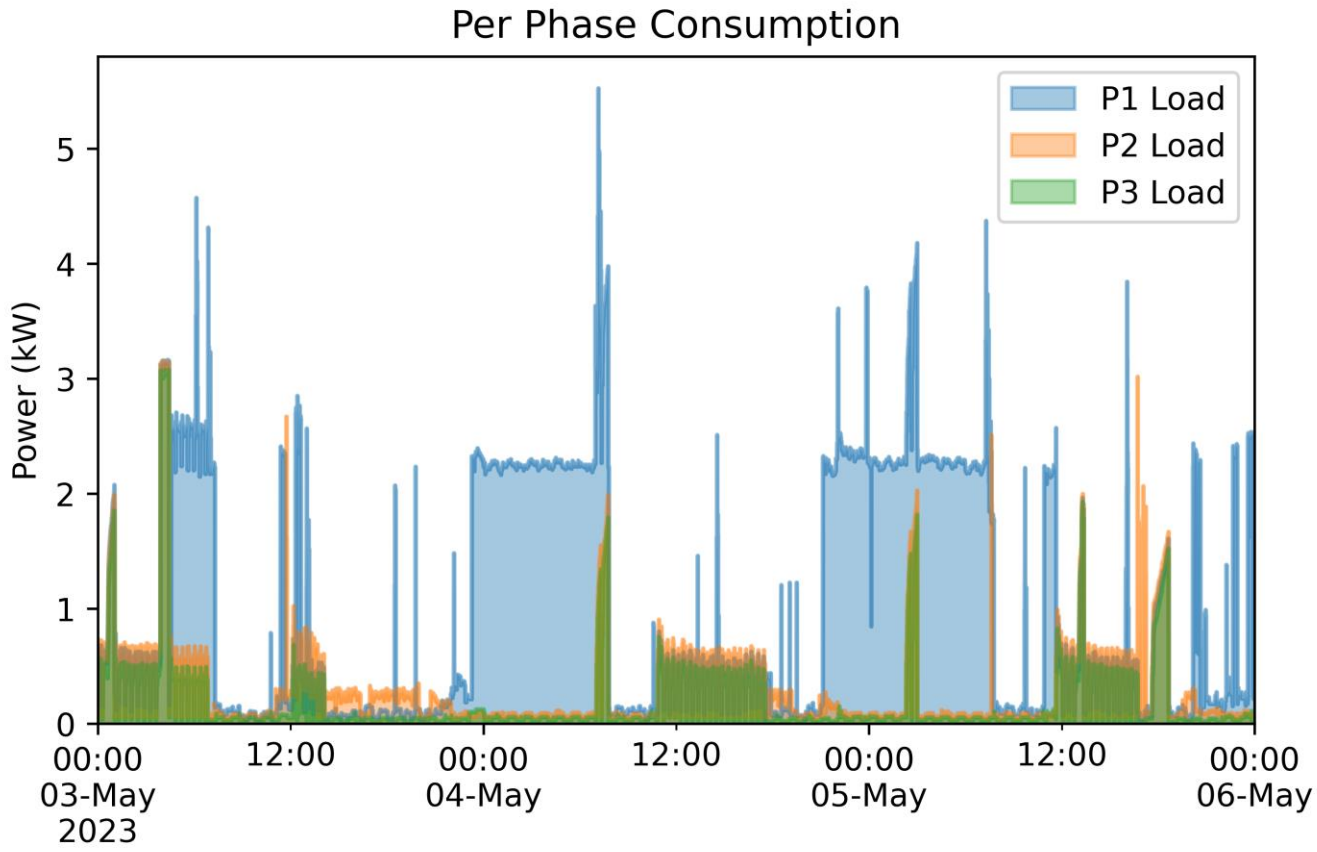
# FULL-ELECTRIC LIFESTYLE WITH AC

## A CLOSER LOOK AT THE PHASE LOAD IMBALANCE

Many residential (home) EV chargers and cheap string inverters have a single-phase grid connection – negative impact on distribution transformers



