380V DC in Commercial Buildings and Offices

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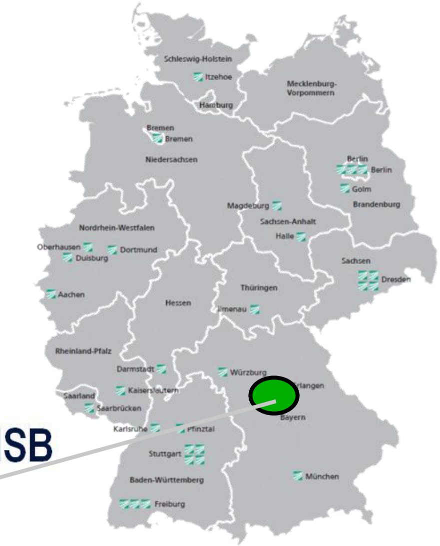
Content

- Basic Information about Fraunhofer and Germany
- Installation and Appliance Technology Today
- History of Electrification
- DC Grid Technologies
- Useful DC Projects
- Summary

Fraunhofer and Fraunhofer IISB in Germany

- Key Figures of Fraunhofer in Germany:

Legal status:	Non-profit association (e.V.)
Mission:	Application-oriented R&D
Staff:	19.000
Institutes:	66
Budget: ca.	1.900 Mio. €/a



Fraunhofer IISB

ZKLM / Nuremberg

Energy Campus / Nuremberg

DC Microgrid Location

THM / Freiberg

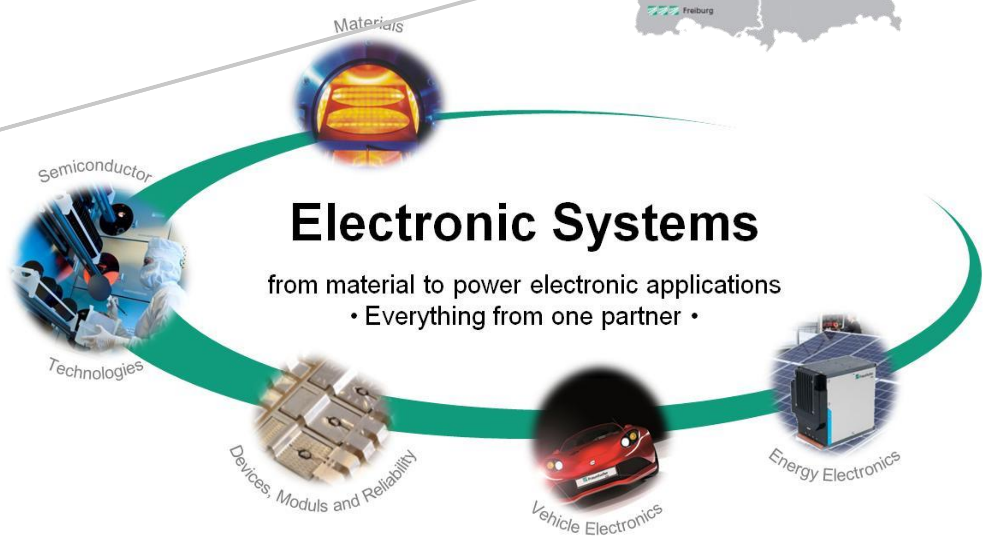
Fraunhofer Institute for Integrated Systems and Device Technology (IISB

Director: Prof. Lothar Frey (deputy: Prof. Martin März)

Staff: ca. 200 (plus 50…70 students)

www.iisb.fraunhofer.de

R&D Focus of Fraunhofer IISB



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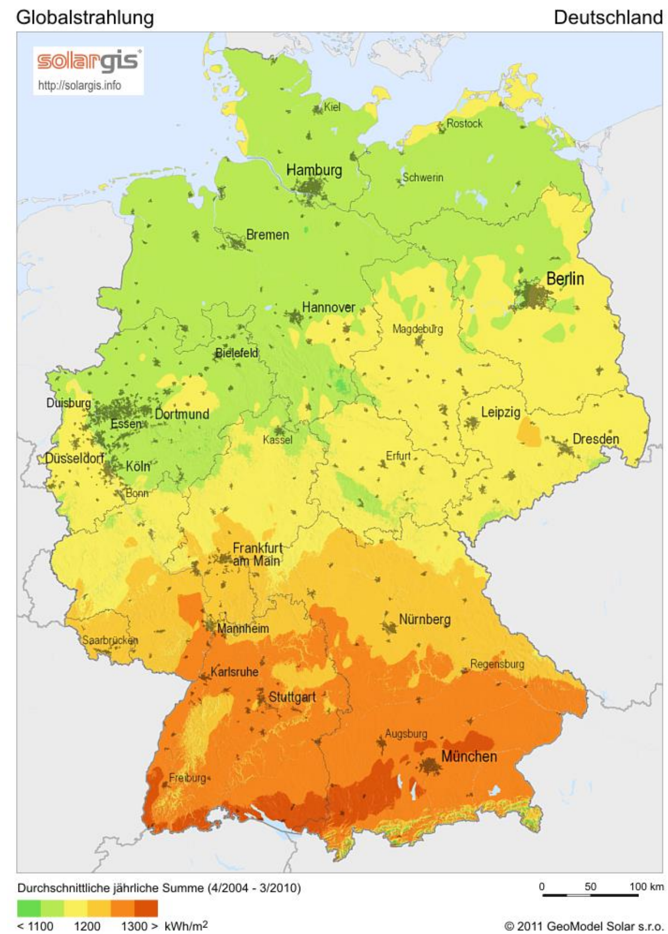
Global Irradiation in Brazil and Germany

Installed PV Power:
- Germany: 40 GW (2014)
- Brazil: 15 MW (2004)

Surface:
- Germany: 357.340 km²
- Brazil: 8.514.215 km²

Global Irradiation:
- Germany: 900-**1250** kWh/m²
- Brazil: **1200**-2400 kWh/m²



⇨ Photovoltaic can bring a huge benefit to the brazil electrification

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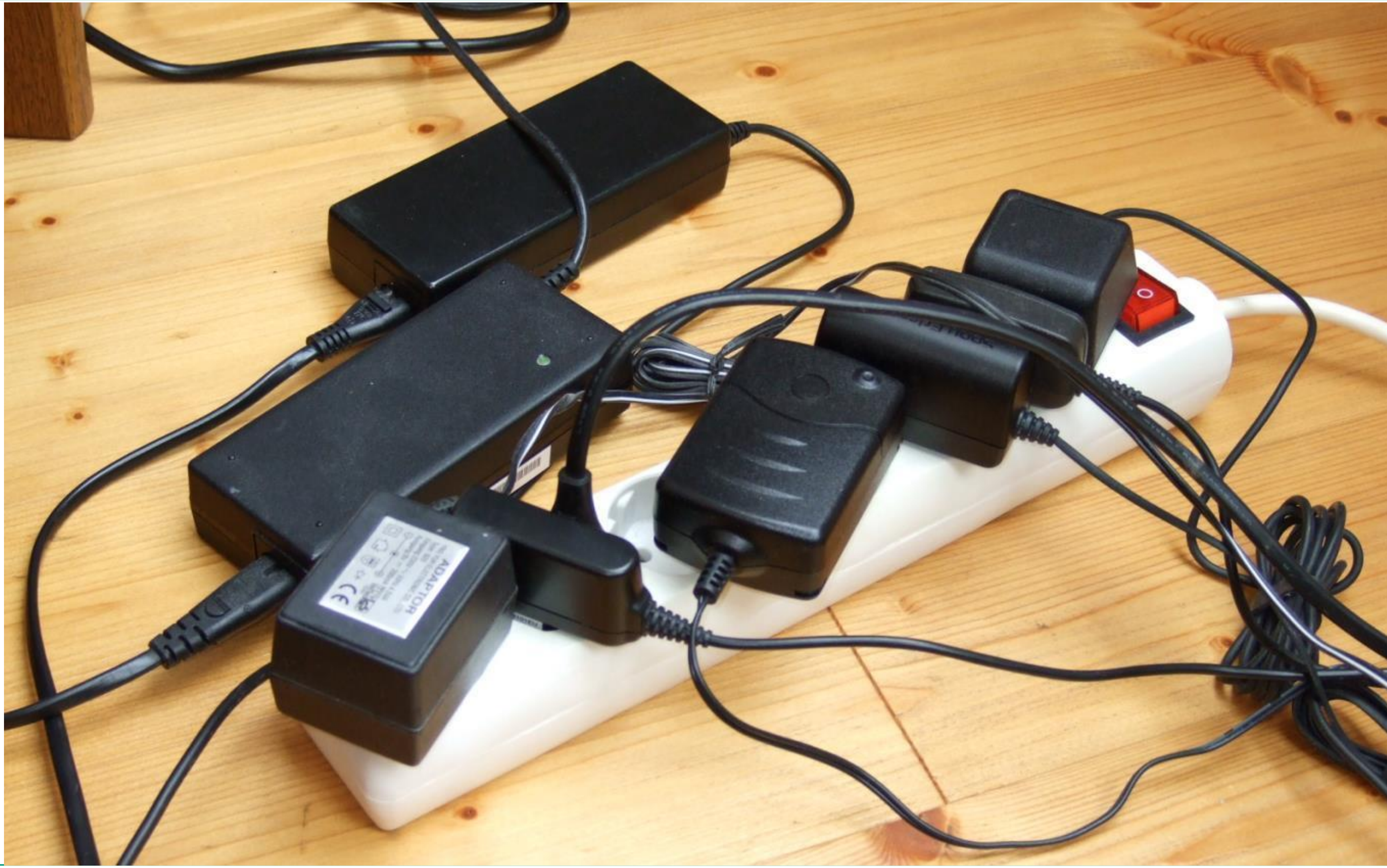
Installation and Appliance Technology Today



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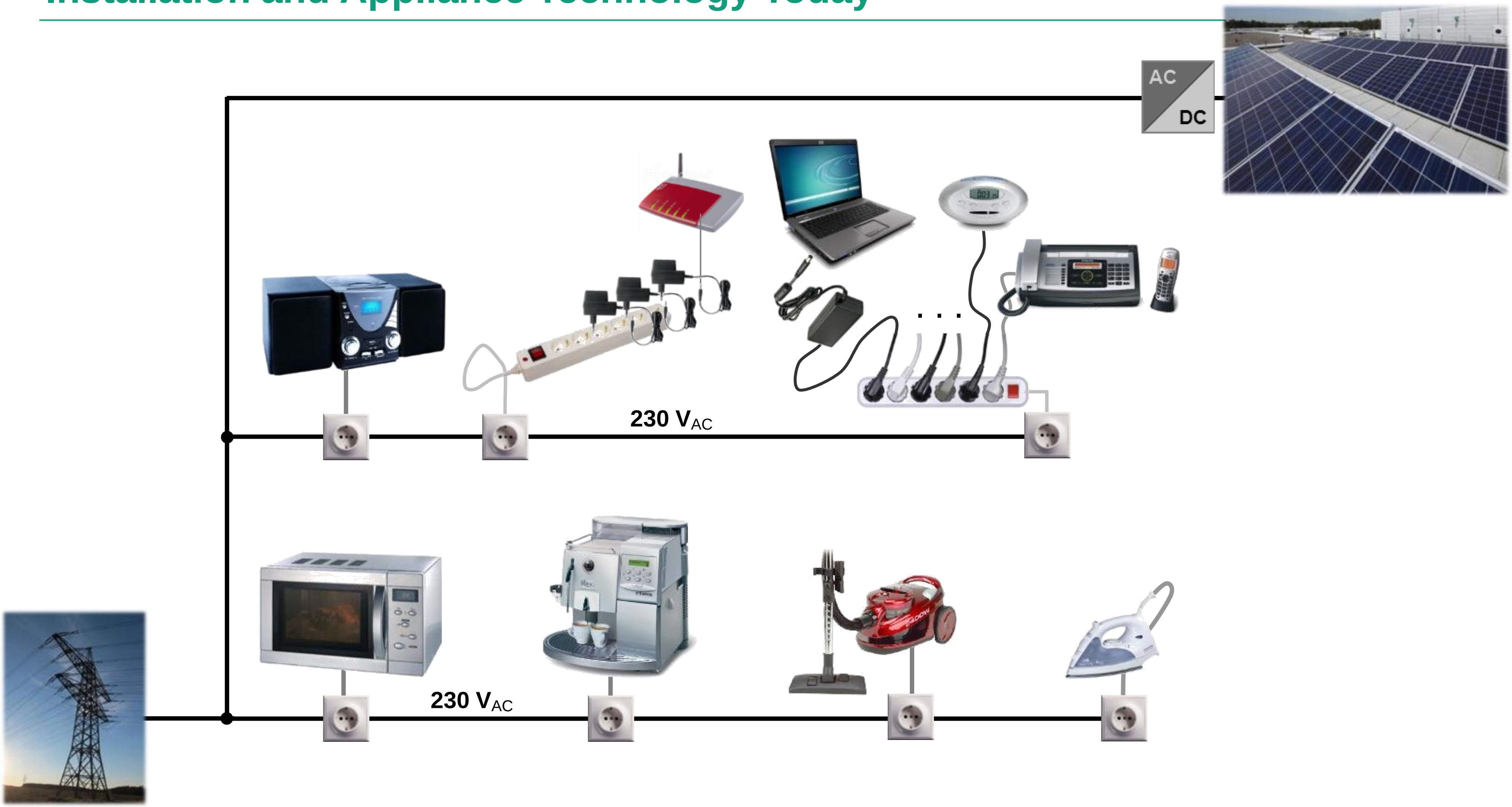
Installation and Appliance Technology Today



