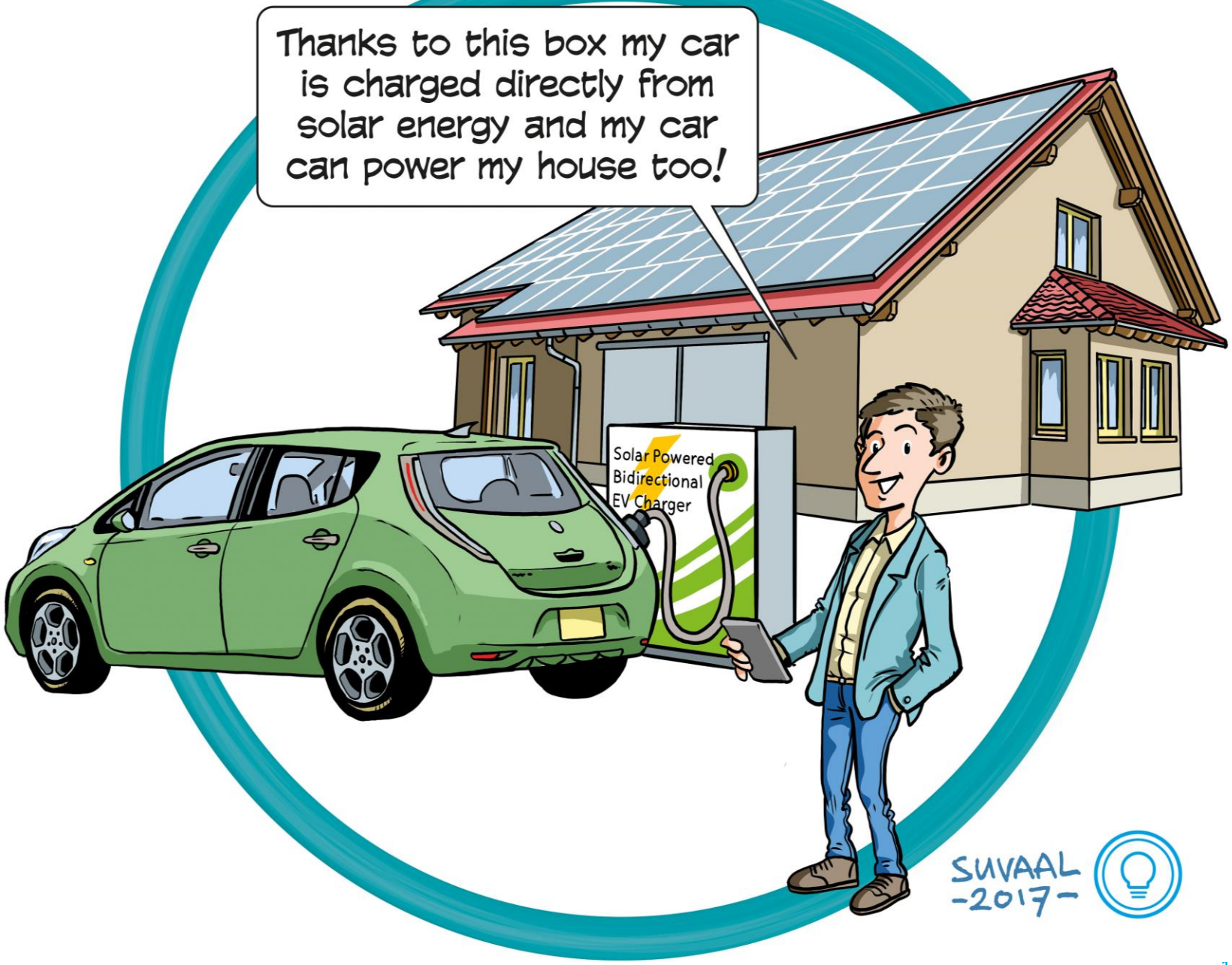

Thanks to this box my car is charged directly from solar energy and my car can power my house too!
Solar Powered Bidirectional EV Charger
SUVAAL
-2017-

DCE&S
DC systems, Energy conversion & Storage

ARCHI 2018 | February 8th, 2018
2nd Symposium Applied Research on Charging Infrastructure

Solar powered bidirectional EV charger with V2G

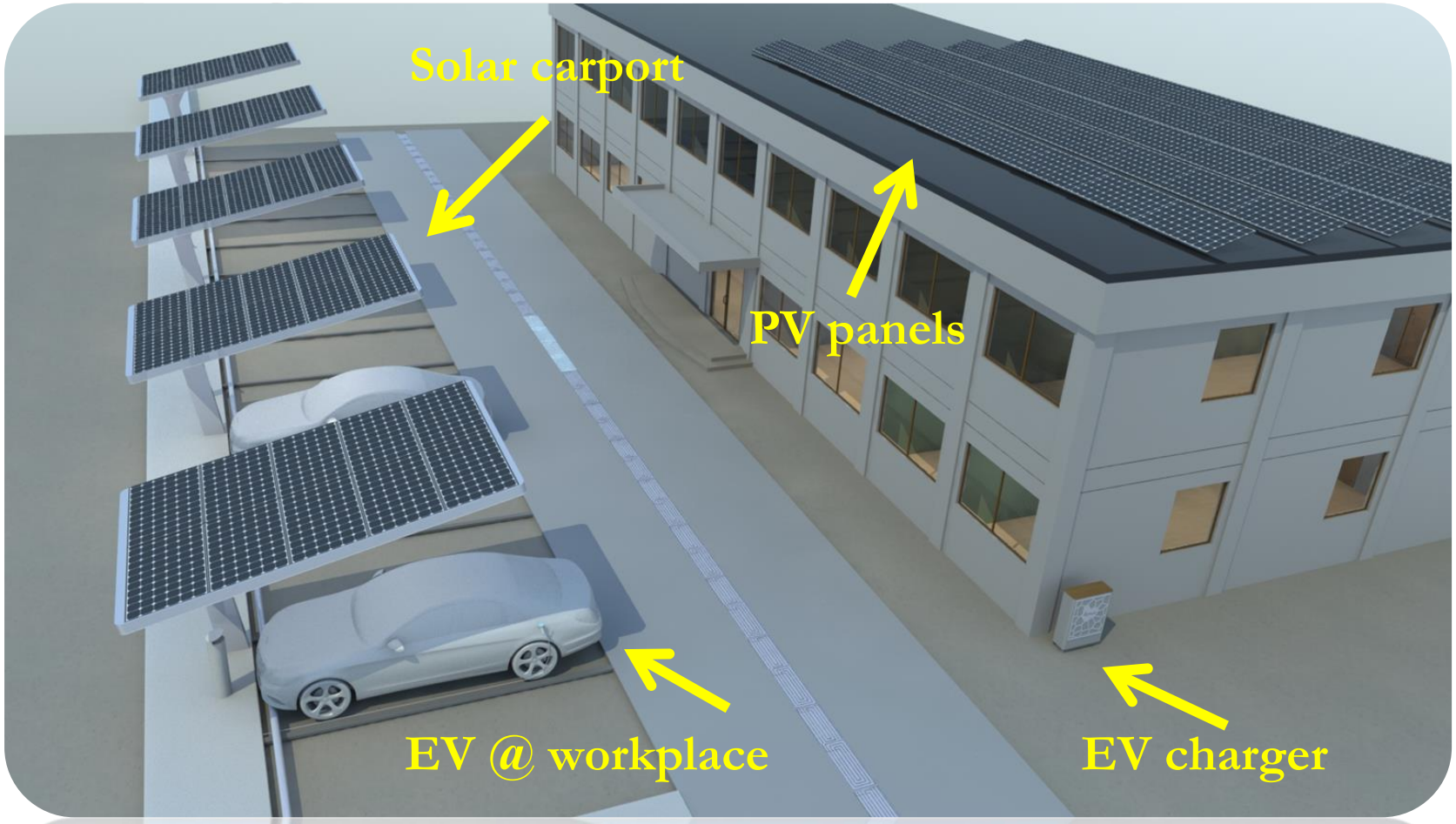
TU Delft	**Gautham Ram**, Dennis van der Meer, Pavol Bauer, Miro Zeman
PRE	Jos Schijffelen, Mike van den Heuvel, Menno Kardolus
TEXAS The University of Texas at Austin	Ross Baldick, Mahdi Kefayati
last mile solutions®	Eric van Voorden