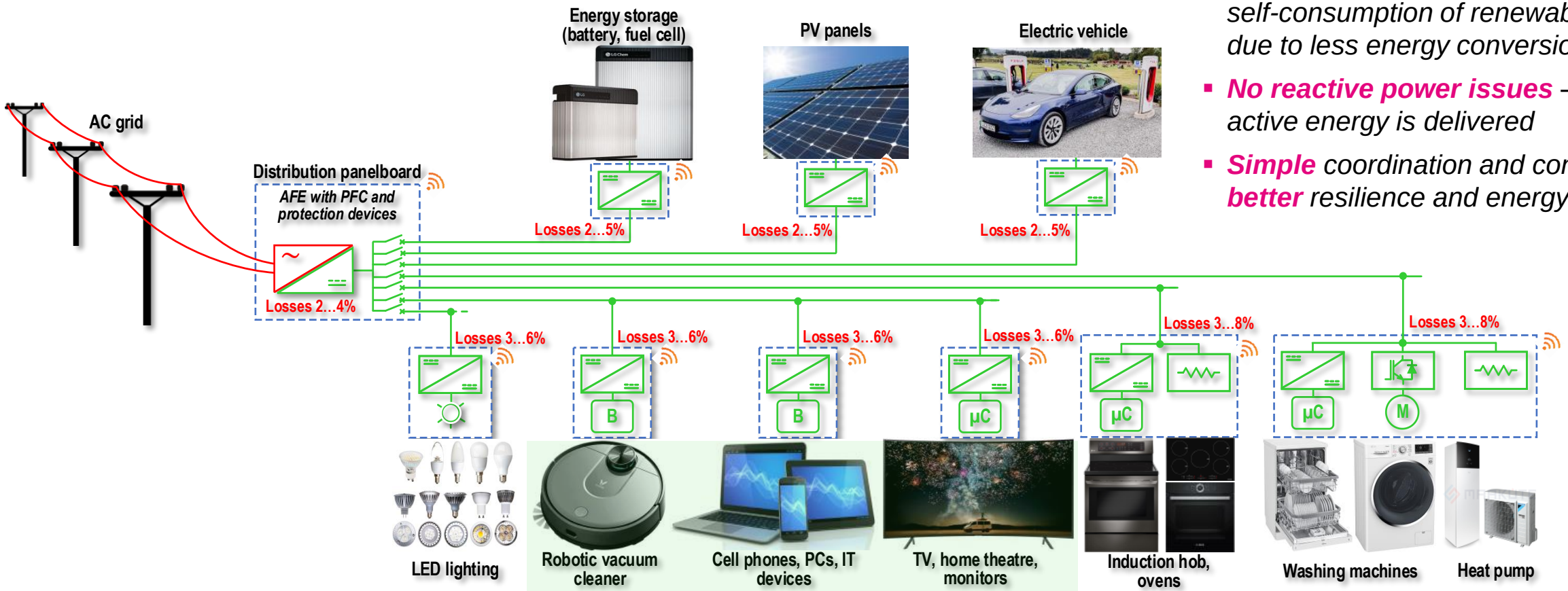
*Single-phase AC charger*




*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*

# NEXT-GEN ELECTRICAL SYSTEM OF A ZEB

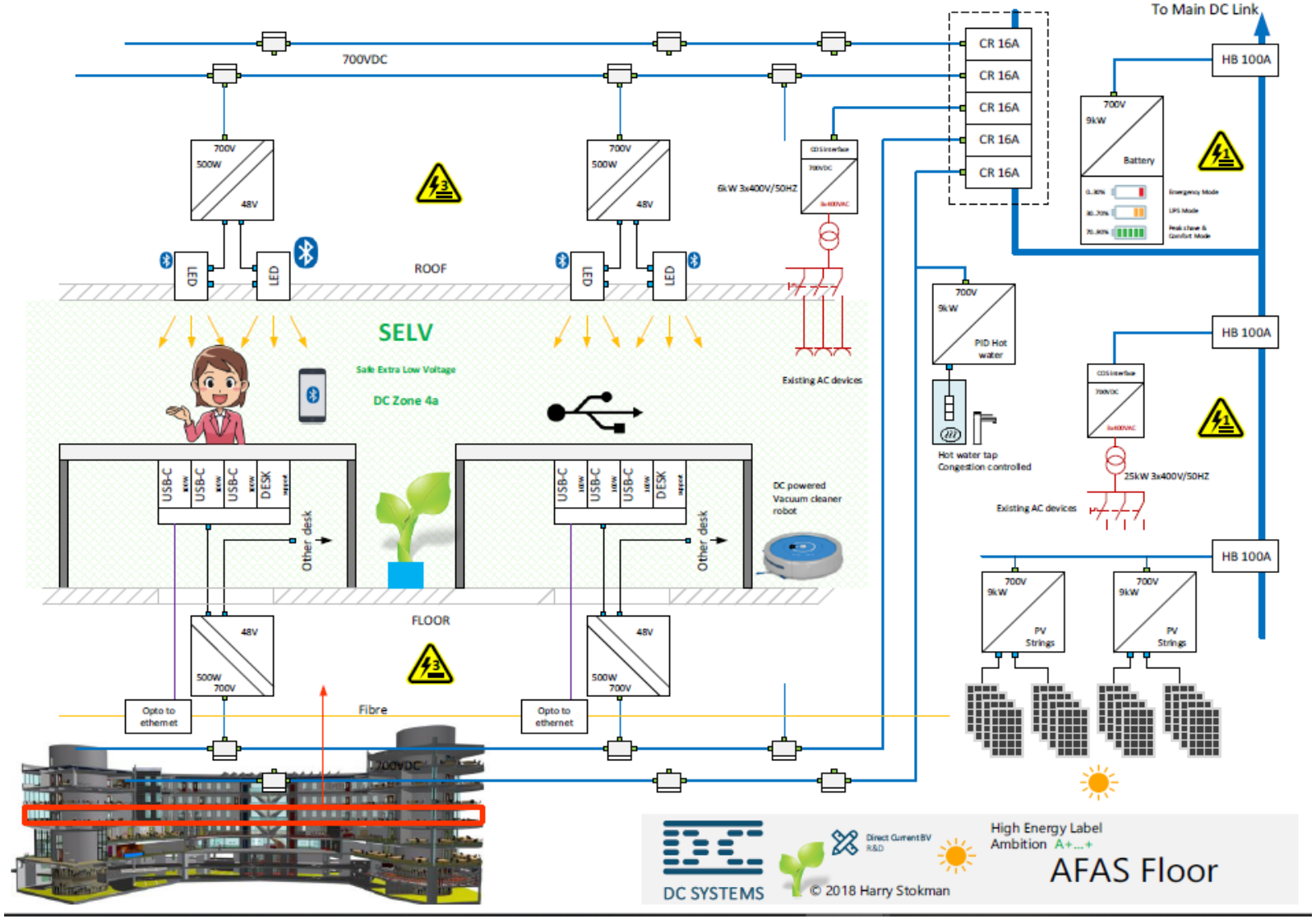
## DC POWER DISTRIBUTION AND DC-FED APPLIANCES




- ***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*

*To be fed via USB Type-C (will become a common standart for most electronic devices in the EU by the end of 2024*

# ENERGY NEUTRAL DC WORKSPACE

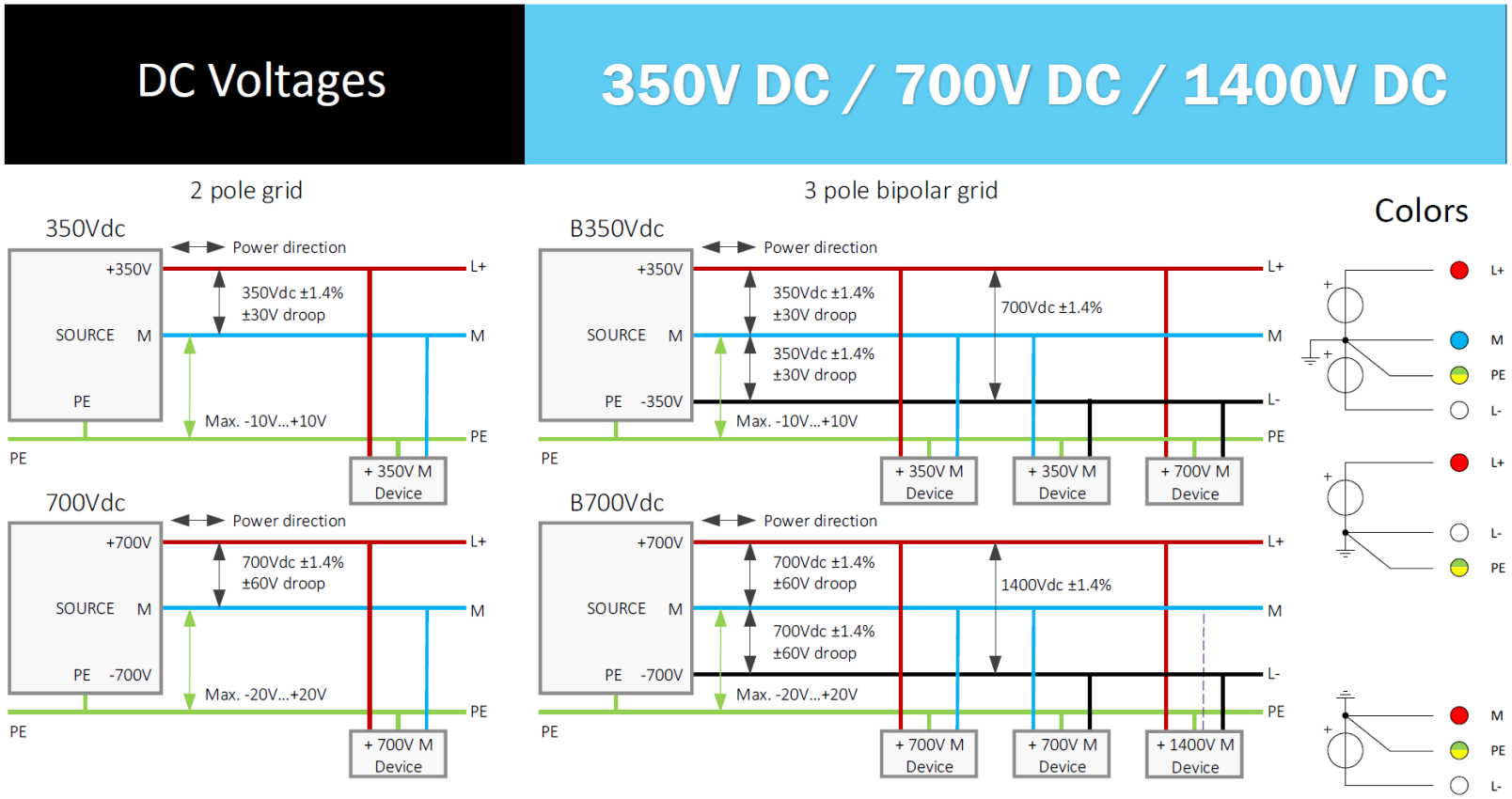



***USB Type-C*** *is used as universal connector for power and data transfer - direct DC connection avoiding numerous AC wall chargers and* ***reducing e-waste***