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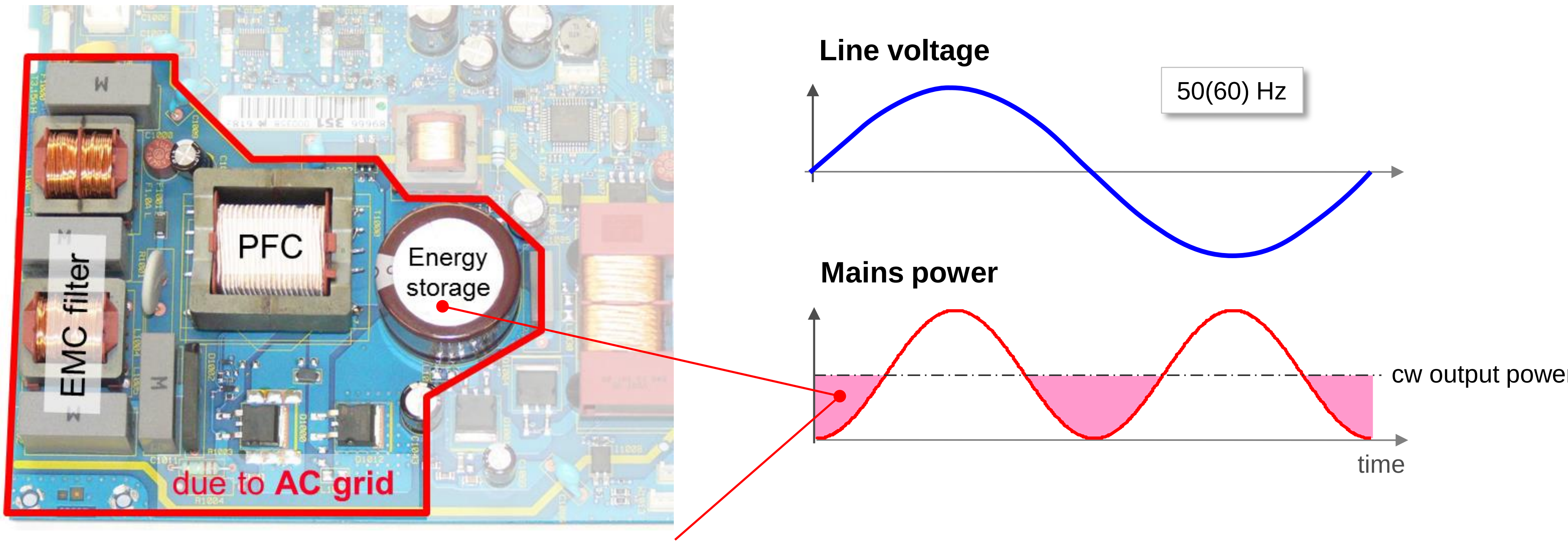
AC ■ Long time success guarantor, today more and more a burden?

Power Supply of Electronic Equipment



One hundred supply gaps per second require a significant energy storage **in each** power supply or line adapter.

⇨ With hugh impact on **size**, **cost** and **energy efficiency!**

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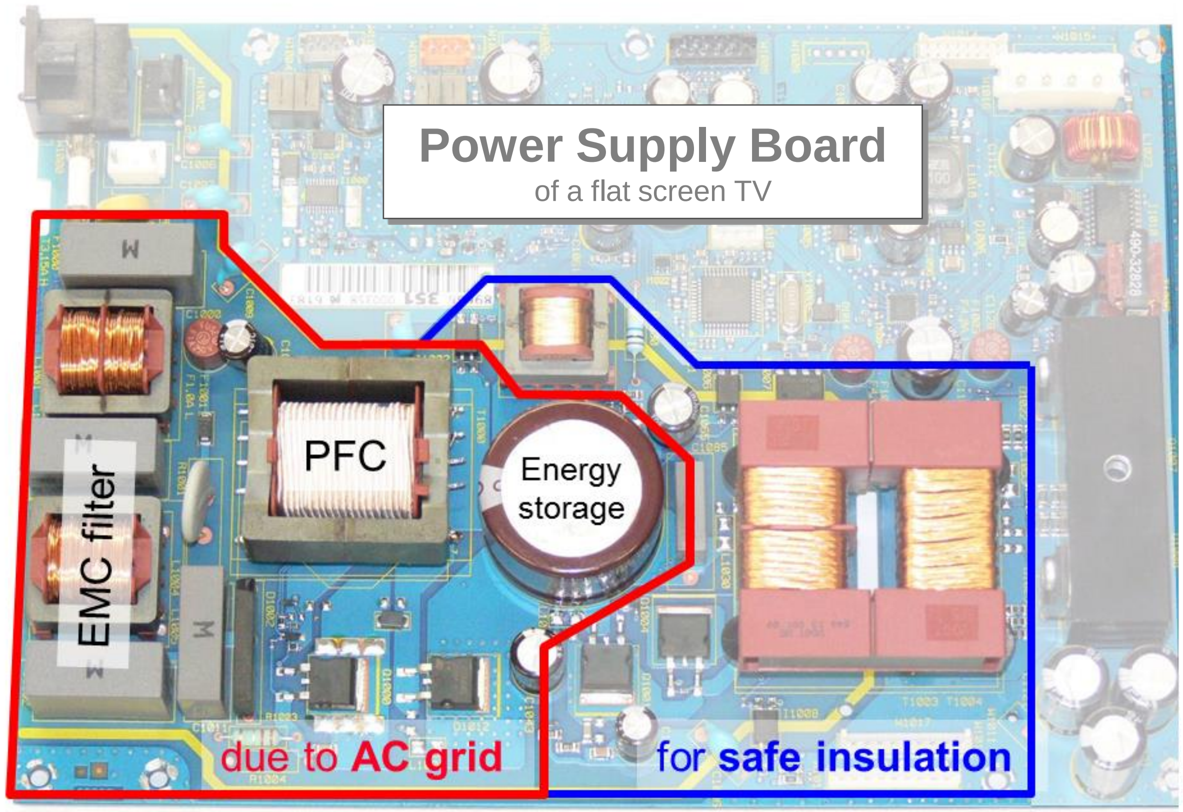
AC ■ Long time success guarantor, today more and more a burden?

Power Supply of Electronic Equipment

AC is responsible for

- **40...80%** of **power dissipation**
- **50...95%** of **weight**
- **50...95%** of **size**

in the line adapter or power supply of any electronic equipment!



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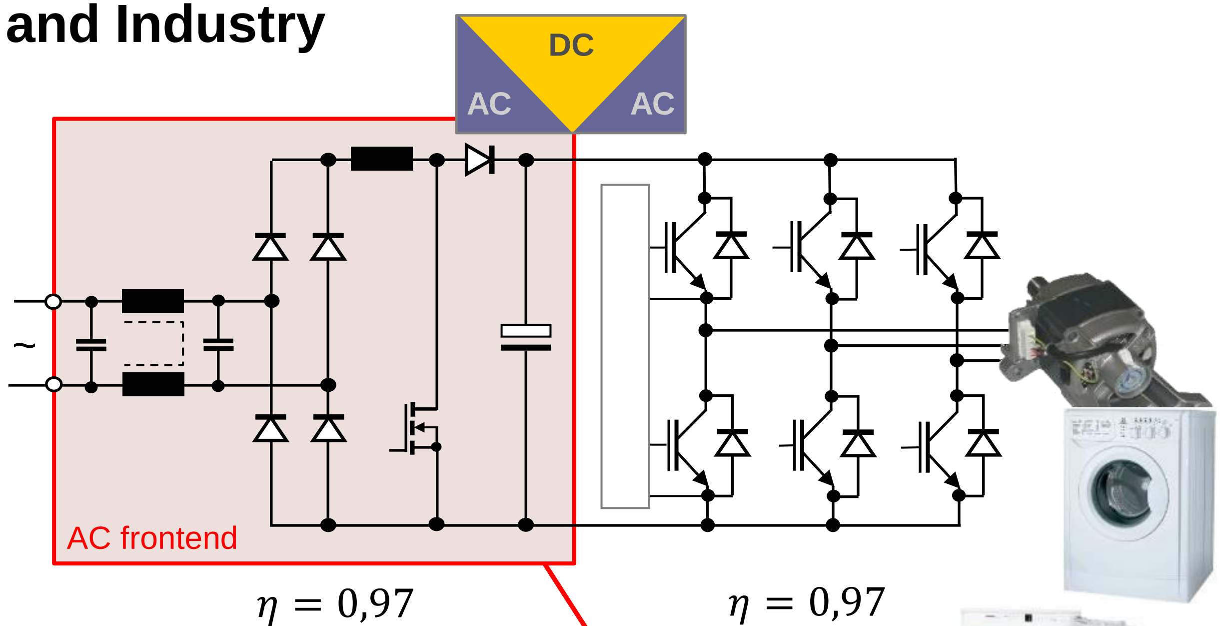
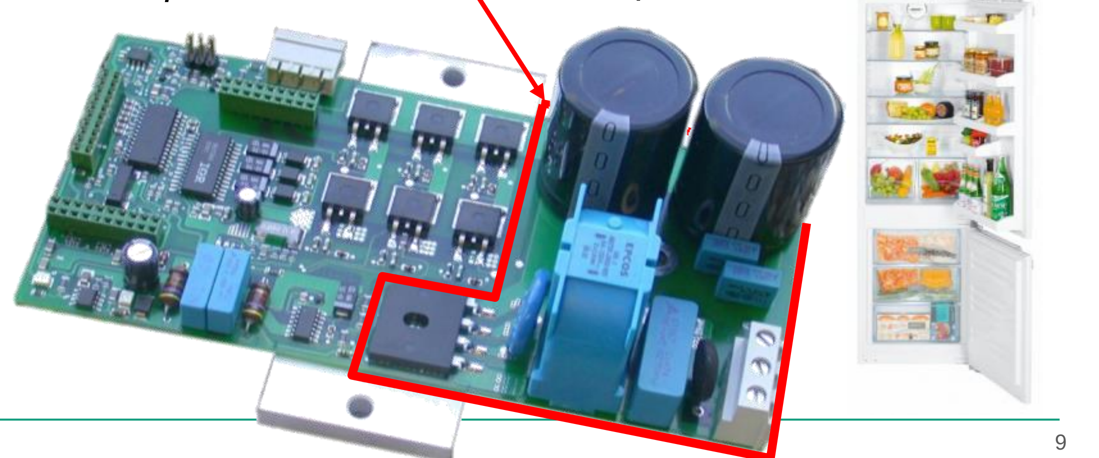
Variable Speed Drives in Home and Industry

The AC frontend is causing

- ca. **50% of cost**
- ca. **50%** of **power losses**
- > **65%** of **construction volume**

of the whole inverter!



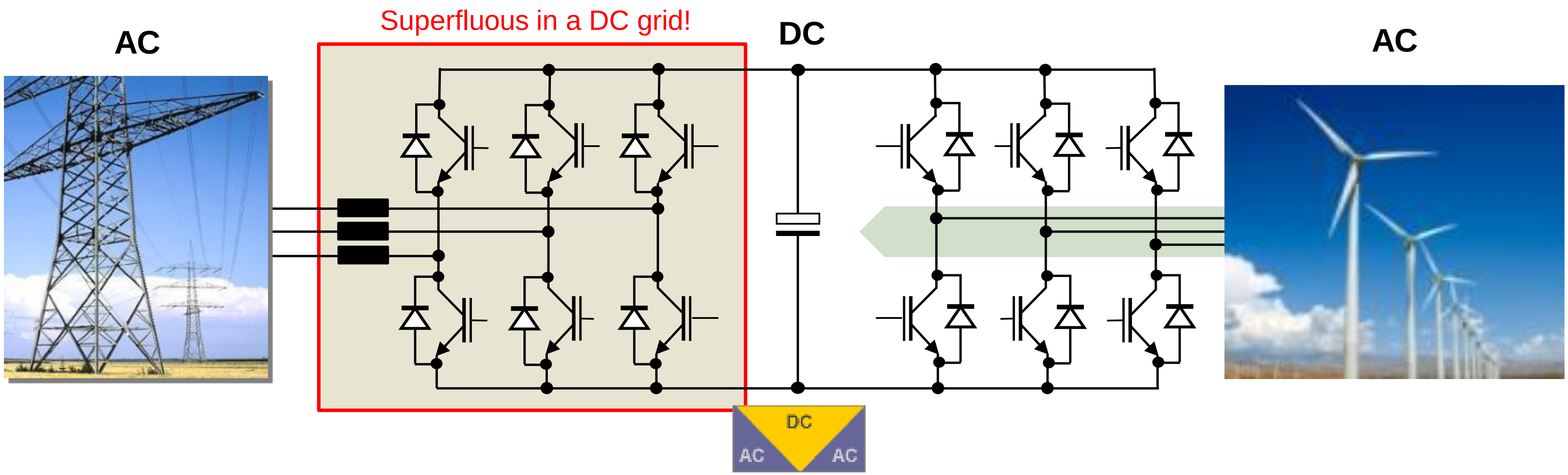


AC: Cost driver and efficiency killer

Electrical Generators

AC supply

- requires an expensive elaborate AC frontend
  ⇨ and thus makes many potentially energy-saving applications uneconomical
- causes problems with mains perturbations,
- complicates peak load buffering by means of electrical energy storages.