Funded by : tki switch 2 smartgrids

TU Delft

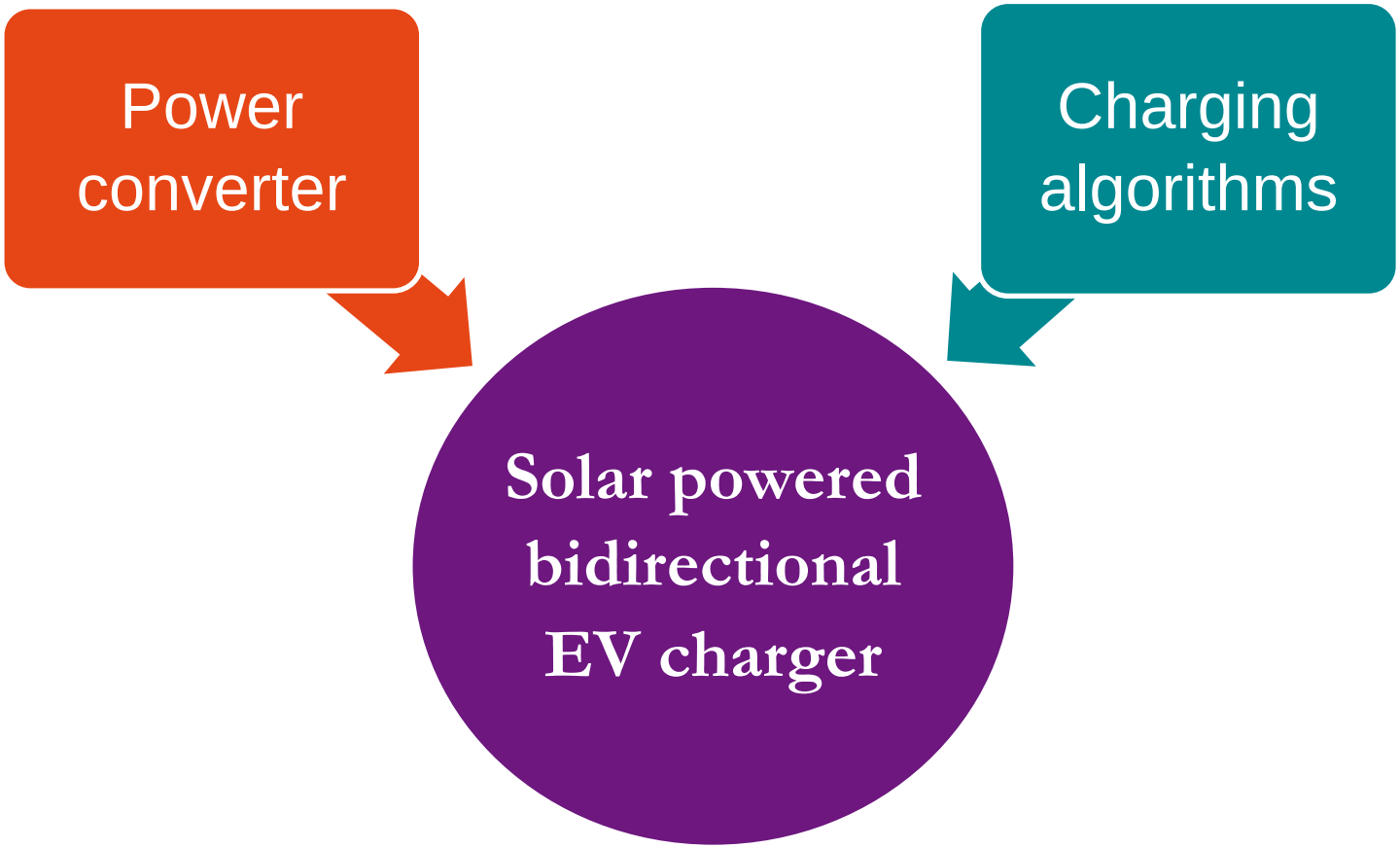
Goal

- Develop a highly efficient, modular, smart charging station for electric vehicles with V2G that is powered by solar energy