# HISTORICAL CHOICE: FROM 230 VAC TO 350 VDC

## NPR9090: THE FIRST PRACTICAL GUIDELINE FOR DC INSTALLATIONS

- ***The Netherlands*** *has a leading position in the global consultation on international standards for DC installations*
- *In 2018 the* ***350 V DC*** *has been implemented formally in the Dutch standardization in the NPR9090 (Dutch Practical Guideline for the installations up to 1500 V DC)*
- *The new* ***core colors for DC*** *installations are red, blue and white*




SYSTEMS

by Schneider Electric

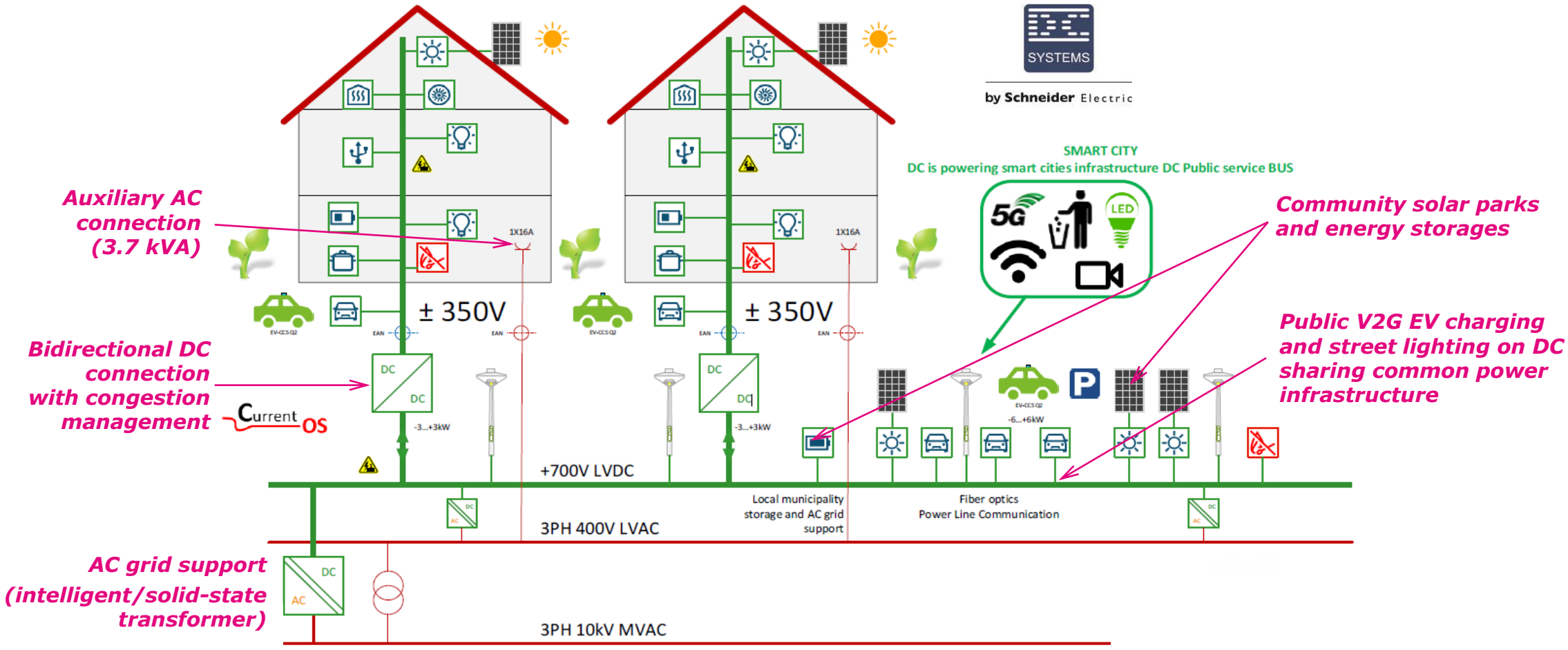
CurrentOS

A native automatic response to power availability

***https://currentos.foundation***

*E. L. Carvalho et al., "Grid Integration of DC Buildings: Standards, Requirements and Power Converter Topologies," in IEEE Open Journal of Power Electronics, vol. 3, pp. 798-823, 2022*

# DC ELECTRIFICATION OF NEIGHBOURHOODS



# DC OPENS A NEW DIMENSION IN ENERGY PERFORMANCE OF BUILDINGS

***RESIDENTIAL DC DISTRIBUTION IS A POWER ELECTRONICS-ENABLED TECHNOLOGY, WHICH***

- *can reduce electricity consumption of a building **by up to 30%****
- *can enhance the energy performance class of a building **from A to A+***
- *offers interoperability, easy integration and interaction of the the main electrical components of the building*
- *enables ultimate control flexibility, higher efficiency, power density and reliability*
- *facilitates energy communities and other collective initiatives and business models (energy hubs, EaaS, VPPaaS, etc.)*


- *supports the main grid and provides grid ancillary services (power consumption curtailment, phase balancing, etc.)*
- *fosters V2X adoption via DC charging thus unlocking the untapped potential of EVs as „mobile energy storages“*



** V. Vossos, S. Pantano, R. Heard, and R. E. Brown, “DC appliances and DC power distribution: A bridge to the future net zero energy homes,” Lawrence Berkeley National Laboratory, Berkeley CA, USA, Technical Report LBNL-2001084, Sep. 2017.*

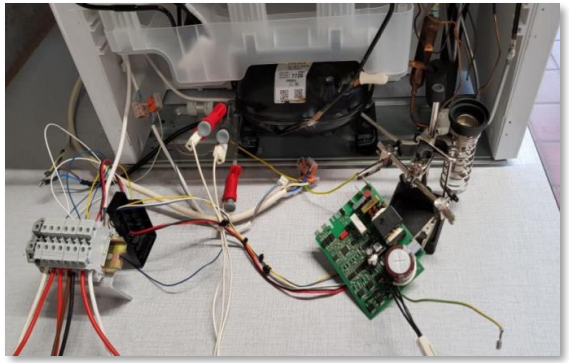
# 350 VDC TECHNOLOGY IS VERY FAST DEVELOPING

## RECENTLY IS A TECHNOLOGY VALIDATION AND DEMONSTRATION PHASE (2020-2025)

- *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) 100W wall socket outlet (DC Systems B.V.)*
- *30/60/90 W public light LED drivers (DC Systems B.V.)*
- *Induction cooktop (ATAG Benelux)*
- *Hood fan (ATAG Benelux)*
- *Refrigerator (ATAG Benelux)*
- *Heat pumps (NRGtec)*
- *Under development: coffee machine, oven, microwave, washing machines, etc.*

SYSTEMS ATAG BENELUX DCpportunities BLIXT


*https://gelijkspanning.org/*
*https://www.dc.systems/*
*https://blixt.tech//*



# MAIN CHALLENGES OF DC TODAY

- *Lack of public awareness*
- *Lack of international standardization and mature technology*
- *Lack of market-ready power electronic systems (PV converters, energy storage interfaces, EV chargers, energy routers, etc.)*