1) energy recuperating drives, wind power, water power, etc.

Aspects for a Reconsideration of the Historic AC Grid Concept

- **The self-use of regenerative energy is to be promoted**
  ⇨ PV, fuel cells, CHP or wind provide directly and more cost-effective DC power
- **Energy storages get outstanding importance with increasing share of wind & PV**
  ⇨ Batteries, electrolysers (H_2) work on DC basis
- **Reactive power increases losses and reduces transmission capacity in AC grids**
  ⇨ Problem does not exist in DC systems
- **Efficiency increasing in drive applications through energy recovery**
  ⇨ Much more easier and economically feasible in DC grids[1)]
- **Design and comfort aspects demand for more compact appliances**
  ⇨ DC/DC converter can be realized much smaller
- **Reduction of electronic scrap quantities**
  ⇨ DC/DC converters shrink with increasing switching frequencies and can be realized with much less material usage than line frequency AC/DC adapters

1) no AFE (active AC frontend) necessary

Electricity Generation began in Distributed Structures - DC dominated

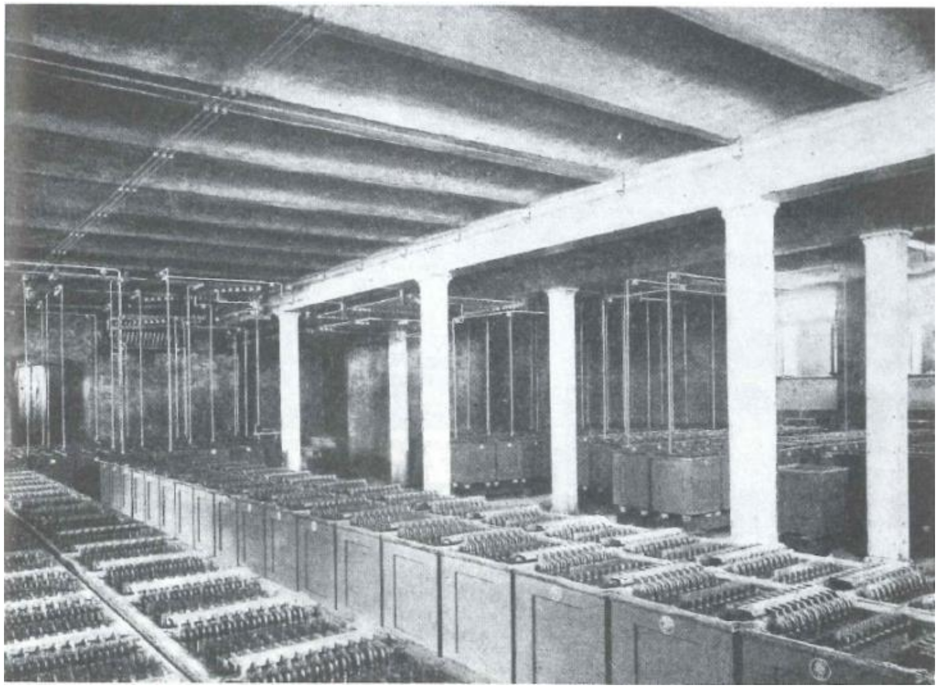
From the annual report 1911 of the Municipal electricity plant Regensburg - Germany:

Am 31. Dezbr.	Anschlußwert in KW							Zunahme in % gegen das Vorjahr	
	Gleichstrom DC				Drehstrom AC			Gleichstr. Licht	Gleichstr. Kraft
	Licht[1])	Kraft[2])	Bahn	Zusammen	Licht	Kraft	Zusammen		
1900	512,87	125,68	—	638,55	—	—	—	—	—
1901	625,83	235,00	—	860,83	—	—	—	22,0	87,2
1902	774,30	358,32	—	1 132,62	—	—	—	23,7	52,4
1903	866,64	436,42	545,60	1 848,66	—	—	—	11,9	21,8
1904	1 049,46	556,96	545,60	2 152,02	—	—	—	21,1	27,6
1905	1 160,70	634,96	545,60	2 341,26	—	—	—	10,6	14,0
1906	1 262,96	683,28	545,60	2 491,84	—	—	—	8,8	7,6
1907	1 351,45	797,55	545,60	2 694,60	—	—	—	7,0	16,3
1908	1 479,73	963,26	545,60	2 988,59	—	—	—	9,5	20,9
1909	1 585,21	1 129,60	545,60	3 260,41	—	—	—	7,1	17,3
1910	1 681,41	1 229,87	715,25	3 626,53	20,09	243,04	263,13	6,1	8,9
1911	1 761,62	1 285,88	715,25	3 762,75	31,84	469,82	501,66	4,8	4,4

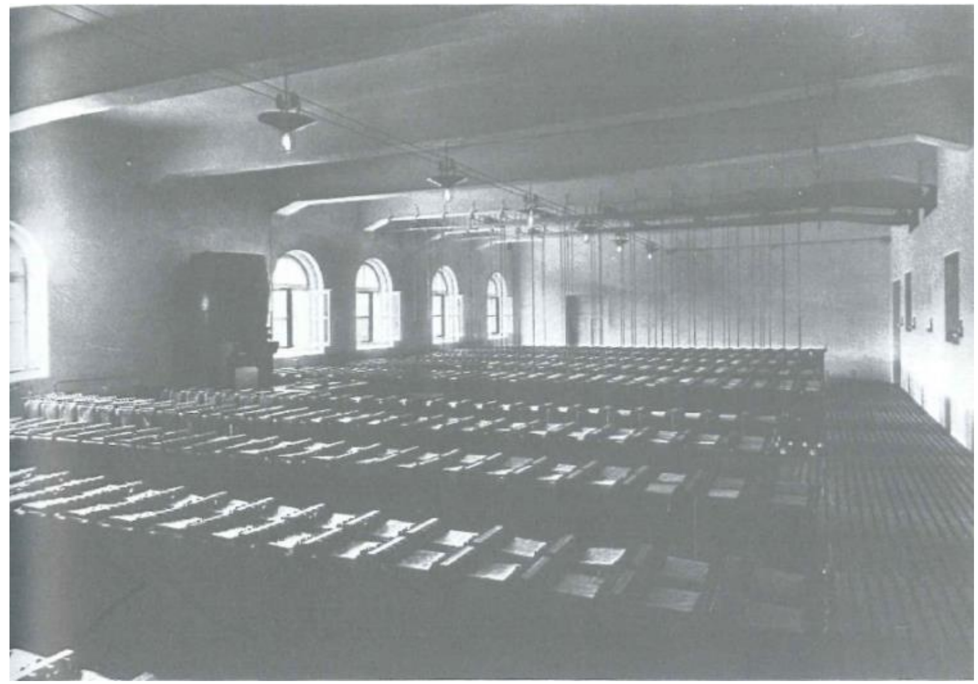
Source: Elektrizität in Ostbayern - Oberpfalz“, Toni Siegert, Bergbau- und Industriemuseum Ostbayern; Band 6;

Buffering the DC Power Supply

Accumulators hall of the municipal power station Straubing - Germany (Photo of 1901)



Accumulators hall of the municipal power station Landshut - Germany



Source: Elektrizität in Ostbayern - Oberpfalz“, Toni Siegert, Bergbau- und Industriemuseum Ostbayern; Band 6;

DC - Long time the dominant current form in rural areas!

Städt. Elektrizitätswerk Landshut: Wirtschaftsdaten 1933–1938[281]

		1933		1938	Differenz nominal	Differenz in Prozent
Stromerzeugung						
Drehstrom (Eigenerzeugung)	in kWh	1819240	AC	4311090	+ 2491850	+ 137,0 %
Gleichstrom (Eigenerzeug.)	in kWh	3361390	DC	4613528	+ 1252138	+ 37,3 %
Gesamte Eigenerzeugung	in kWh	5180630		8924618	+ 3743988	+ 72,3 %
Strombezug	in kWh	34680		156630	+ 121950	+ 351,6 %
Gesamterzeugung	in kWh	5215310		9081248	+ 3865938	+ 74,1 %
Nutzbare Stromabgabe	in kWh	4525987		8185879	+ 3659892	+ 80,9 %
Netzverluste	in kWh	689323		895369	+ 206046	+ 29,9 %
Netzverluste	in %	13,2 %		7,6 %		− 5,6-%-Punkte
Höchstlast	in kW	1440		1830	+ 390	+ 27,1 %
Benutzung der Höchstlast	in Stunden	3088		3788	+ 700	+ 22,7 %
Stromverteilung						
Niederspannung – Leitung	in km	53,5		58,9	+ 5,4	+ 10,1 %
Niederspannung – Kabel	in km	28,0		32,6	+ 4,5	+ 16,4 %
Hochspannung – Leitung	in km	19,3		18,4	− 0,9	− 4,7 %
Hochspannung – Kabel	in km	1,1		5,1	+ 4,0	+ 363,6 %
Gesamtleitungslänge	in km	101,9		115,0	+ 13,1	+ 13,0 %

Source: Elektrizität in Ostbayern - Oberpfalz“, Toni Siegert, Bergbau- und Industriemuseum Ostbayern; Band 6;

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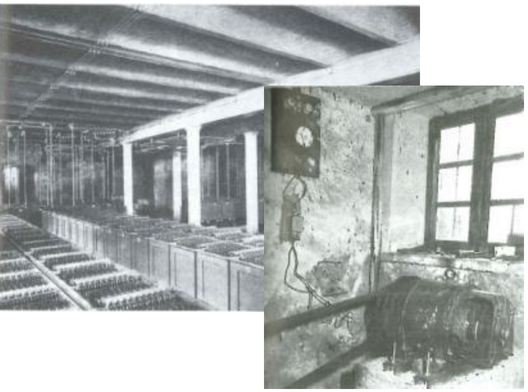
Historical development of transformer and power electronics

Was it the breakthrough for AC or just a stage win?

DC



Distributed grids
Many individual producers, mains supply buffered by batteries

AC

High supply reliability through transnational distribution grid and availability of practically any amounts of energy from large centralized power plants

?

AC and/or DC

Sustainable Energy Supply
central & distributed generators in conjunction with storages and consumers within a smart grid

1900 | 1950 | 2000

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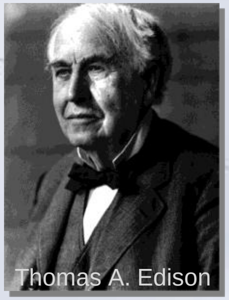
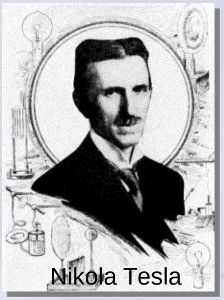
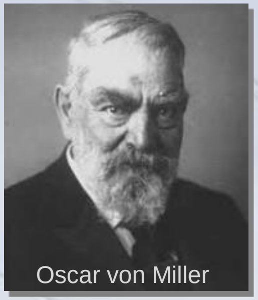
Historical development of transformer and power electronics

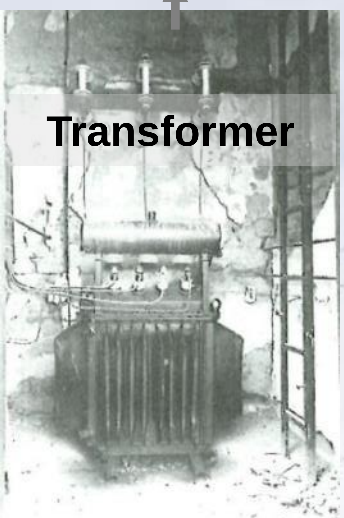
Some technical boundary conditions have changed







1885 — **1960** — **1970** — **1980**



Si power diodes

Bipolar power transistors

Power modules

Power MOSFET

IGBT

Power electronics

today allows for flexible and highly efficient conversion of electrical energy into any desired form.