Motivation

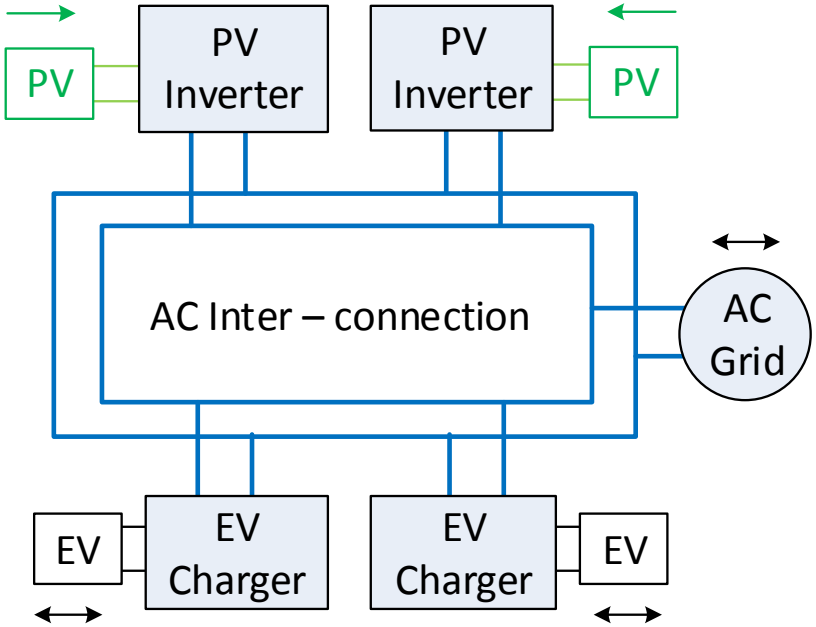
* Images taken from the internet


Power converter
Charging algorithms
Solar powered bidirectional EV charger

System architecture

DCE&S
DC systems, Energy conversion & Storage

AC interconnection of EV and PV



PV Inverter

EV Charger

TU Delft

Charging of EV from PV : Our solution

tki switch 2 smartgrids

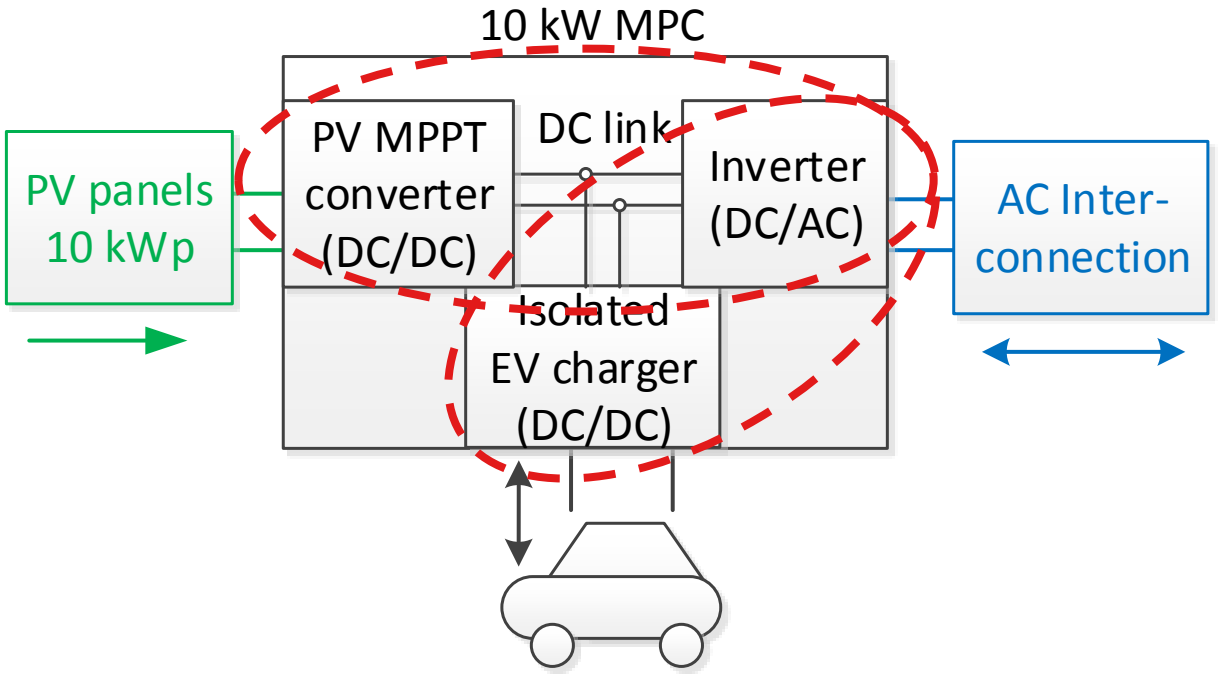
TU Delft Delft University of Technology

PRE power developers

last mile solutions®

Integrated Design

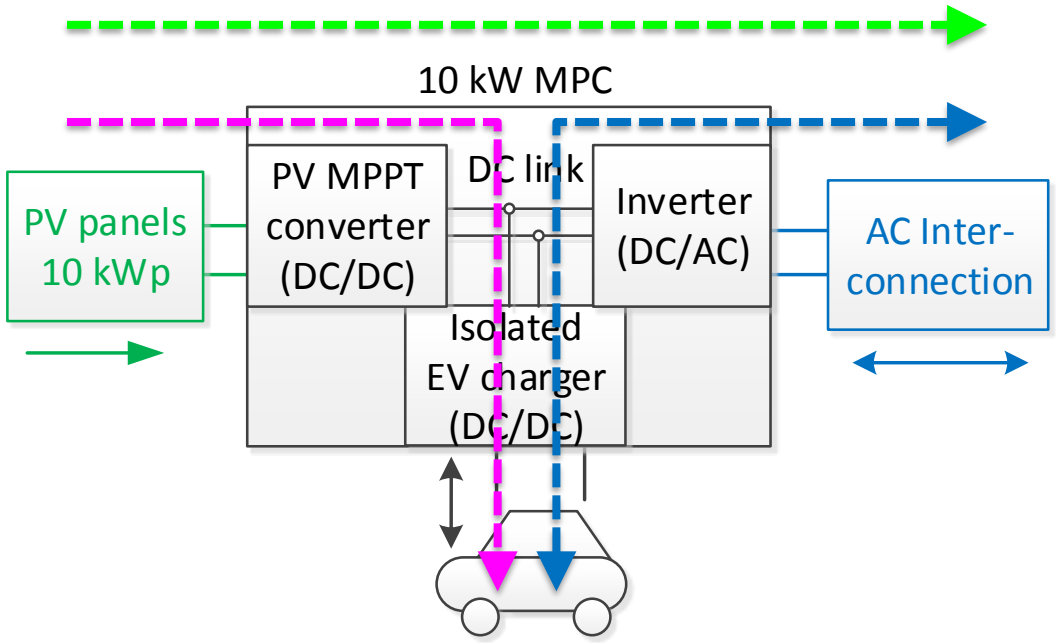
- Only one DC/AC converter → Lower cost of converter
- DC-DC connection of EV-PV → Improved efficiency
- Bi-directionality of DC/AC inverter → Charge / V2G

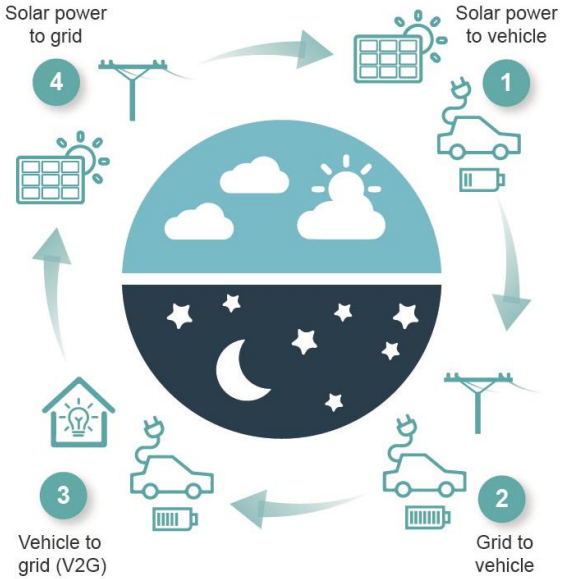


G. R. Chandra Mouli, P. Bauer, and M. Zeman, "Comparison of system architecture and converter topology for a solar powered electric vehicle charging station," in *2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia)*, 2015, pp. 1908–1915.