# $i^3$ DC INITIATIVE: *i*nform, *i*nspire & *i*nnovate (est. 2020)

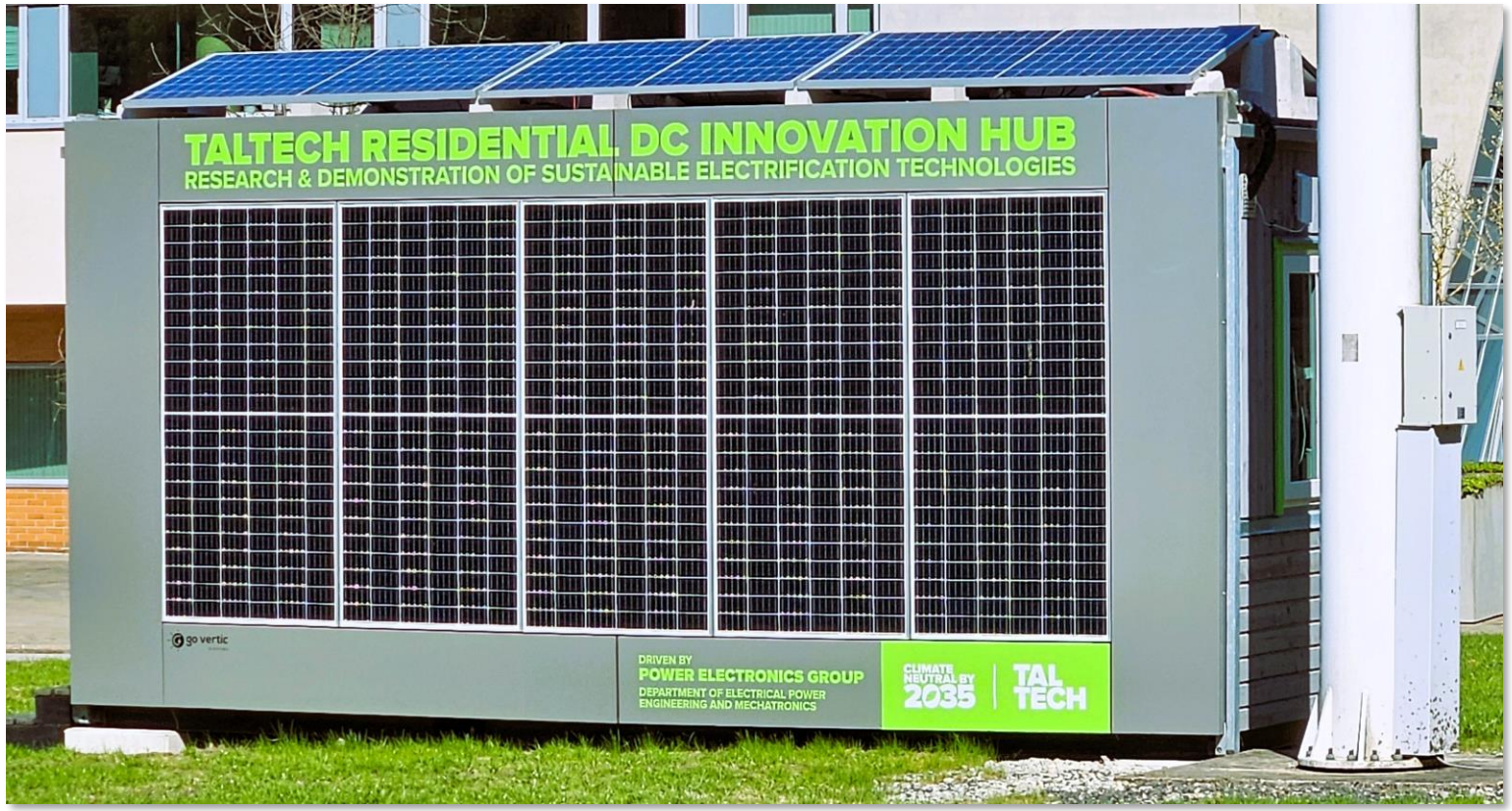
*Non-profit joint venture of TalTech aimed at increasing the awareness, pushing forward the innovation and acceleration of the industrial uptake of the residential DC nanogrid technology in Estonia, Baltic states and Northern Europe*

- ✓ *organization of national and international seminars and workshops on residentilal DC nanogrids, DC buildings and districts*
- ✓ *research, development and showcasing of innovative technologies*
- ✓ *development of public policies and standards for DC buildings*
- ✓ *creation of new cleantech ventures and joint seeking for funds*

i³ DC
Accelerates Energy Transition

# TALTECH RESIDENTIAL DC INNOVATION HUB

## THE FIRST DC EXPERIENCE CENTER IN NORTHERN EUROPE




- ***First academic member of Current OS Foundation***
- ***International open platform*** *for research and demonstration of residential DC power distribution technology*
- *Validation of the* ***net-zero-energy solutions*** *(workplace, space heating and cooling, ventilation, etc.)*
- ***Living lab*** *allows for blending the everyday real-life experience of pilot users with academic research to develop future-proof energy saving technologies*
- ***Data collection*** *for the future design of the energy-neutral TalTech campus*
- ***https://taltech.ee/en/i3dc-initiative***

TAL TECH CLIMATE NEUTRAL BY 2035 i³ DC Accelerates Energy Transition CurrentOS ENERGIA PARTNER go vertic by ACM Metal sunly Estonian Research Council