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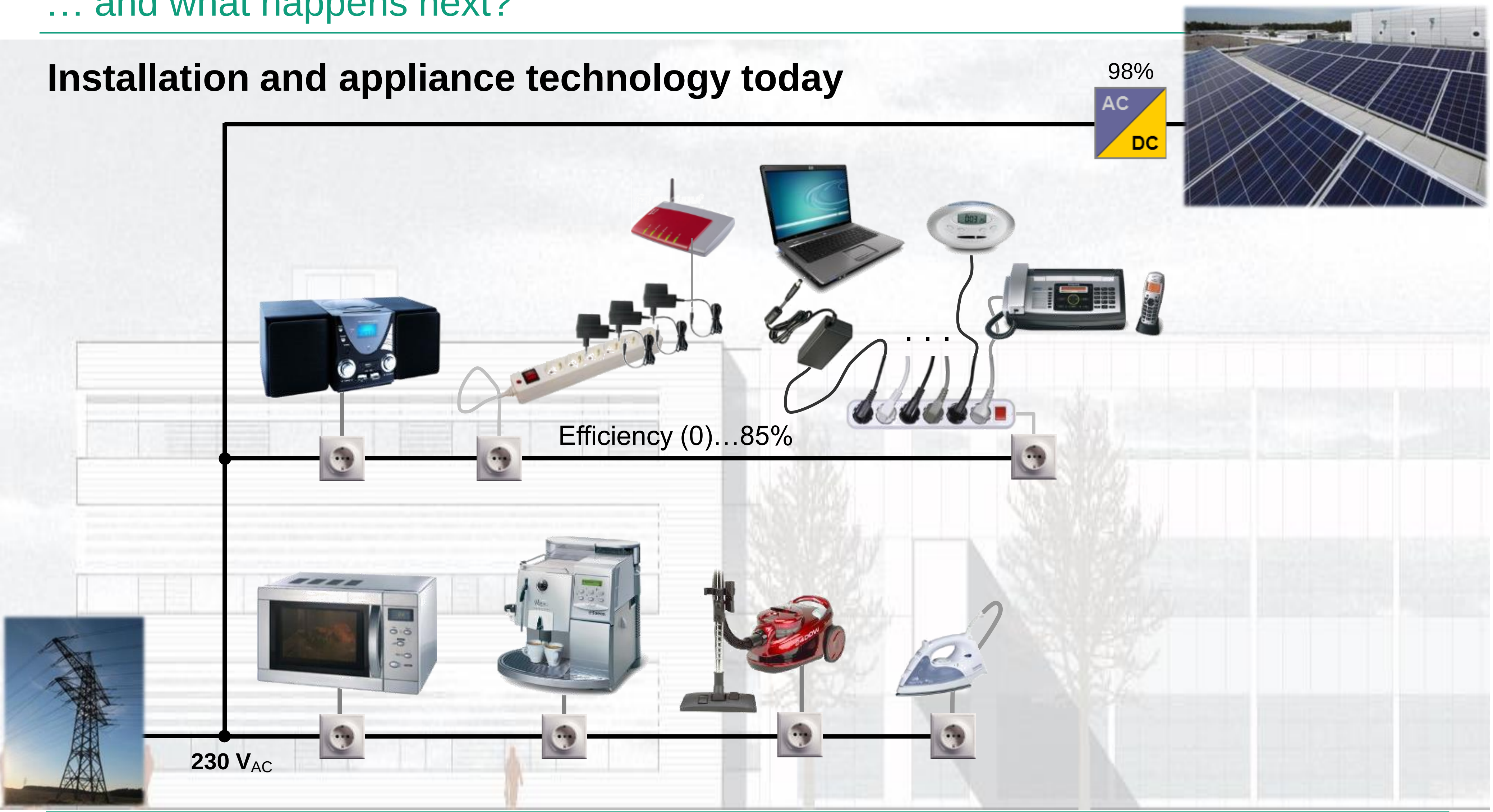
… and what happens next?

Installation and appliance technology today



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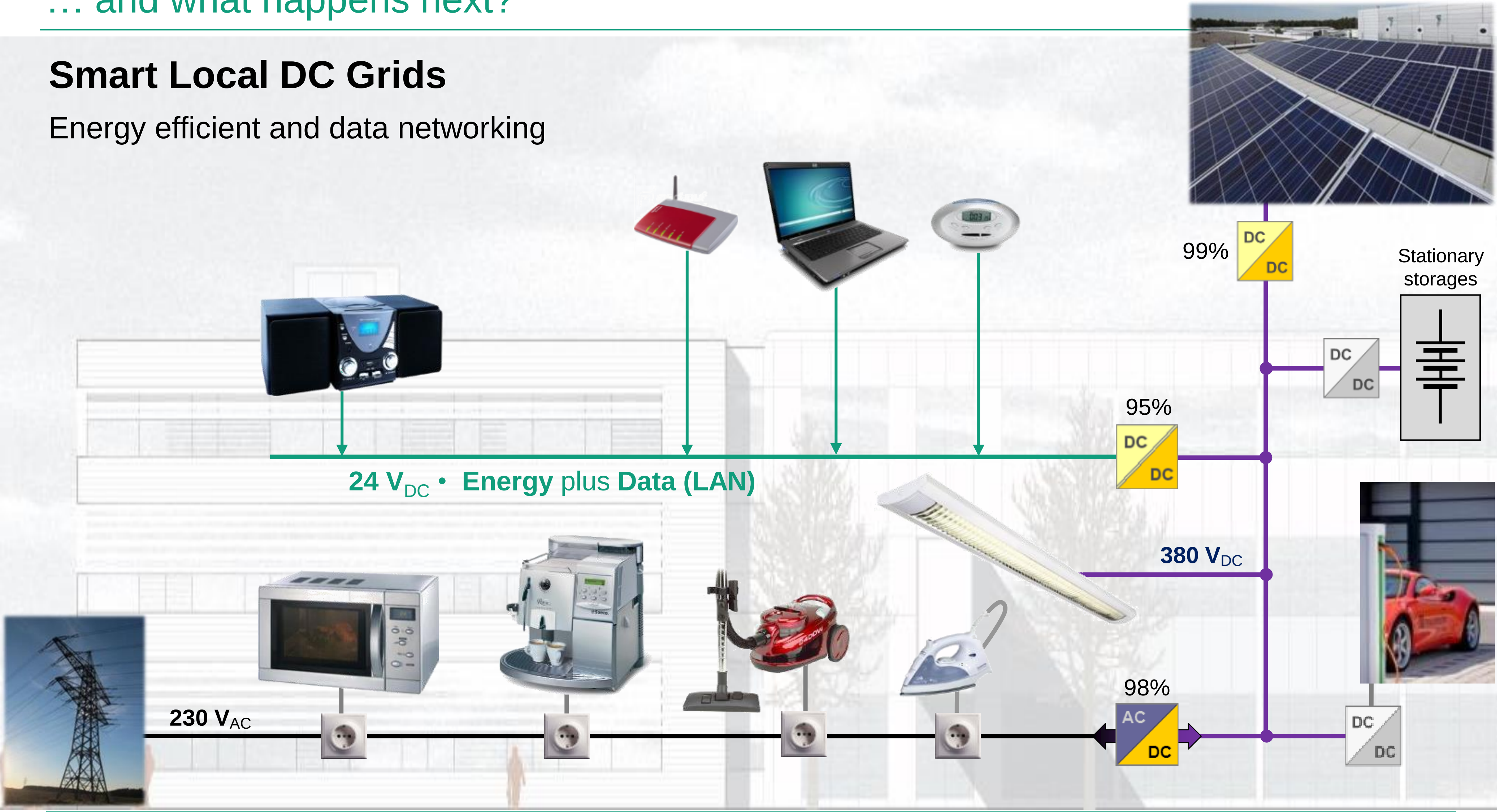
Smart Local DC Grids

Energy efficient and data networking



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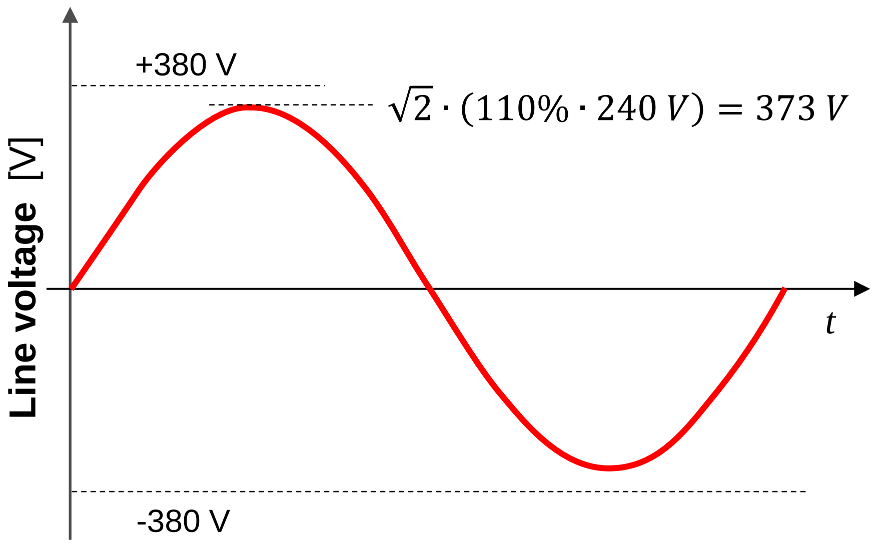
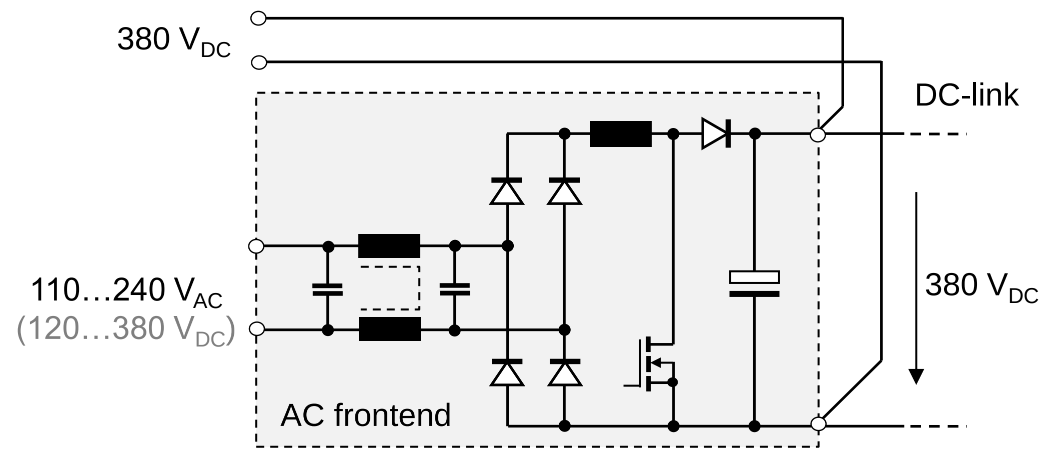
Why a DC voltage of 380 Volt?

Virtually all electronic equipment today has a switch mode power supply at the AC input, that internally uses a voltage in the range of 380...400 V as DC-link voltage.





⇨ In principle, all these appliances can be operated directly to 380 V_{DC}.

More and more electronic devices already allow an operation also with DC

Examples: Drivers (power supplies) for LED lighting

aimtec
Your Power Partner

Series AMER120-AZ
up to 5A | AC-DC LED driver

FEATURES:

- AC-DC Constant current LED Driver
- Input range 90-277VAC/47-440Hz
- High Efficiency up to 91%
- Operating temperature -40 to 85°C
- Over Temperature Protection
- Waterproof Case rated IP67
- Power Factor Correction
- SCP, Over Current Protection

RoHS CE cULus

Models
Single output

Model	Max Output Power (W) *	Output Voltage Range (V)	Output Current (A)	Input Voltage (VAC/Hz)	Input Voltage (VDC)	Efficiency (%)
AMER120-50250AZ	125	36-50	2.5	90-277/47-440	120-390	91
AMER120-36340AZ	122.4	24-36	3.4	90-277/47-440	120-390	90
AMER120-24500AZ	120	12-24	5	90-277/47-440	120-390	90

MW MEAN WELL

INPUT	VOLTAGE RANGE Note.5	90 ~ 295VAC	127 ~ 417VDC	
	FREQUENCY RANGE	47 ~ 63Hz		
	POWER FACTOR	PF≥0.95/230VAC	PF≥0.98/115VAC at full load a	
	EFFICIENCY (Typ.)	88%	88%	90%
	AC CURRENT	2A / 115VAC	1A / 230VAC	
	INRUSH CURRENT(max.)	COLD START 65A/230VAC		
	LEAKAGE CURRENT	<1mA / 240VAC		

Although the universal voltage capability brings only little gain in efficiency and no benefits with respect to overall volume, weight and cost, it facilitates changeover scenarios significantly.