4 Power Flows

1. PV → EV
2. Grid → EV
3. EV → Grid
4. PV → Grid

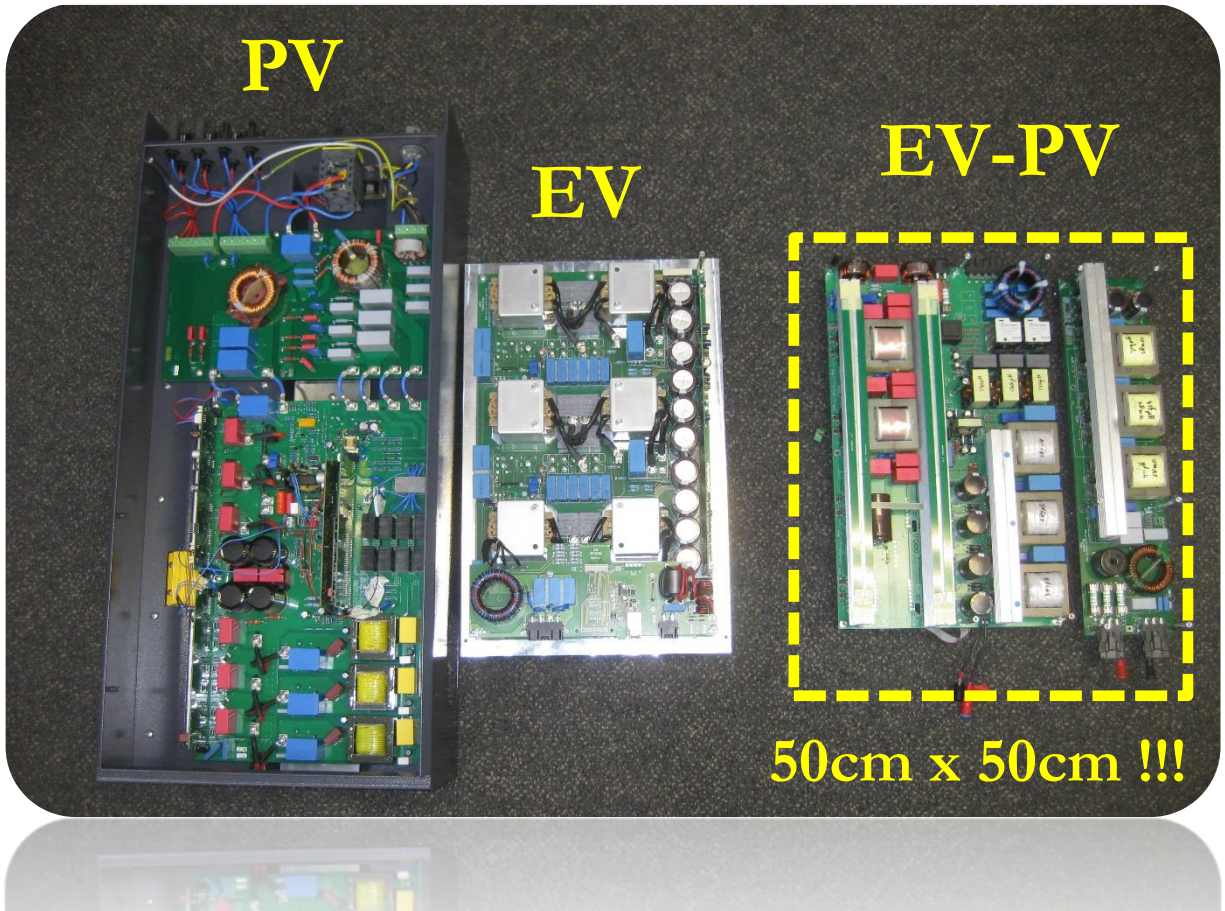




3x Power Density

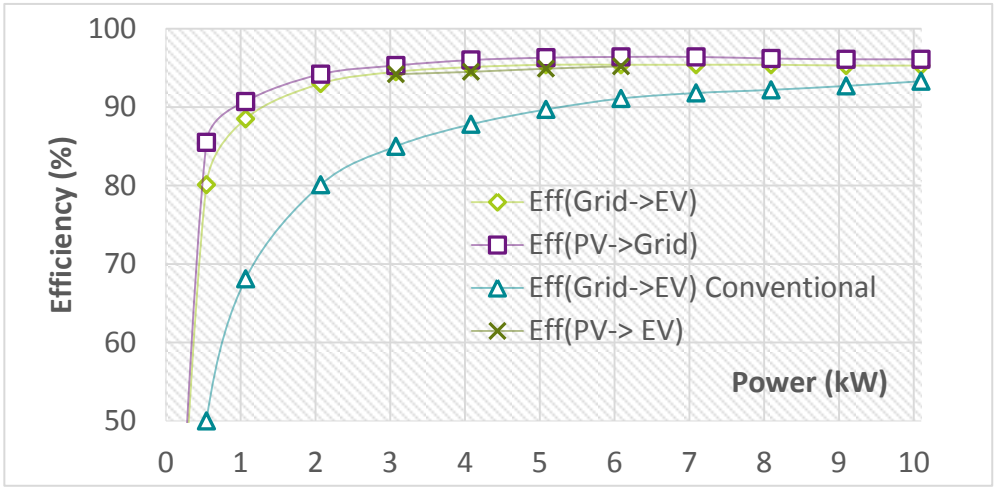
- Higher power density
- Higher efficiency
- Bidirectional EV charging