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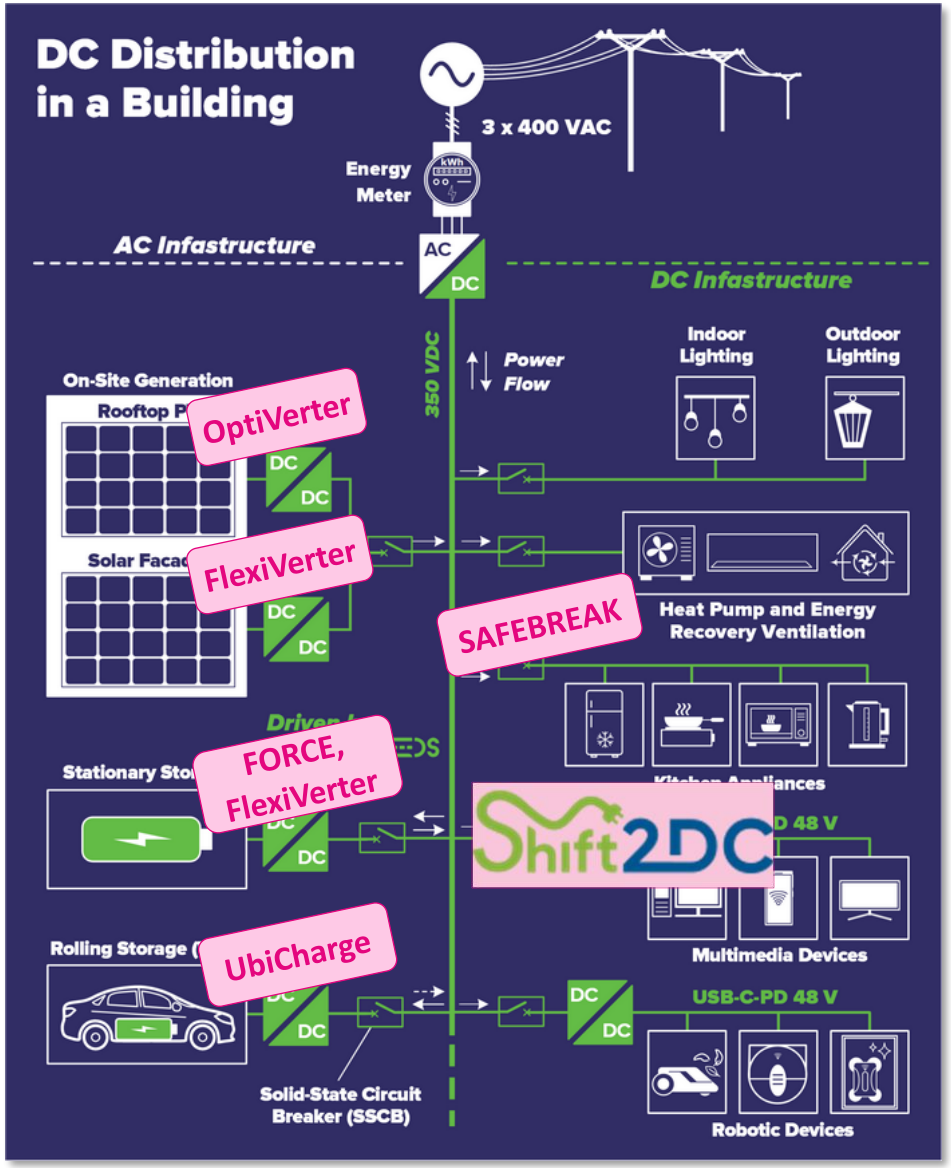
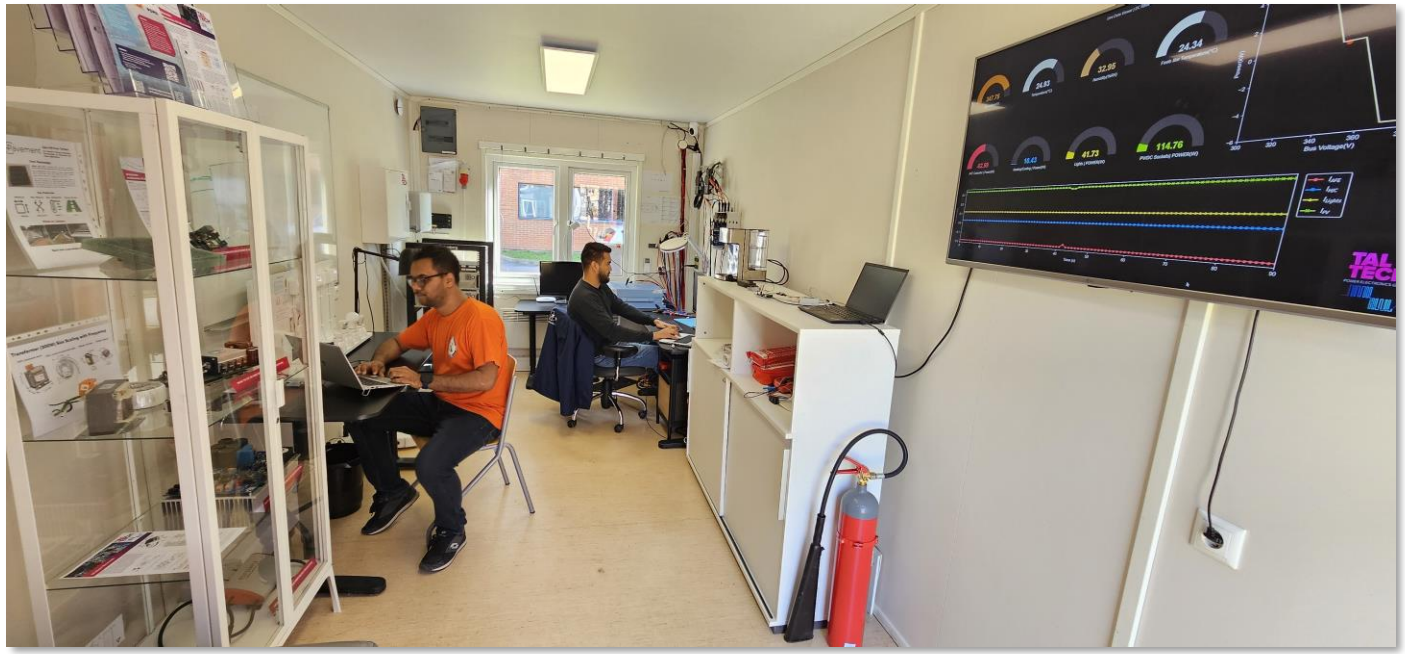
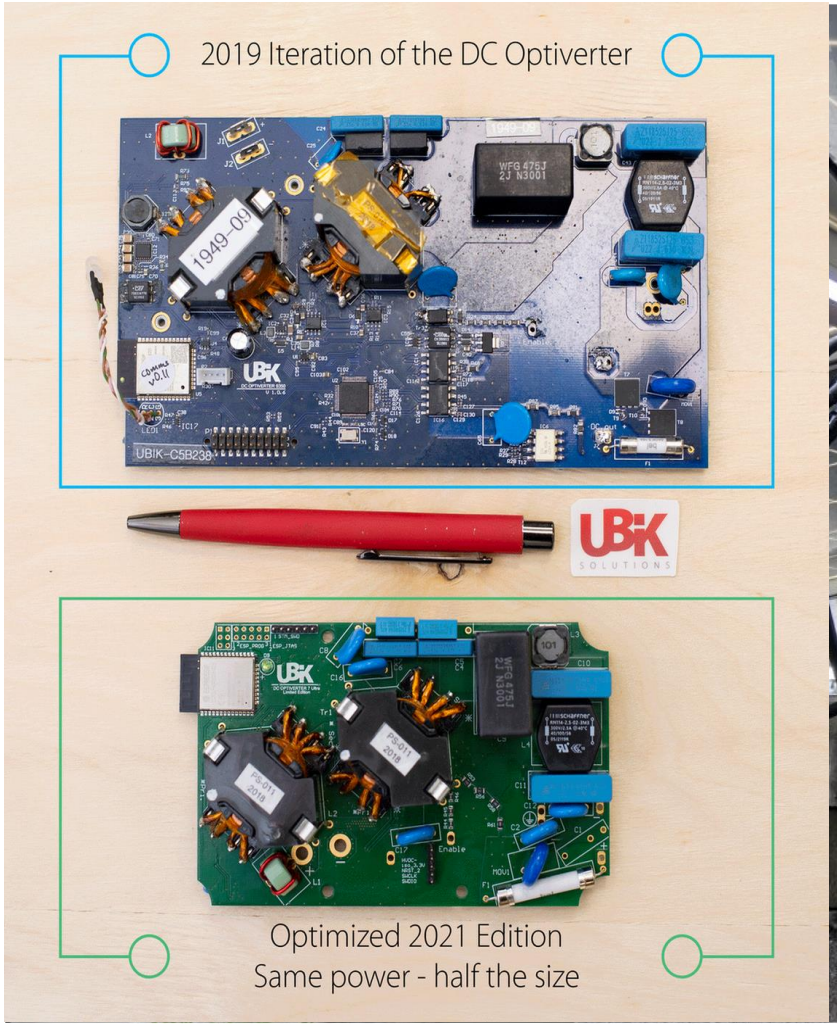
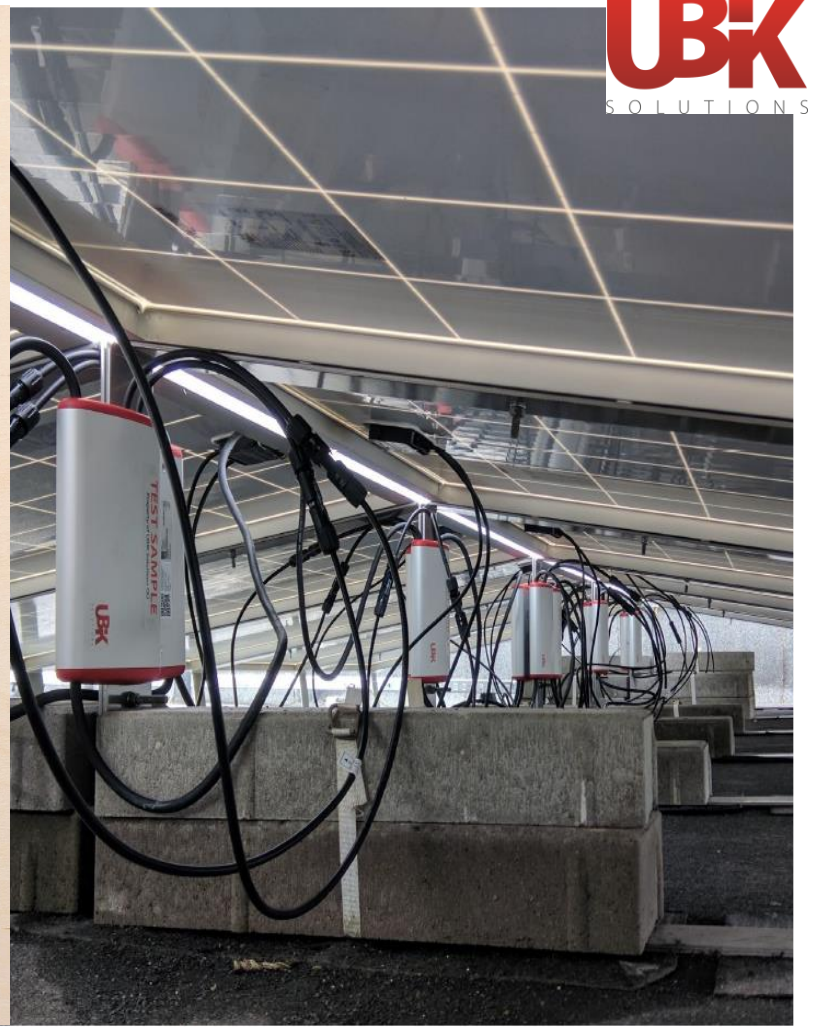