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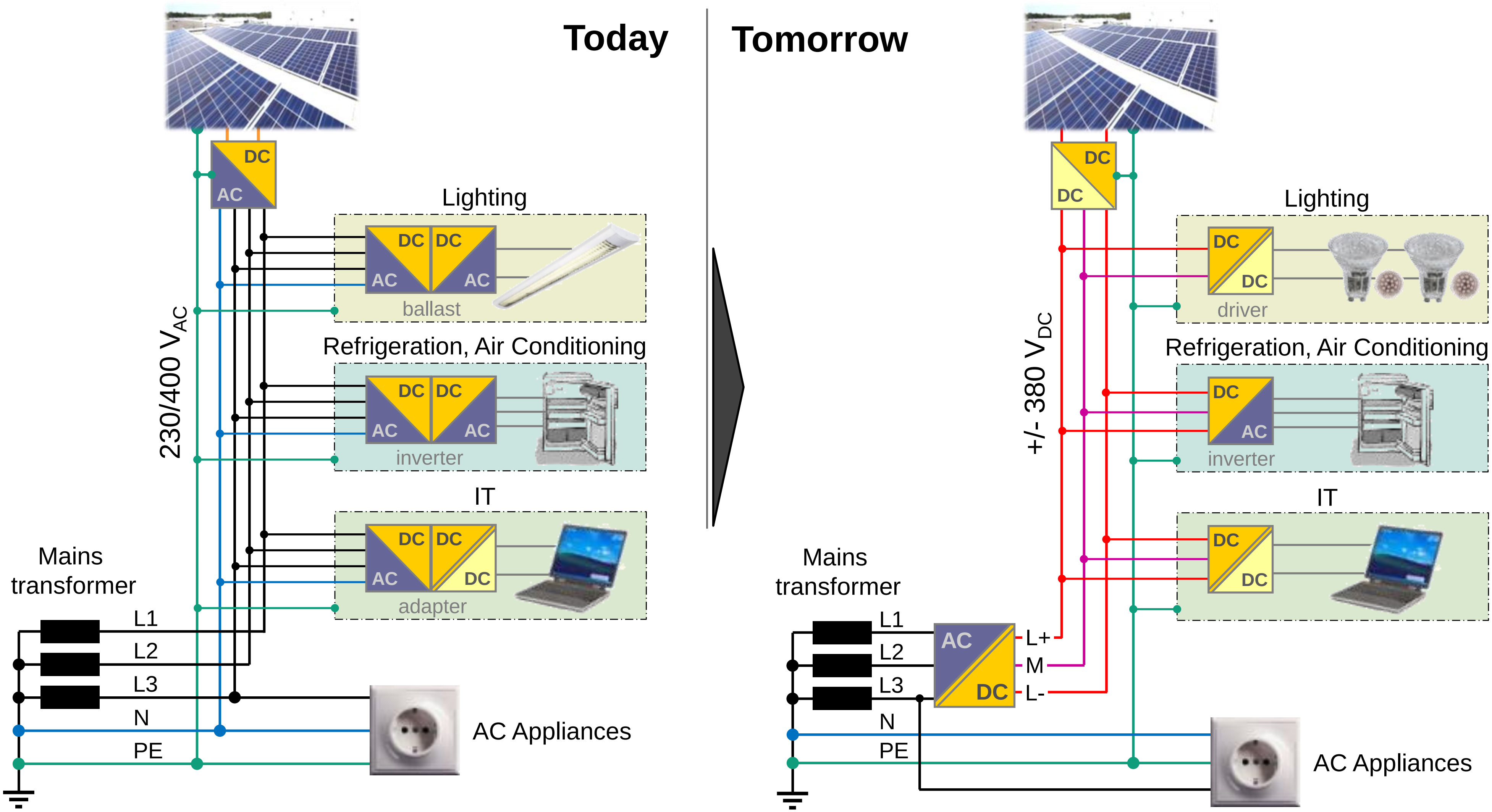
DC Grid Technologies



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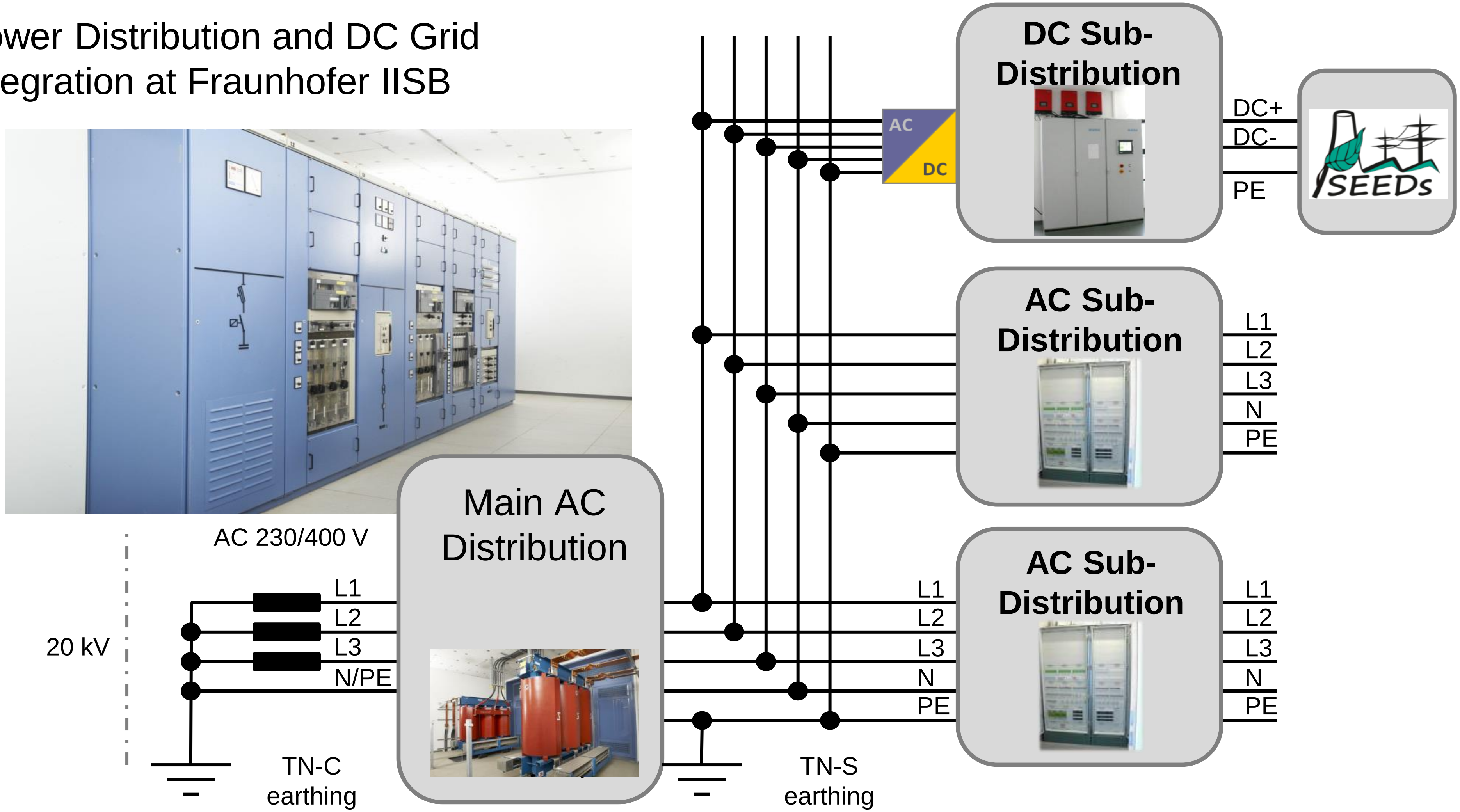
DC Grid Technologies

Power Distribution and DC Grid Integration at Fraunhofer IISB



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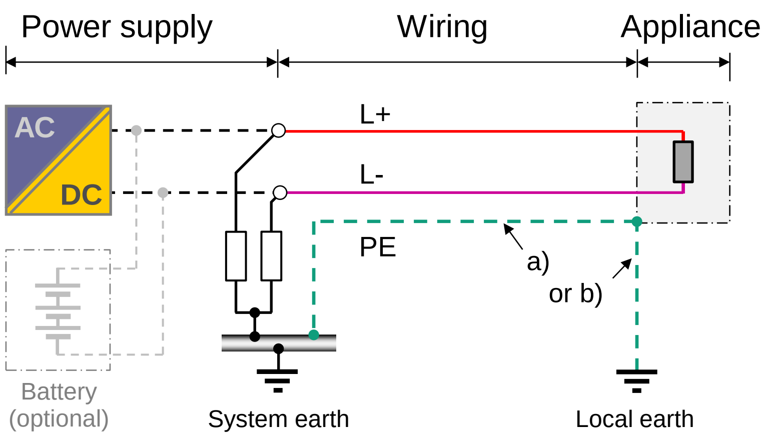
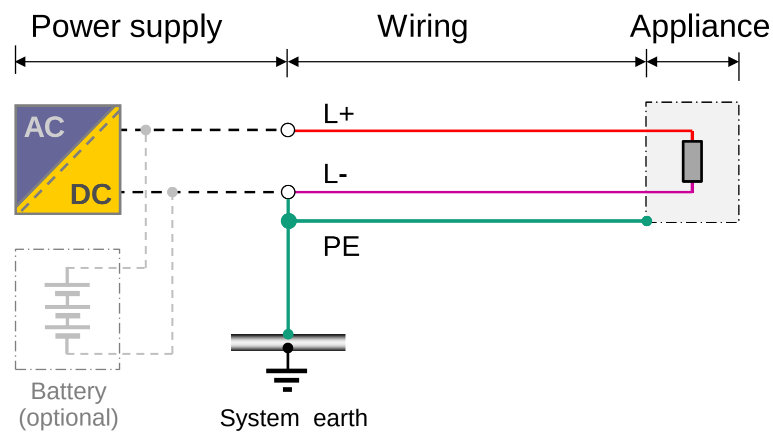
Protection and Earthing Concepts

IT system with high-ohmic symmetric grounding



- A single fault (e.g. ground fault) causes a message but no shutdown ⇨ high availability
- High-ohmic earthing is permissible, however, the impedance must be high enough so that no dangerous body currents can flow (typ. > 50 kΩ)
- Symmetrical earthing facilitates error detection and avoids problems with CM-filter chokes

TN-S system



- A single fault already leads to a shutdown
- Higher compatibility with (from AC world) established earthing concepts and appliances
- Higher robustness as well as easier fault identification and fault isolation

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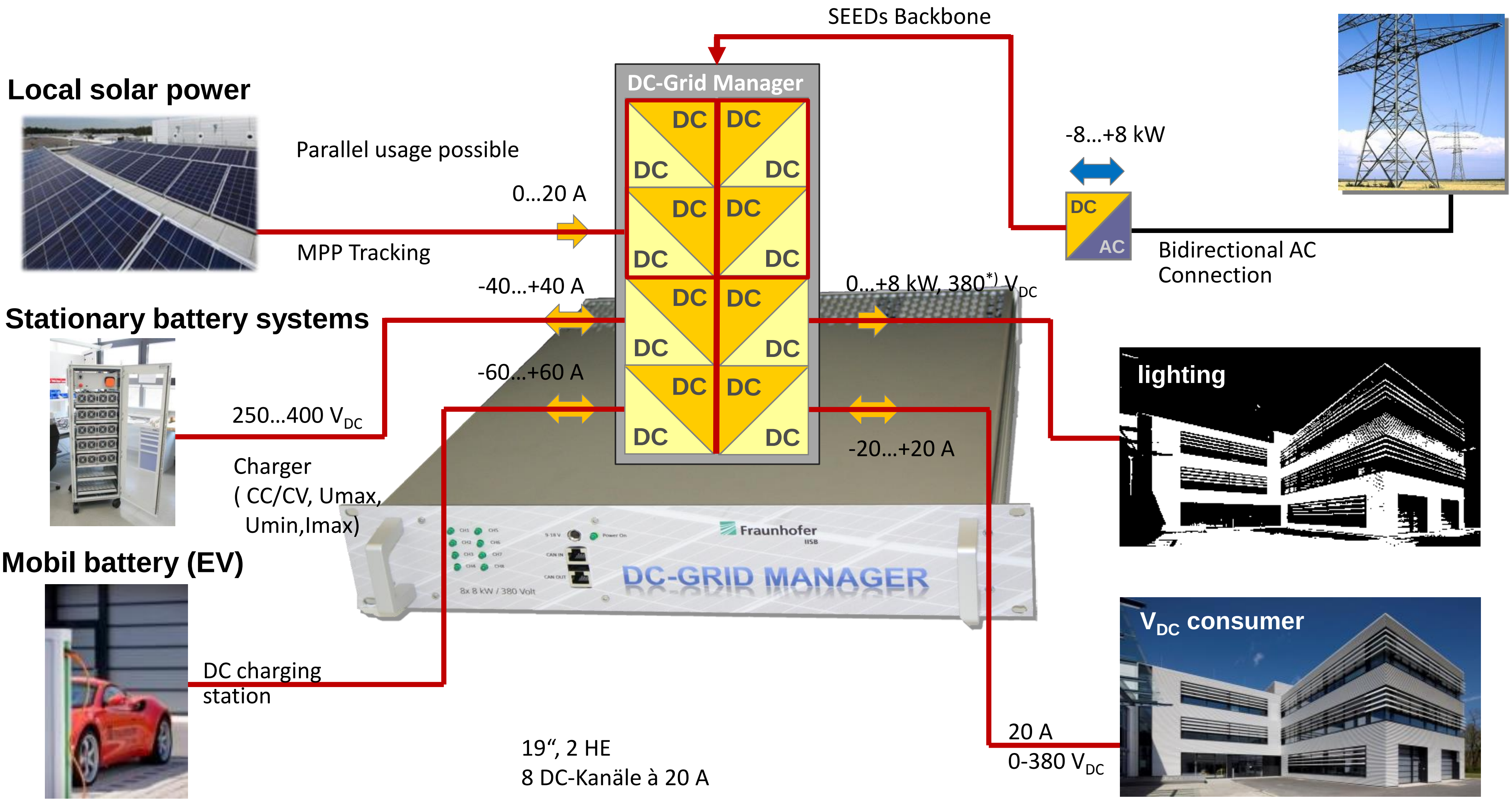