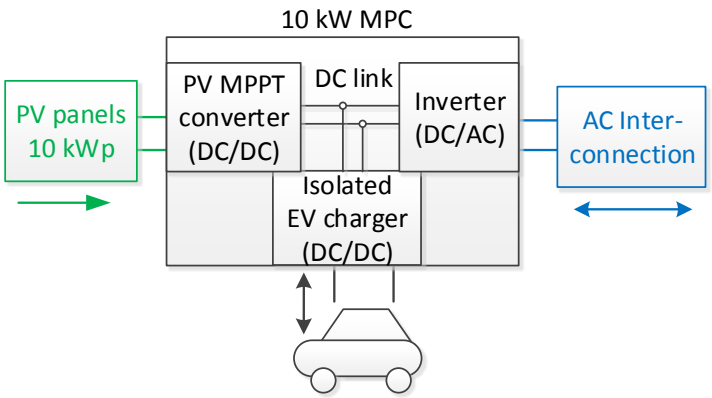
- SiC MOSFET, diode
- Interleaving of converters
- Powdered alloy inductors



Power Converter Efficiency

- Power converter efficiency
- Peak Efficiency Grid ↔ EV : 95.4%
- Peak Efficiency PV → Grid : 96.4%
- Peak Efficiency PV → EV : 95.2%



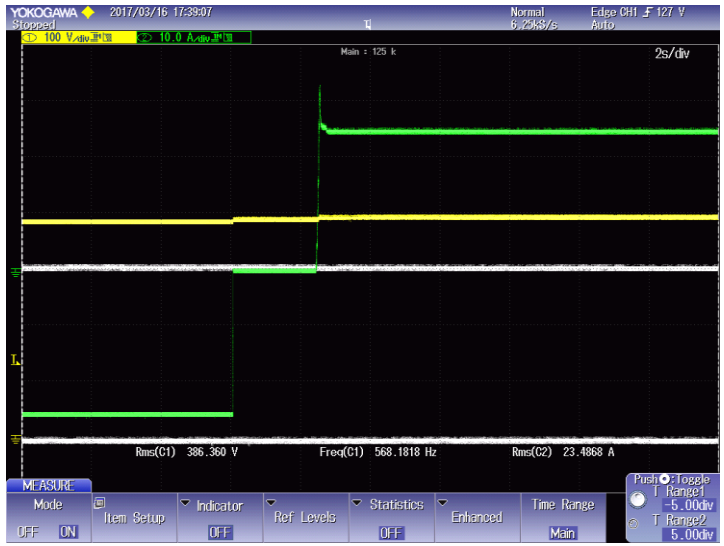


G. R. Chandra Mouli, J. Schijffelen, P. Bauer, and M. Zeman, "Design and Comparison of a 10kW Interleaved Boost Converter for PV Application Using Si and SiC Devices," IEEE J. Emerg. Sel. Top. Power Electron.2016.

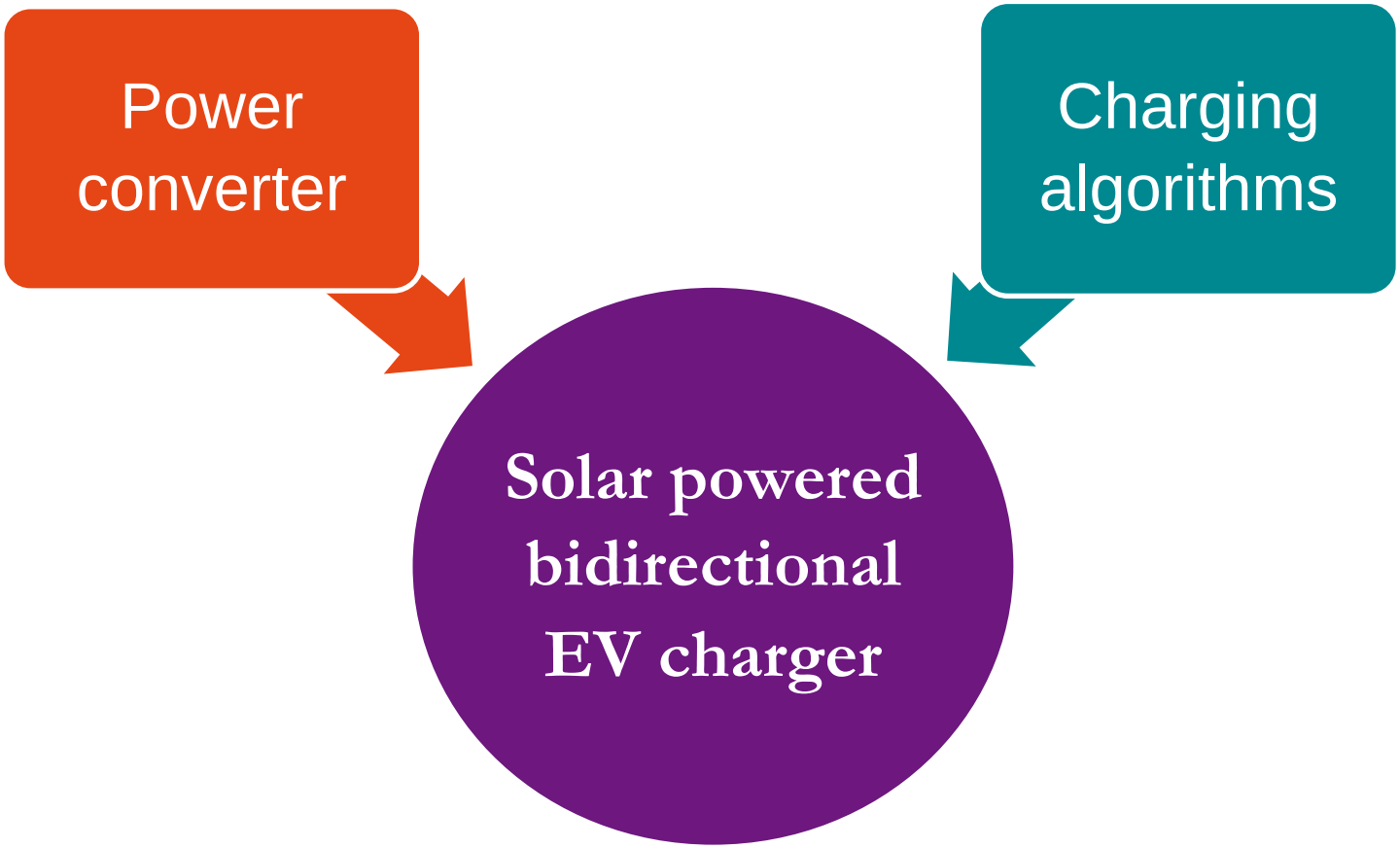
CHAdeMO & CCS compatible

DCE&S
DC systems, Energy conversion & Storage

- Level 2, Mode 4, Type 4 - DC charging of up to 10kW
  - CHAdeMO
  - Combined charging system (CCS)
- 10kW*(8h) = 80kWh delivered to EV
- 390V EV successfully (dis)charged with 24A



G. R. Chandra Mouli, J. Schijffelen, M.v.d Heuvel, M.Kardolus, P. Bauer, and M. Zeman, “A 10kW Solar-Powered Bidirectional EV Charger Compatible with Chademo and COMBO”, IEEE Transactions on Power Electronics, under review