- *Thermally insulated for year-round operation*
- *2 energy neutral working places for researchers*
- *350V±30V DC droop-controlled microgrid (operating system Current/OS)*
- *Solar facade composed of 5 c-Si PV modules*
- *Solar roof with 3 south-facing and 3 north-facing c-Si PV modules*
- *Battery energy storage*
- *LED lighting and heat pump fed from DC (both are energy neutral)*
- *Solid-state protection (both commercial and research samples)*
- *DC appliances (continuous development)*
- *Data logging and visualization (online access soon)*



# OPTIVERTER – A Hybrid of Photovoltaic OPTImizer and MicroconVERTER



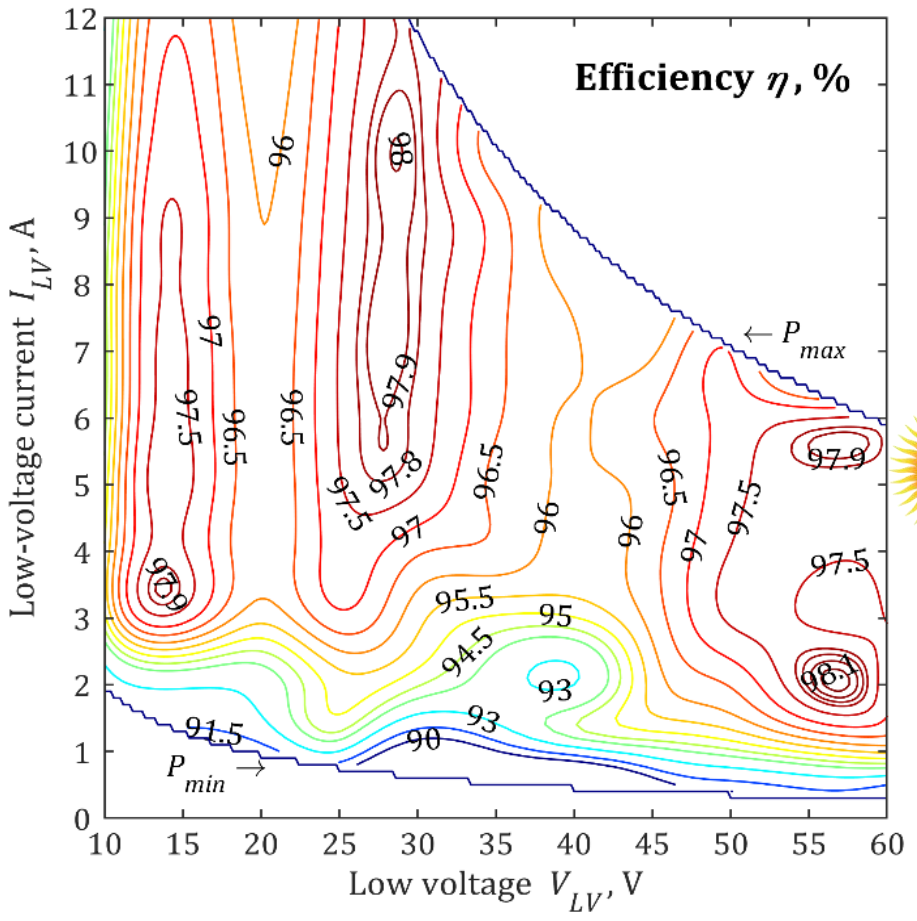



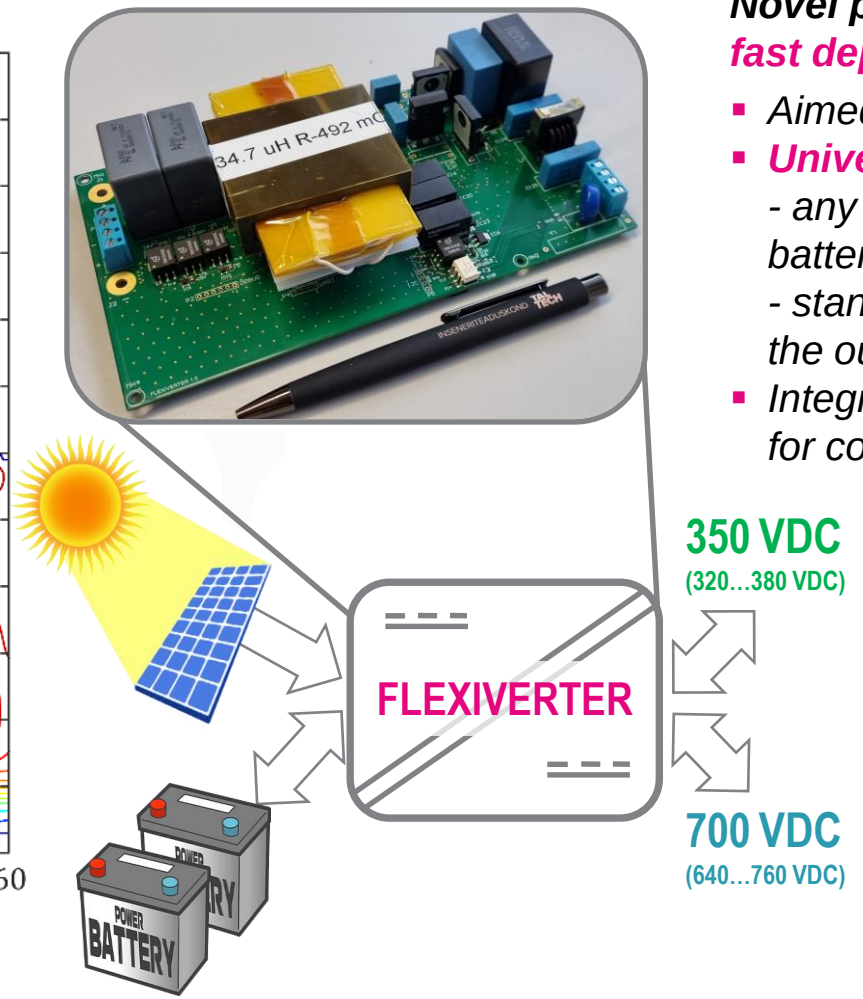
- *An entirely **novel PV MLPE technology***
- *Can be paired with all commercial **60- and 72-cell** PV modules*
- ***Fast GMPPT** and ultimate shade tolerance resulting in up to 30% better energy harvest*
- *Can be plugged either in **the 350 VDC or in 700 VDC** microgrids*
- ***Fully compatible** with emerging NPR9090 standard and Current OS DC microgrid protocol*
- *Supports the **droop control** functionality and features the integrated **solid state protection** circuitry for ensuring the highest level of fire and electric shock safety*
- ***All-in-One approach** with integrated gateway*
- *Integrates **2.4 GHz WiFi** and **BLE** for effortless cloud monitoring and on-site commissioning*