* Voltage according to ETSI EN 300 132-3-1

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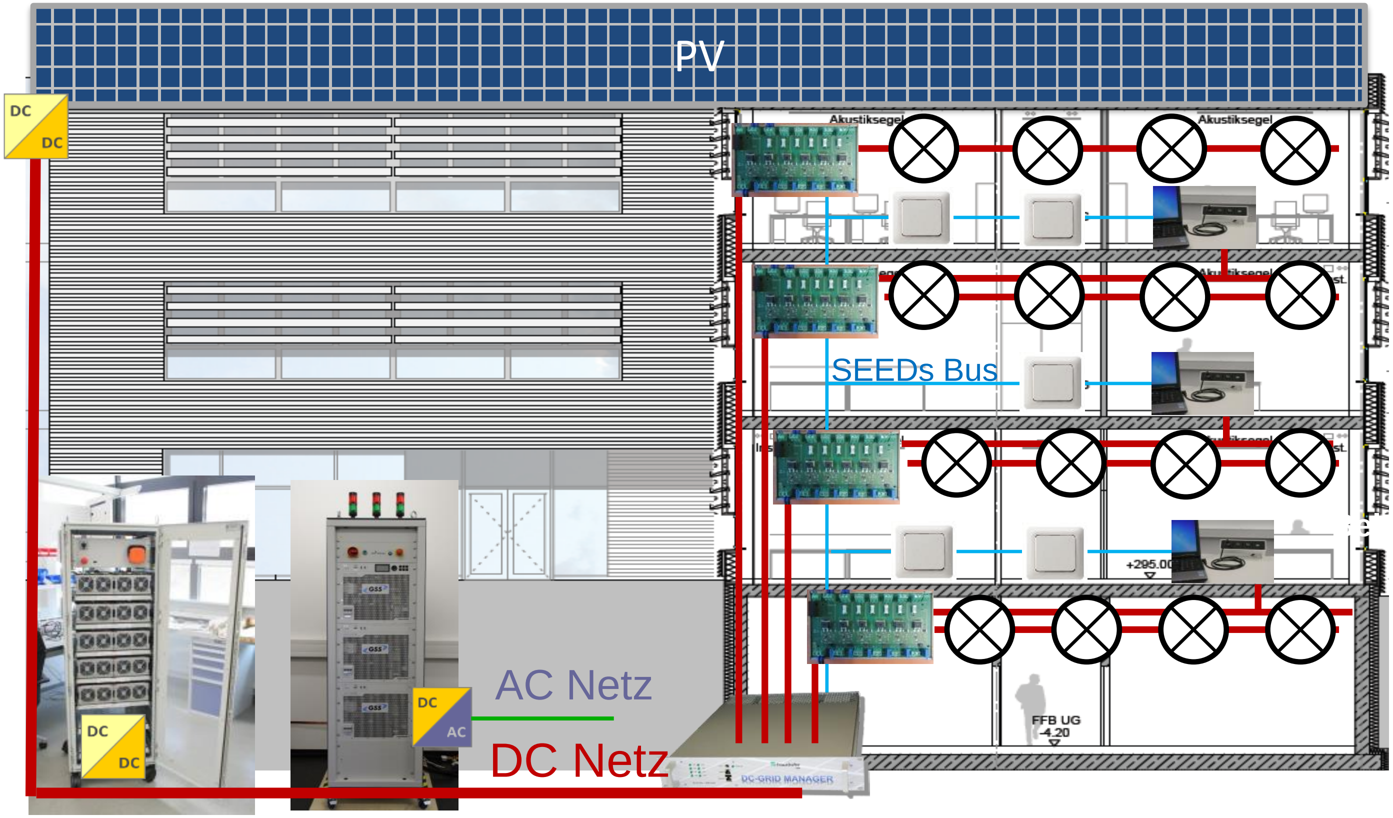


IISB Battery Storage
3x 20 kWh
P_{max} = 100 kW

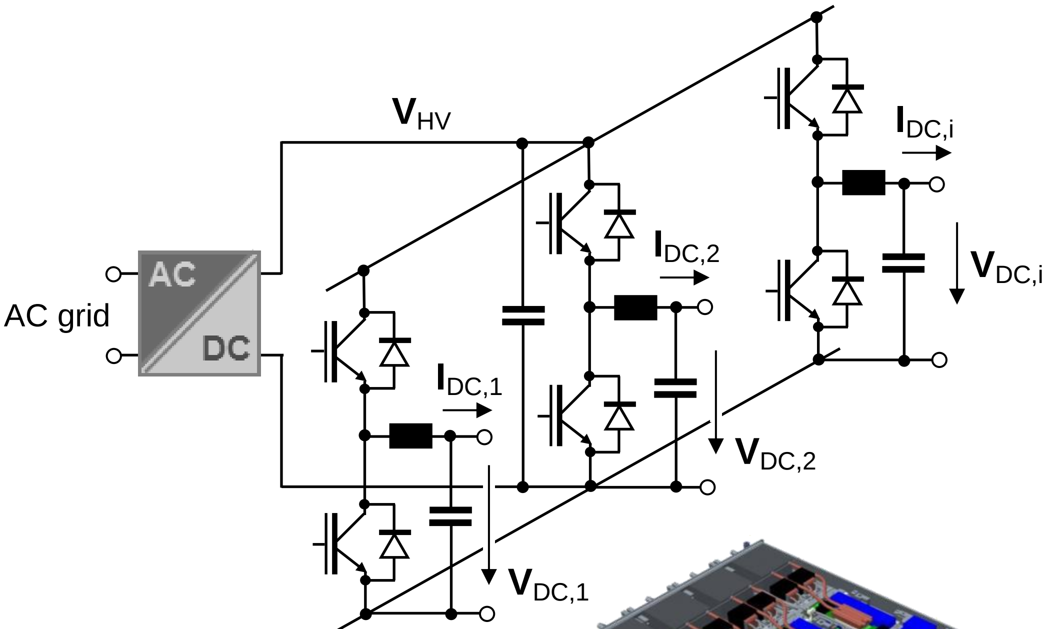
Inverter and Rectifier
P_{max} = 100 kW

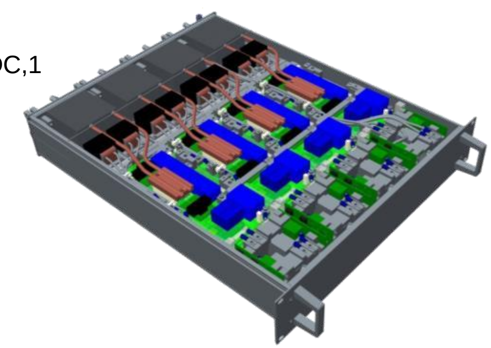
DC-Grid Manager
P_{max} = 64 kW

24 V Desk System
(3x100W 5-24 V)

DC-Grid Manager

Block diagram

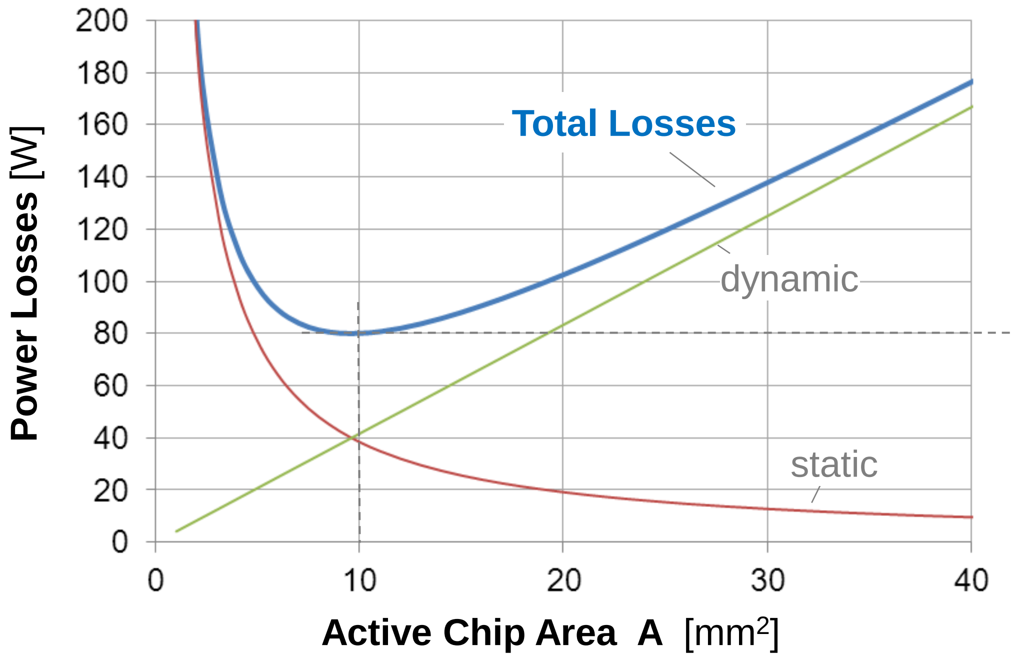




Characteristics

- Arbitrarily configurable DC channels (as voltage/current controlled source or sink)
- High control dynamics for fast fault-control and lowest fault energy
- Separate channels for single load or grid sections allow:
  - fast fault isolation
  - individual current limiting characteristics (short circuit behavior)
  - complex control functions (MPP tracking, charge/discharge control of batteries, …)
  - arc extinction
- High efficiency over a very wide load range

Intrinsic Losses in Hard Switched Topologies



$$A_{\mathrm{opt}} = \frac{I_{eff}}{\sqrt{f_{\mathrm{sw}}}} \cdot \sqrt{\frac{R_{on}^{(A)}}{E_{oss}^{(A)}}}$$

$$P_{\mathrm{v,total}}(A) = \frac{R_{on}^{(A)}}{A} \cdot I_{eff}^{2} + E_{oss}^{(A)} \cdot A \cdot f_{\mathrm{sw}}$$

$$P_{\mathrm{v,min}} = 2 \cdot I_{eff} \cdot \sqrt{f_{\mathrm{sw}}} \cdot \sqrt{R_{on}^{(A)} \cdot E_{oss}^{(A)}} = 2 \cdot I_{eff} \cdot \sqrt{f_{\mathrm{sw}}} \cdot \sqrt{R_{on} \cdot E_{oss}}$$

Circuit: $2 \cdot I_{eff} \cdot \sqrt{f_{\mathrm{sw}}}$

FOM of power semi-conductor technology[1)]: $\sqrt{R_{on} \cdot E_{oss}}$

Fundamental efficiency limit

$$\eta_{\max} = 1 - \sqrt{\frac{2}{\pi} \cdot \frac{f_{\mathrm{sw}}}{f_{22}^{*}}} \quad \text{with} \quad f_{22} = \frac{1}{2\pi \cdot R_{on} C_{oss,e}}$$

1) as a Figure-of-Merit (FOM) this term characterizes a technology not only a certain device!

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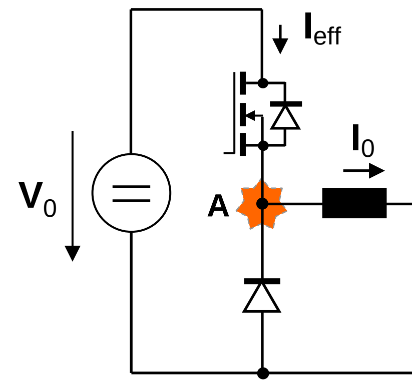
Fundamental Efficiency Limit

With the **cut-off frequency** of a switching cell[1)], e.g.

$$f_{22} = \frac{1}{2\pi\, C_{tot}\; R_{on,150°C}} = \frac{1}{2\pi \cdot 80\,\mathrm{pF} \cdot 0{,}5\,\Omega} = 4{,}0\,\mathrm{GHz}$$



the upper efficiency limit can be written as:

$$\eta_{max} = 1 - \frac{P_{v,min}}{P_{in}} = 1 - \sqrt{\frac{2}{\pi} \cdot \frac{f_{sw}}{f_{22}}} = \begin{cases} 99{,}9\% & @\; f_{sw} = 10\,\mathrm{kHz} \\ 99{,}6\% & @\; f_{sw} = 100\,\mathrm{kHz} \\ 98{,}7\% & @\; f_{sw} = 1\,\mathrm{MHz} \end{cases}$$

Requirements

- Power semiconductors with very high cut-off frequencies and **unipolar** behaviour in the 1 **and** 3(!) quadrant of the output characteristic
- Very low-capacitance dynamic nodes, i.e. power inductors with very low winding capacitance, substrate designs with very low ground capacitance
- Very low-inductive commutation cells

1) where C_{tot} is the total capacitive load of the dynamic node A!