Power converter
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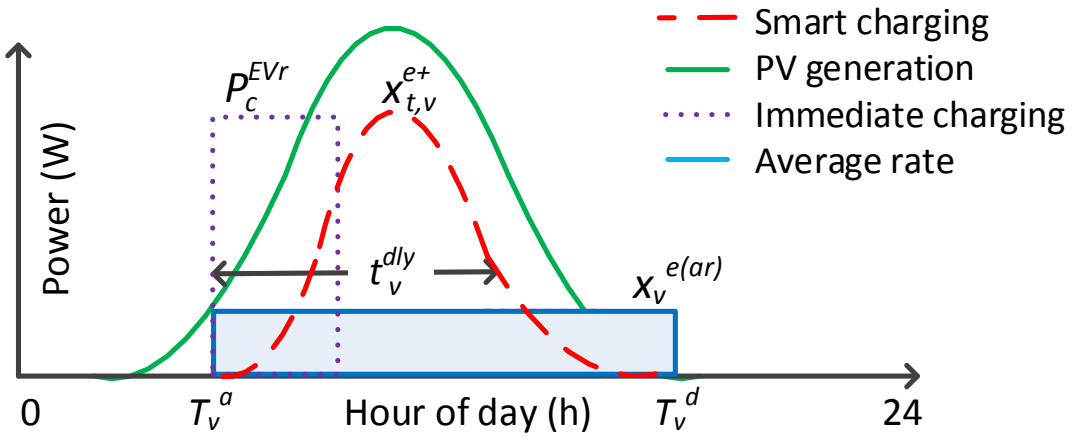
Energy Management System (EMS)



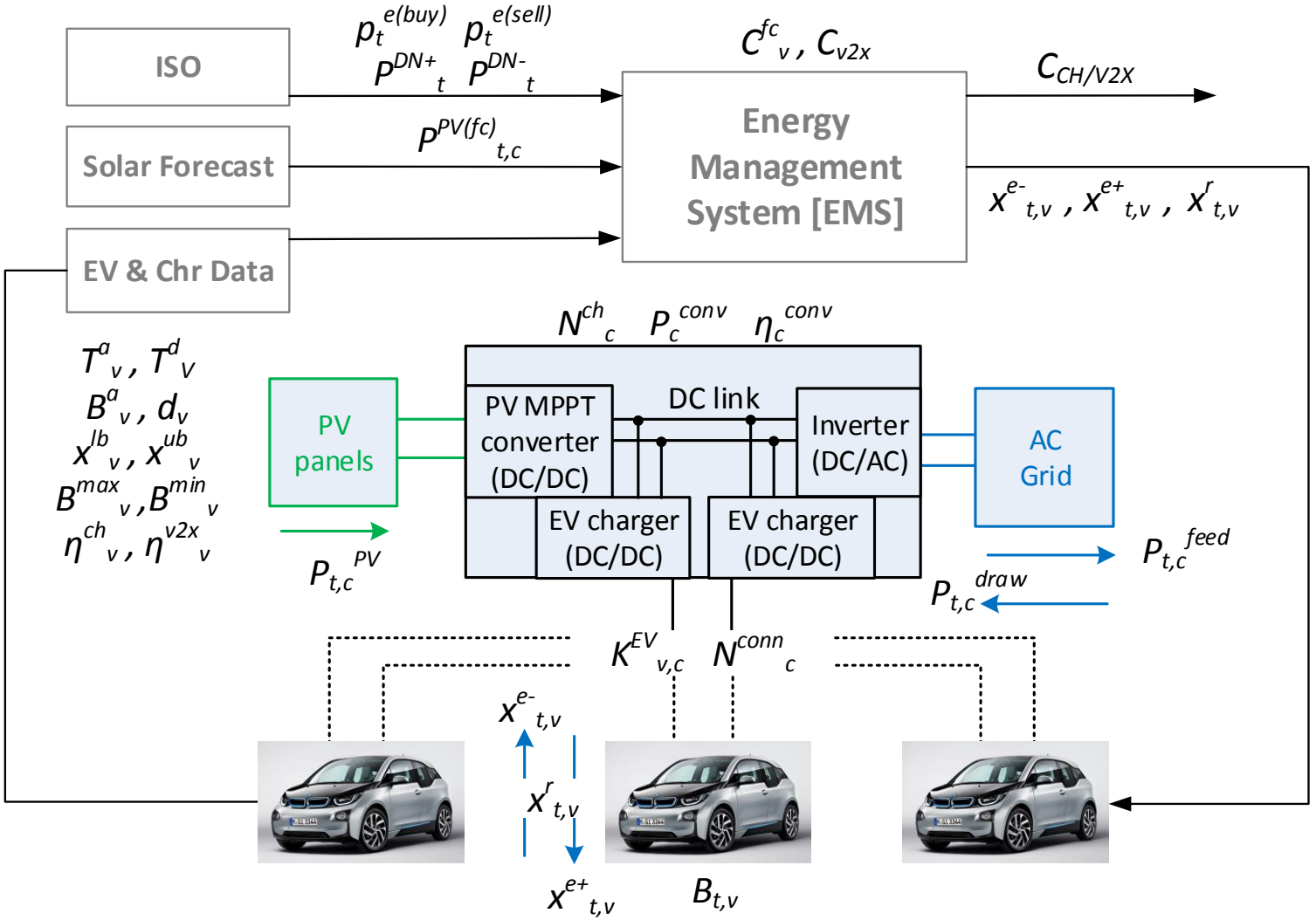
How can a EV fleet be optimally charged at workplace based on :

Texas

Netherlands

- Energy prices
- V2G
- Charging from renewables (PV)
- Distribution network limits
- Multiplexing of EV
- Regulation services

Energy Management System (EMS)



D. van der Meer; G. R. Chandra Mouli; G. Morales-Espana; L.R. Elizondo; P. Bauer, "Energy Management System with PV Power Forecast to Optimally Charge EVs at the Workplace," in *IEEE Transactions on Industrial Informatics*