*D. Vinnikov, A. Chub, E. Liivik, R. Kosenko and O. Korkh, "Solar Optiverter—A Novel Hybrid Approach to the Photovoltaic Module Level Power Electronics," in IEEE Transactions on Industrial Electronics, vol. 66, no. 5, pp. 3869-3880, May 2019, doi: 10.1109/TIE.2018.2850036.*

# FLEXIVERTER – FLEXIble conVERTER
## power electronics "LEGO" for ZEB




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

- *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*

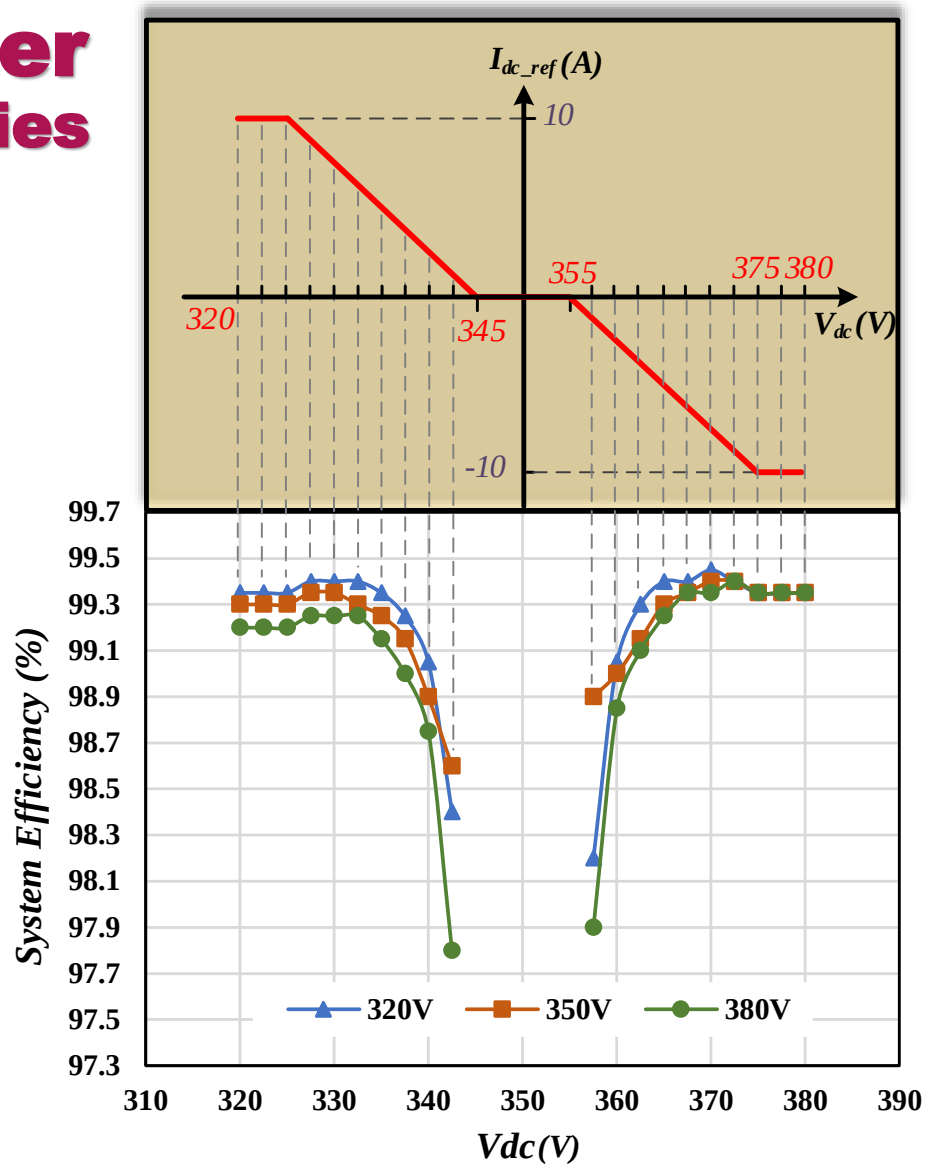


*V. Sidorov, A. Chub, D. Vinnikov and A. Lindvest, "Novel Universal Power Electronic Interface for Integration of PV Modules and Battery Energy Storages in Residential DC Microgrids," in IEEE Access, vol. 11, pp. 30845-30858, 2023.*

# FORCE – Fractional pOweR ConvErter

## For efficient integration of high-voltage 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.*

# DEVELOPMENTS IN PROGRESS (1)

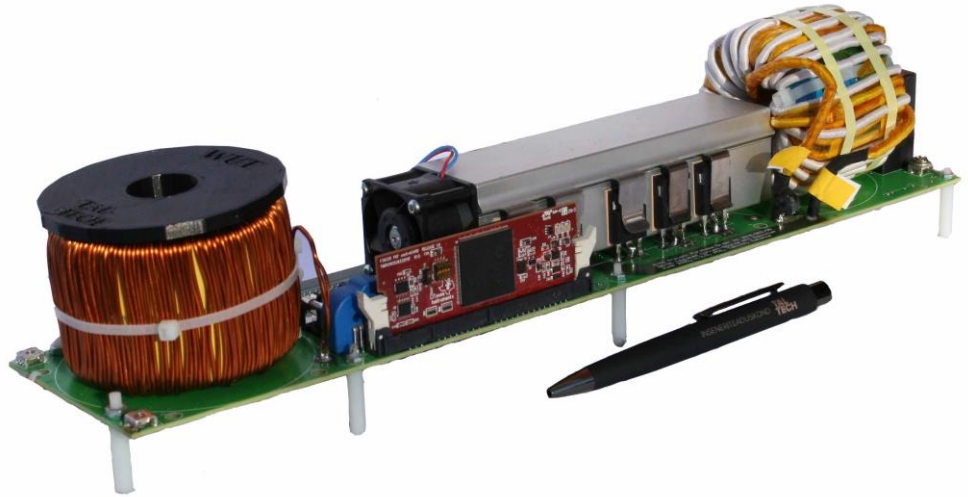
## MERGE: Smart energy gateway for DC house connection to AC grid

- *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 CurrentOS protocol*
- *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 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 200…800 VDC*
- *Droop controlled according to CurrentOS (in emergency bands)*
- *High weighted efficiency of >97%*
- *Low-cost single-stage design*