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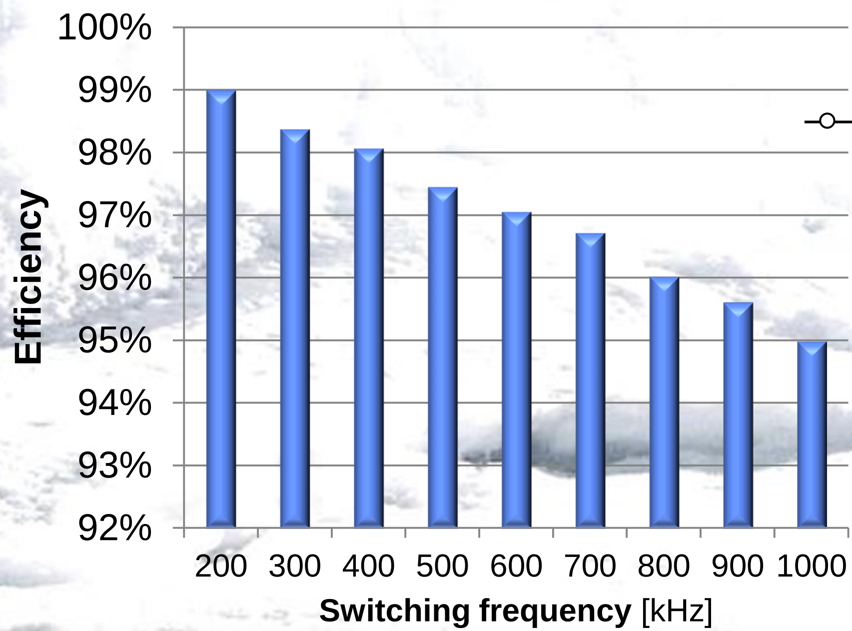
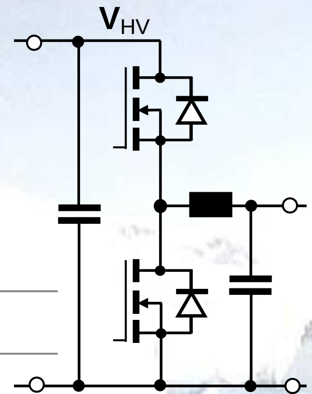
SiC and GaN open new Horizons in Power Density and Efficiency

Fraunhofer IISB ■ **GaN-Reference Design**[1)]

- Buck/Boost converter
- GaN devices (600 V, normally-off)
- Output power: 1,5 kW (@380 V)
- **Power density: >30 kW/dm³**





Fraunhofer IISB ■ **SiC-Reference Design**[1)]

- Buck/Boost converter
- SiC MOSFET, 1200 V, normally-off
- Switching frequency: **200 kHz**
- **Efficiency: >98,5 %** (760 V ⇨ 670 V)
- **Power density: 140 kW/dm³**

1) with Panasonic devices

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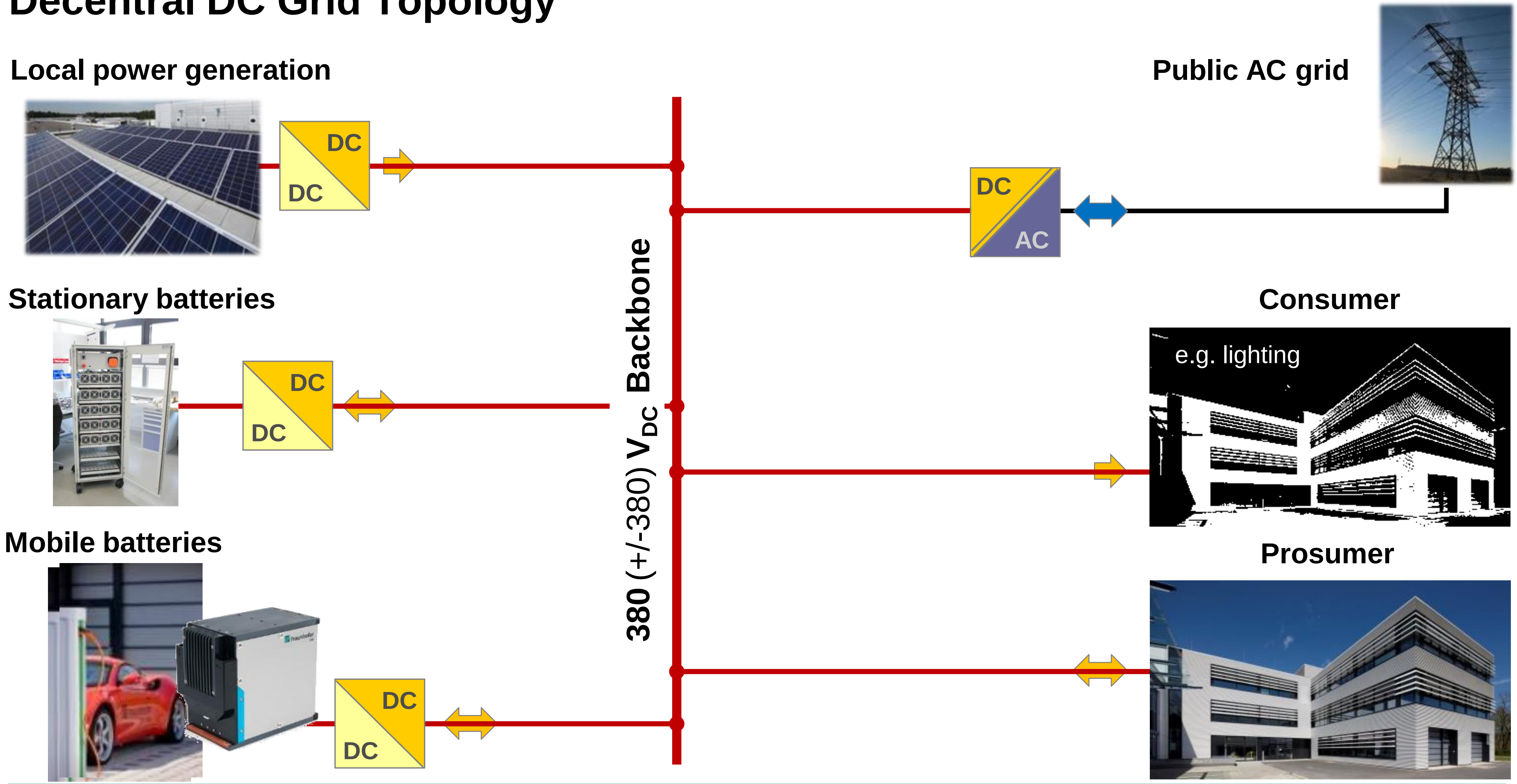
DC Grid Technologies

Decentral DC Grid Topology



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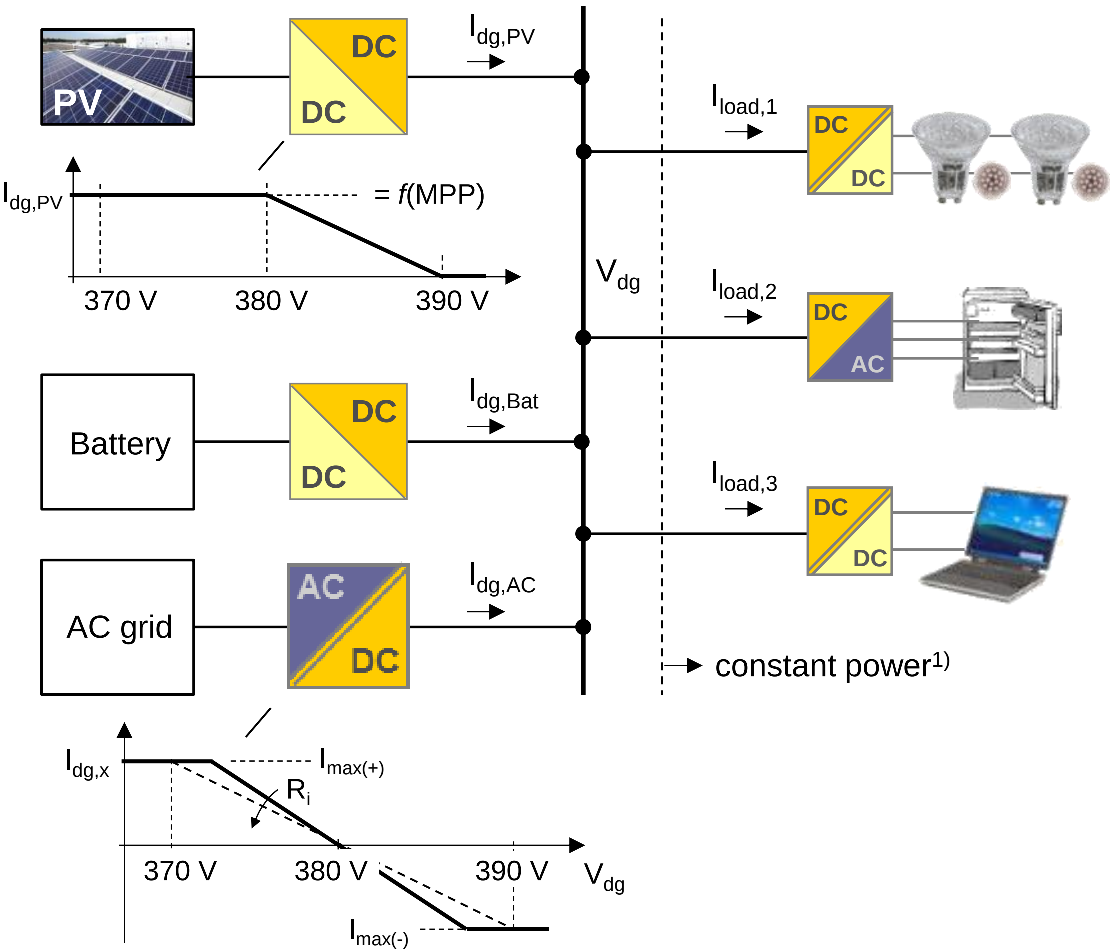
How to control a grid without a superordinated master?



Droop Control

- The grid voltage (V_{dg}) serves as the central control variable
- All feed-in converters operate as voltage sources **with internal resistance**

Advantages

- No superordinate controller in the grid necessary
- Maximum in reliability, availability and flexibility

Challenge

- Ensuring the dynamic grid stability under any constellations
  ⇨ self-parameterizing controller

1) typically negative differential input impedance, i.e., input current increases as line voltage drops

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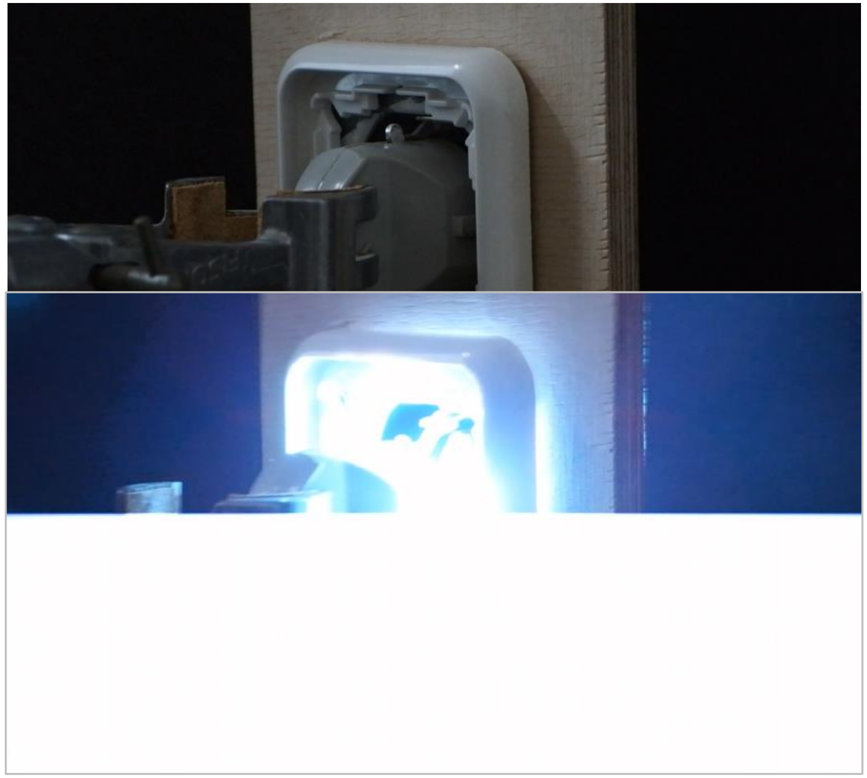
Problem "Mechanical Switches and Connectors"

230 V_{AC} / 10 A

380 V_{DC} / 10 A



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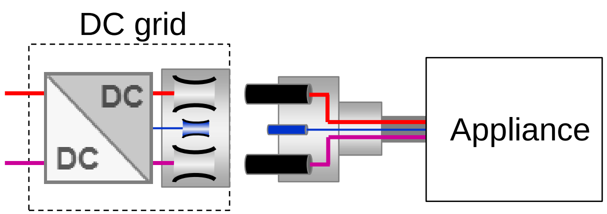
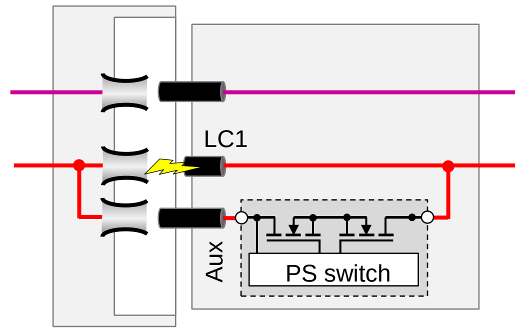
HV-DC Plug Concepts

Pilot Contact
(leading opening)



- Plug-in is performed without current
  (Appliance draws load current only when pilot contact is closed, i.e. after closing the load contacts, and reduces current to zero before disconnecting)
- Evaluable also on the source side to shutdown the voltage

Hybrid Connector[1)]



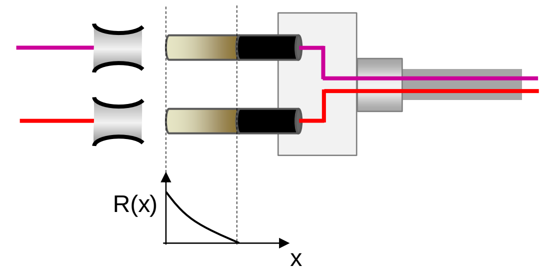
The arc voltage, arising when the leading contact LC1 opens, drives a power semiconductor switch:

⇨ PS switch and auxiliary contact (Aux) take over the load current

⇨ the arc at LC1 extinguishes immediately

⇨ PS switch disconnects current before the load contacts open

Resistive Pin Tip



- Resistive pin tip (e.g. of SiC)
- Auto precharge for capacitive loads
- Error case "incomplete plugging" must be suitably catched

1) after patents of SMA (DE102 25 259 B3) and E.T.A (DE20 2009 004 198 U1)