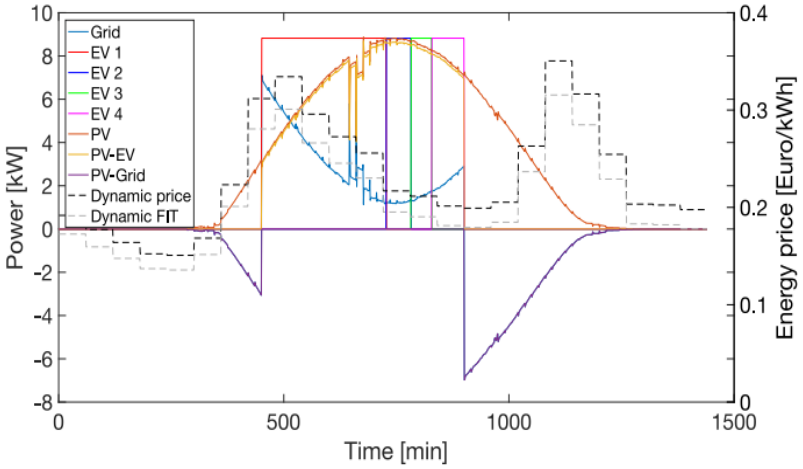
G. R. Chandra Mouli, R. Baldick, M.Kefayati, and P. Bauer, "Integrated PV Charging of EV Fleet Based on Dynamic Prices, V2G and Offer of Reserves", IEEE Transactions on Smart Grids, 2017, accepted

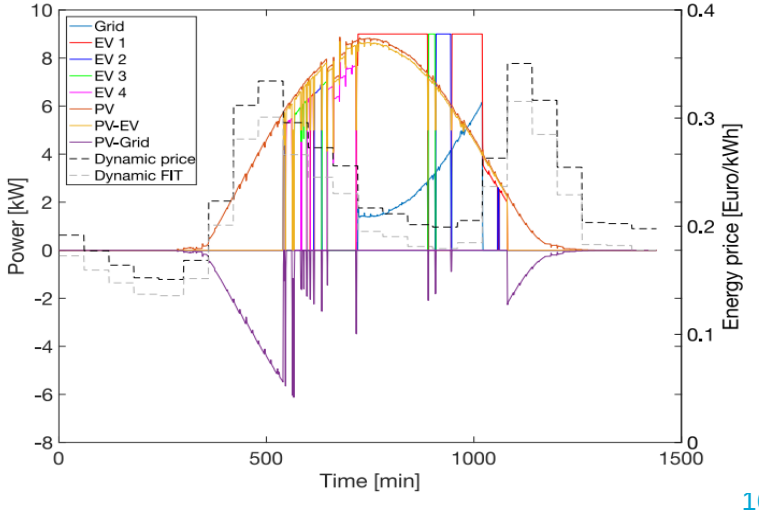
Case Netherlands : Scenario 1

- EV car park with 4 EV connected to one EV-PV charger
- Energy prices from APX

$$C_{net} = \text{Cost(EV charging)} - \text{Sales (PV power)}$$

	PV self consumption (%)	E_{grid} (kWh)	C_{tot} (€)	Cost reduction (%)
Uncontrolled charging	73.65	39.61	2.181	
Optimal charging	82.41	27.07	-0.4022	118.44



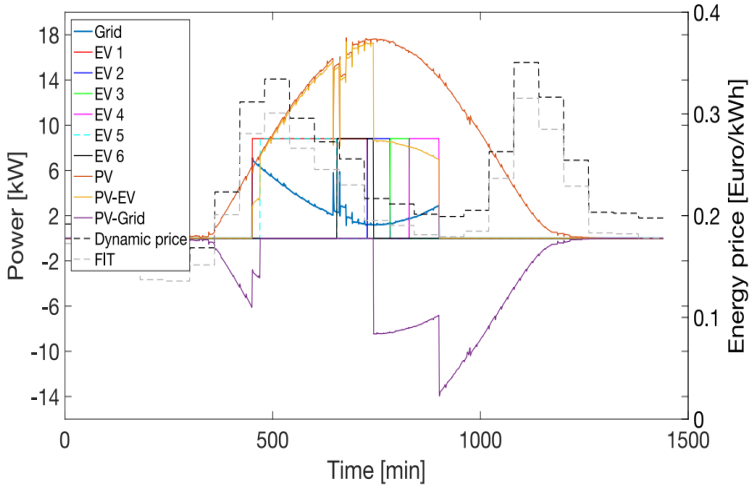


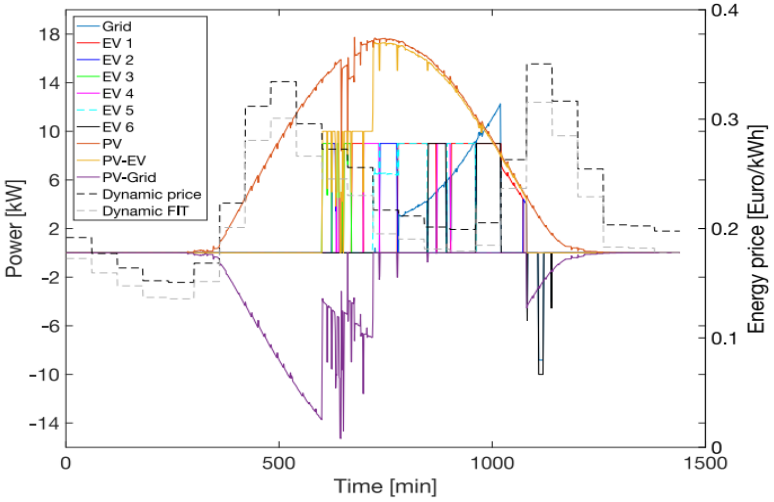
Case Netherlands : Scenario 2

- EV car park with
  - 4 EV connected to one EV-PV charger
  - 2 EV connected to second EV-PV charger
- Energy prices from APX

$$C_{net} = \text{Cost(EV charging)} - \text{Sales (PV power)}$$

	PV self consumption (%)	E_{grid} (kWh)	C_{tot} (€)	Cost reduction (%)
Uncontrolled charging	58.04	94.24	-1.468	
Optimal charging	66.32	75.20	-7.743	427.45