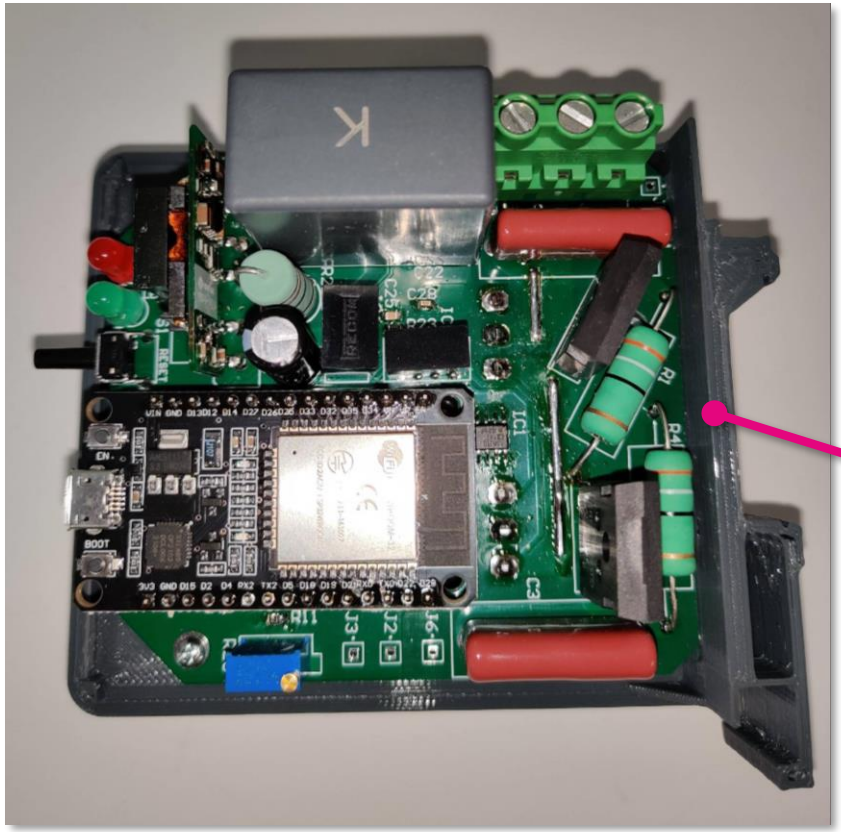


*D. Zinchenko et al. "High-Efficiency Single-Stage On-Board Charger for Electrical Vehicles," in IEEE Transactions on Vehicular Technology, vol. 70, no. 12, pp. 12581-12592, Dec. 2021*

# DEVELOPMENTS IN PROGRESS (2)

## SAFEBREAK – SAfe and Fast DC Electronic BREAKer

- *Optimized for **350 VDC/16A** residential applications*
- *Utilizes SiC JFETs for **low $R_{DSon}$**, efficiency **99.8% @ 16A***
- *Contains **residual current sensor** for ultimate safety*
- ***Fast speed** – short circuit detected within 10 µs*
- *MQTT smart connection to **Energy Management System***



# ICDCM 2025 IN TALLINN – MARK THE DATE!

## THE 7TH IEEE INTERNATIONAL CONFERENCE ON DC MICROGRIDS (ICDCM 2025)

**FULLY SPONSORED BY THE IEEE PELS (TC1)**

**You can expect:**

- *Highly relevant program on DC microgrids and applications*
- *~100 papers to be presented*
- *7 tutorials from world-renown experts*
- *Conference venue next to the Tallinn's Old Town – a UNESCO World Heritage Site*
- *Entertaining social events for attendees, special events for PELS student and WiE members*
- *Lunches and coffee breaks*
- *White nights and mild summer weather*

ICDCM 2025

International Conference on DC Microgrids

The 7th IEEE International Conference on DC Microgrids

June 4-6, 2025

Tallinn, Estonia

IEEE pels IEEE POWER ELECTRONICS SOCIETY Powering a Sustainable Future

**PRE-ANNOUNCEMENT**

**MARK YOUR CALENDAR!**

We are pleased to announce that the 7th IEEE International Conference on DC Microgrids (ICDCM) will be held in **Tallinn, Estonia, on June 4-6, 2025**.

**ICDCM** brings together researchers, engineers and students from academia, government and industry for an interactive discussion on the latest advances in DC Grid Technologies and Applications. This conference is sponsored by the **IEEE Power Electronics Society**, organized by **TC1:** Control and Modeling of Power Electronics.

**Topics**

**DC Grid Core Technologies**

- Medium voltage power distribution
- Circuit breaker and protection
- Power converters
- Modeling
- Control and stability
- Reliability
- Safety
- Medium voltage engineering

**DC Grid Core Applications**

- Transportation electrification
- Renewable energy systems
- Energy storage and integration
- Micro-grids and nano-grids
- Telecommunication and data center
- Smart homes and buildings
- Other industrial applications

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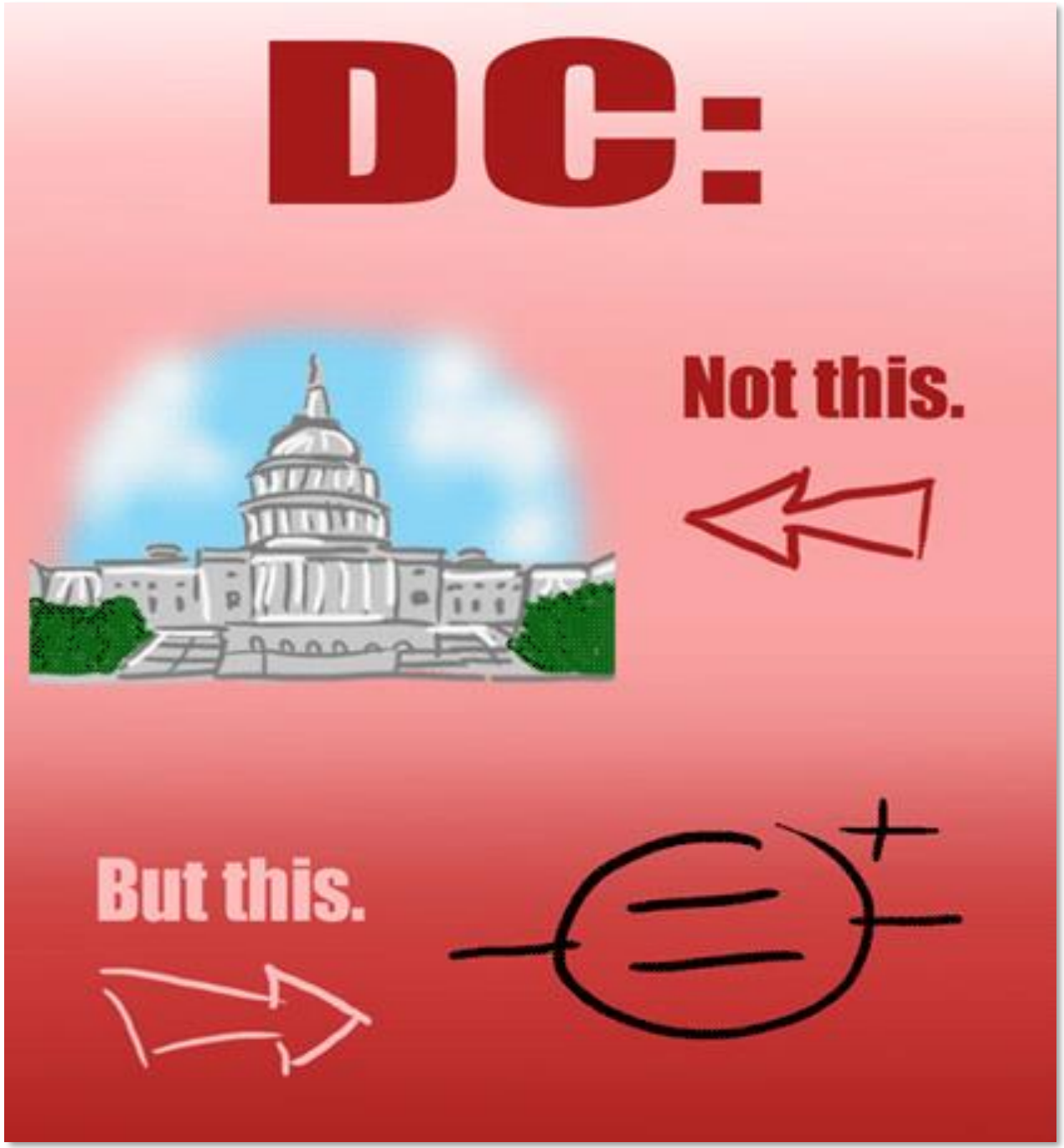


# QUESTIONS

Centre of Excellence in Energy Efficiency

Estonian Research Council

i³ DC Accelerates Energy Transition