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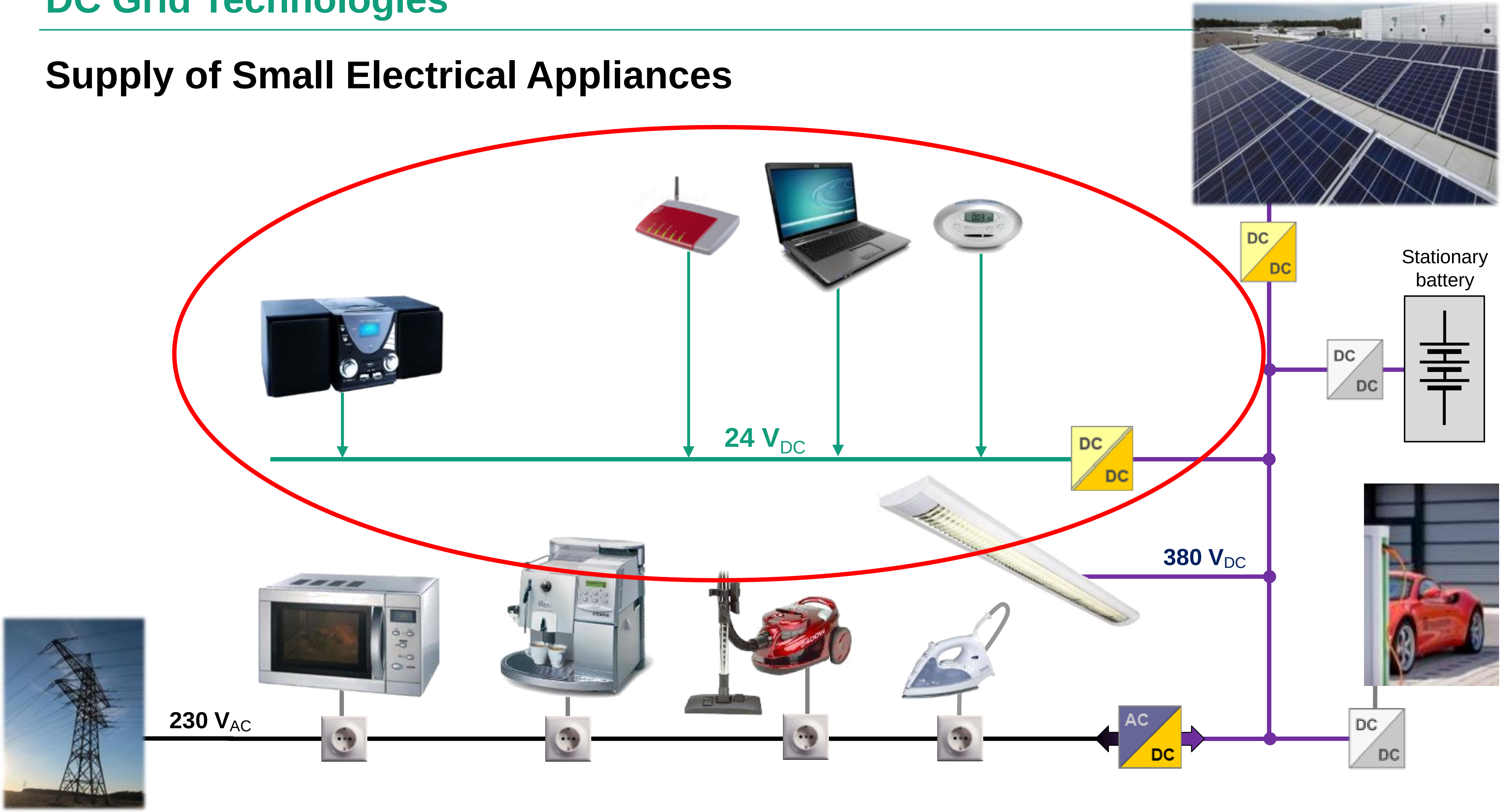
Supply of Small Electrical Appliances



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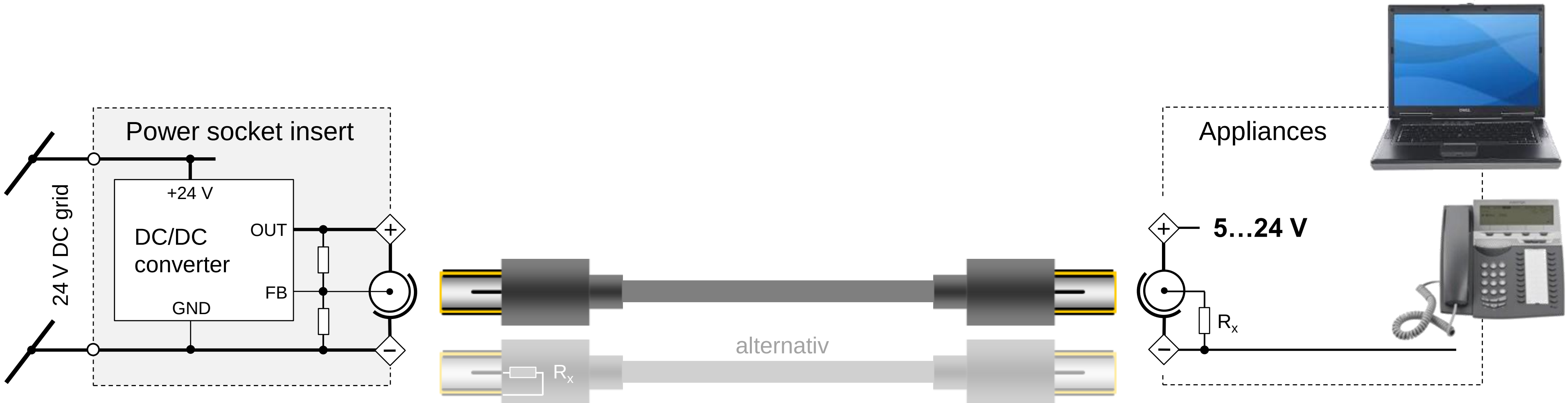
An Universal LV-DC Plug System



- **One** plug for **all** low-power appliances[1)]
- The socket provides the individual supply voltage requested from the appliance
- Electroless, arc-free (dis)connection by leading opening pilot contact

1) up to 100 Watt

Size Comparison

AC Line Adapter vs. LV-DC/DC Converter

75 W

230 V_{AC} ⇨ 19 V_{DC}

Efficiency: **87 %**

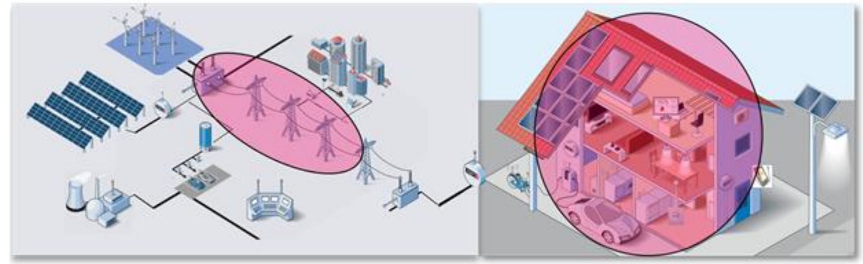
75 W

24 V_{DC} ⇨ 19 V_{DC}

Efficiency: **95 %**

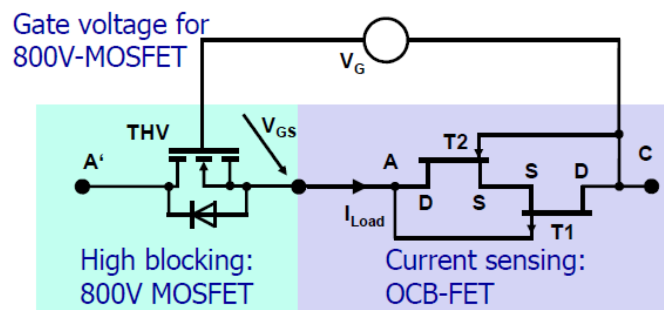
European Projects

E2SG – "Energy to Smart Grid"
http://www.e2sg-project.eu/



SEEDs – "Keimzellen für die Energiewende im Industriemaßstab"
http://www.energy-seeds.org/

NEST-DC – Research Objective Is Innovative Electronic Circuit Breaker for Renewable Energy and On-Board Grids
http://www.infineon.com/cms/en/about-infineon/press/press-releases/2014/INFXX201407-050.html



Other DC Projects: DC Forward, DC=DeCent, Smart Grid Solar, …

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DC Micro Grids

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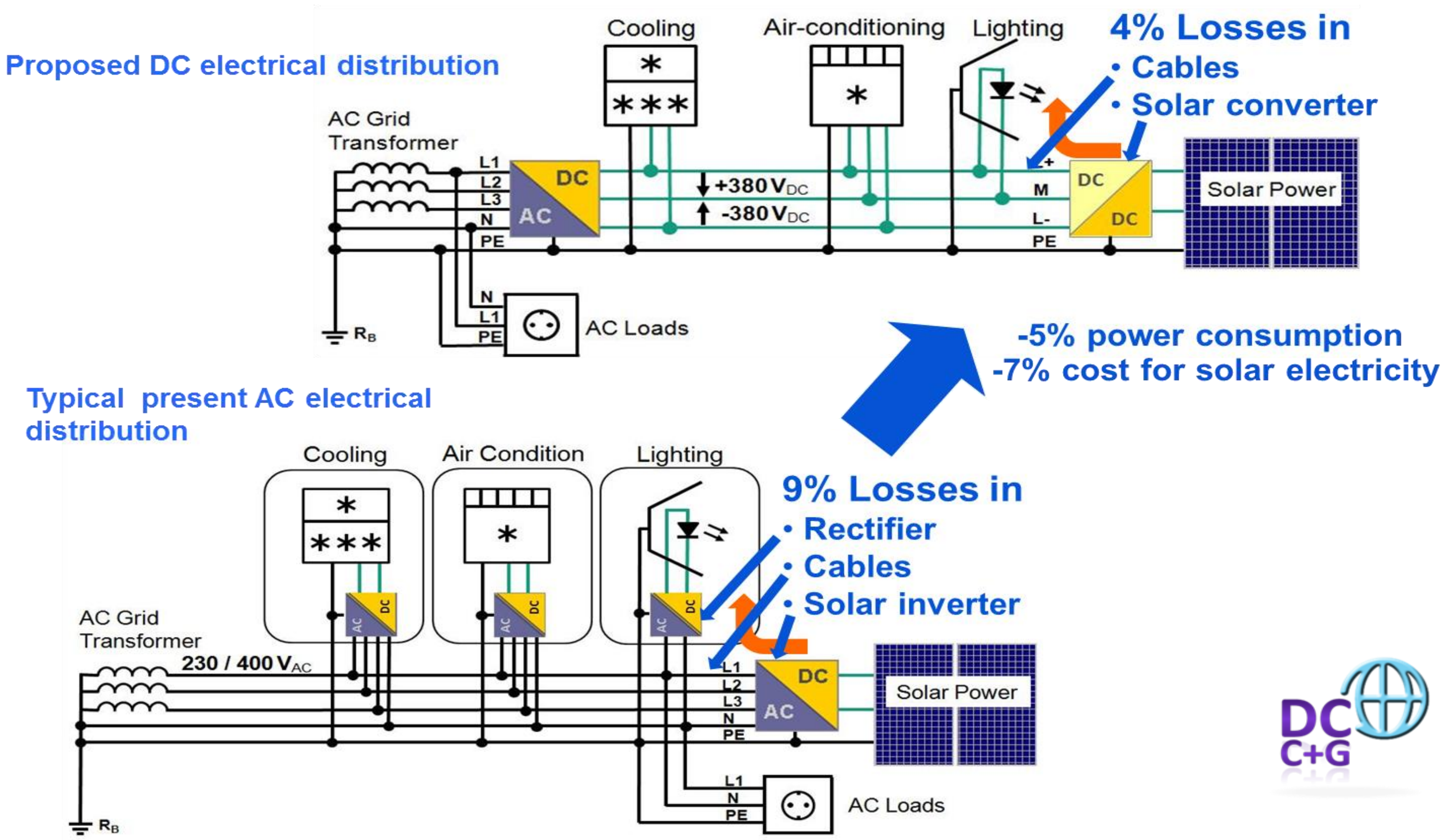
DCC+G



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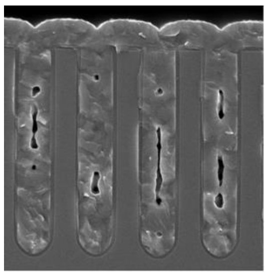
MPT-IGBT technology



Semiconducter Technologies

Hybrid DC-Switch (5 kA @ 380 V_{DC})

Development of new Devices and Komponents (IGBT, DC-Current Sensor, DC-Switches, Arc Detection, ...)

µCHP Unit (Gas to DC Grid)

Design and Development of complete Systems and Demonstrators with new Devices

Deomonstration

In real Applications

Office Testbed at Fraunhofer IISB (Erlangen)

Ligthing Testbed at Philipps Resarch Center (Eindhoven)

Evaluation and Verification of DC-Grid compared to AC-Grid

04 /2015

Philips Lighting Test Bed in Eindhoven

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Summary

The combination of DC and AC to a smart hybrid grid allows

- **Cost reduction** on device, infrastructure and system level
- **Increase of comfort** („smaller, lighter“) **and connectivity** („Internet of things“)
- **Increase of design freedom** (e.g. LED lighting)
- **Easier integration of renewable energy sources and electric storages**
- **Increase of energy efficiency**

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