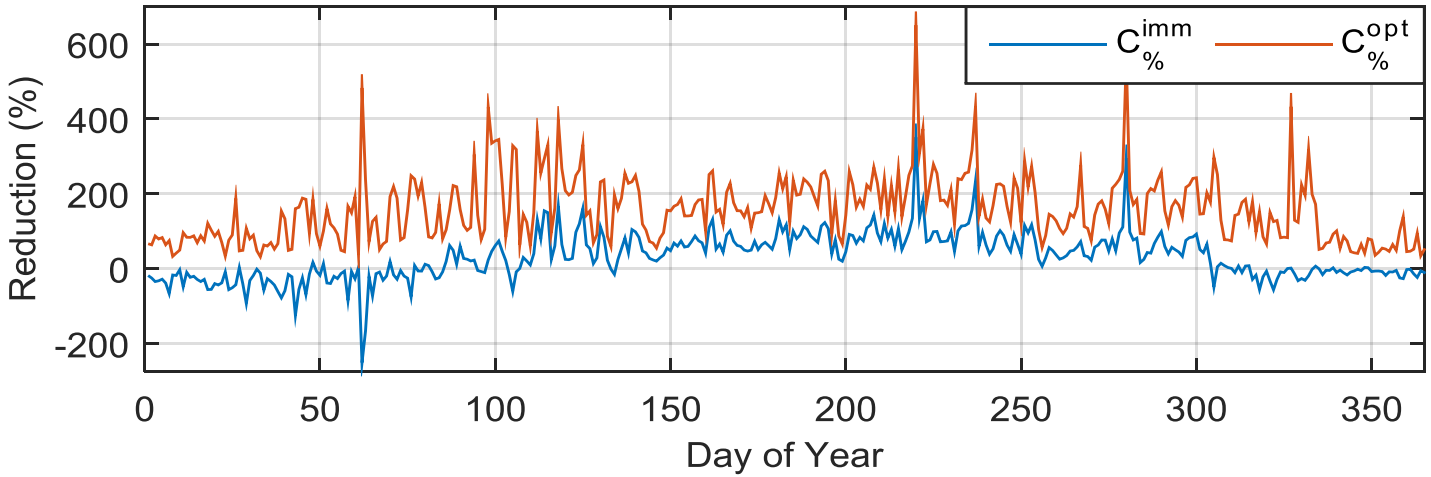




Case Texas

- EV car park with 60 EV and 40 Chargers with solar
- Energy and regulation prices from ERCOT market
- 32% to 651% cost reduction ☺

Charging Strategy	AVERAGE RATE	UNCONTROLLED	OPTIMAL
C^{ar}, C^{imm}, C^{opt} ($)	37.9	29.0	-15.3
$C^{imm}_{\%}, C^{opt}_{\%}$ (%)		31.72	158.63



Case Texas

- EV car park with 60 EV and 40 Chargers
- Energy and regulation prices from ERCOT market
- 32% to 651% cost reduction ☺

Case	Bidirectional V2G	Energy prices	Regulation services	PV forecast
Case 1	No	No	Yes	No
Case 2	No	Yes	No	No
Case 3	No	Yes	Yes	No
Case 4	No	Yes	No	Yes
Case 5	Yes	No	Yes	Yes
Case 6	No	Yes	Yes	Yes
OPTIMAL	Yes	Yes	Yes	Yes

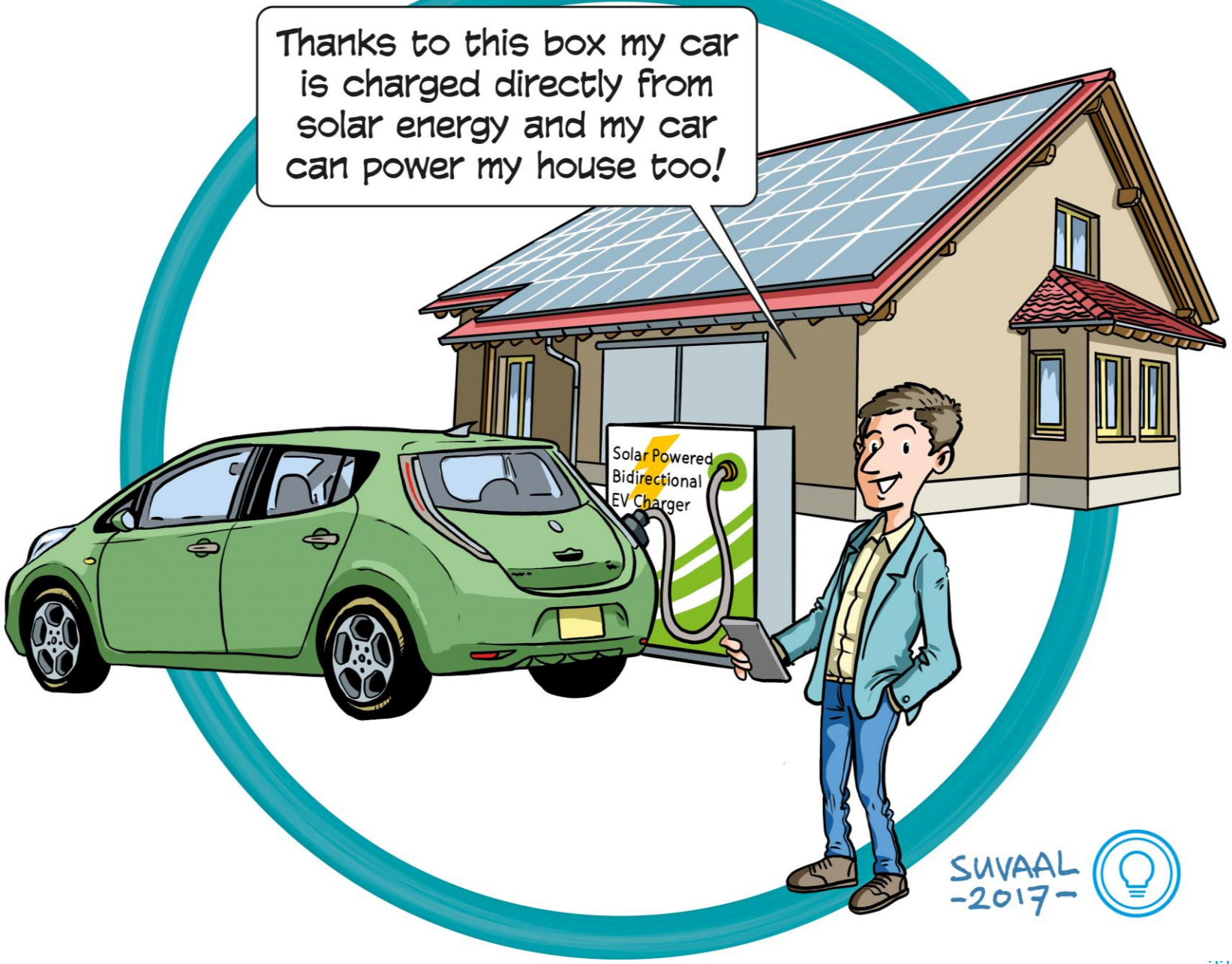
Case Texas

- EV car park with 60 EV and 40 Chargers
- Energy and regulation prices from ERCOT market
- 32% to 651% cost reduction ☺

Day	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	OPT
33	13.60	6.42	20.76	7.62	11.49	22.26	31.62
83	38.83	12.81	57.71	19.75	30.90	65.81	96.73
153	74.95	38.51	99.14	53.80	45.10	112.84	186.47
220	239.96	205.76	355.53	244.61	451.93	376.11	650.83
332	243.91	9.29	255.63	19.56	256.58	280.15	317.83
Mean	122.25	54.56	157.76	69.07	159.20	171.43	256.70

PV charging of EV at workplace

www.youtube.com/watch?v=smrOCOLxBvg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