ETIP SNET
South-Eastern Region Workshop

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SUCCESS (2017-2019)

- SUstainable ConCept for integration of distributed Energy Storage Systems is a project at the Faculty of Electrical engineering and Computing University Zagreb, funded by the Croatian Science Foundation
- Value: 130.000 €
- Partner institutions:
  - Faculty of Economics Univ. Zagreb
  - Aalborg University
  - Croatian DSO

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Research focus

SUCCESS

- Missing regulatory aspects for DER/EV market participation,
- New business models for (EV) aggregators,
- Batteries – ownership, role(s), modells

EVBASS

- IRM approach for achieving policy goals,
- New business models for EV,
- Batteries – from testing to modelling

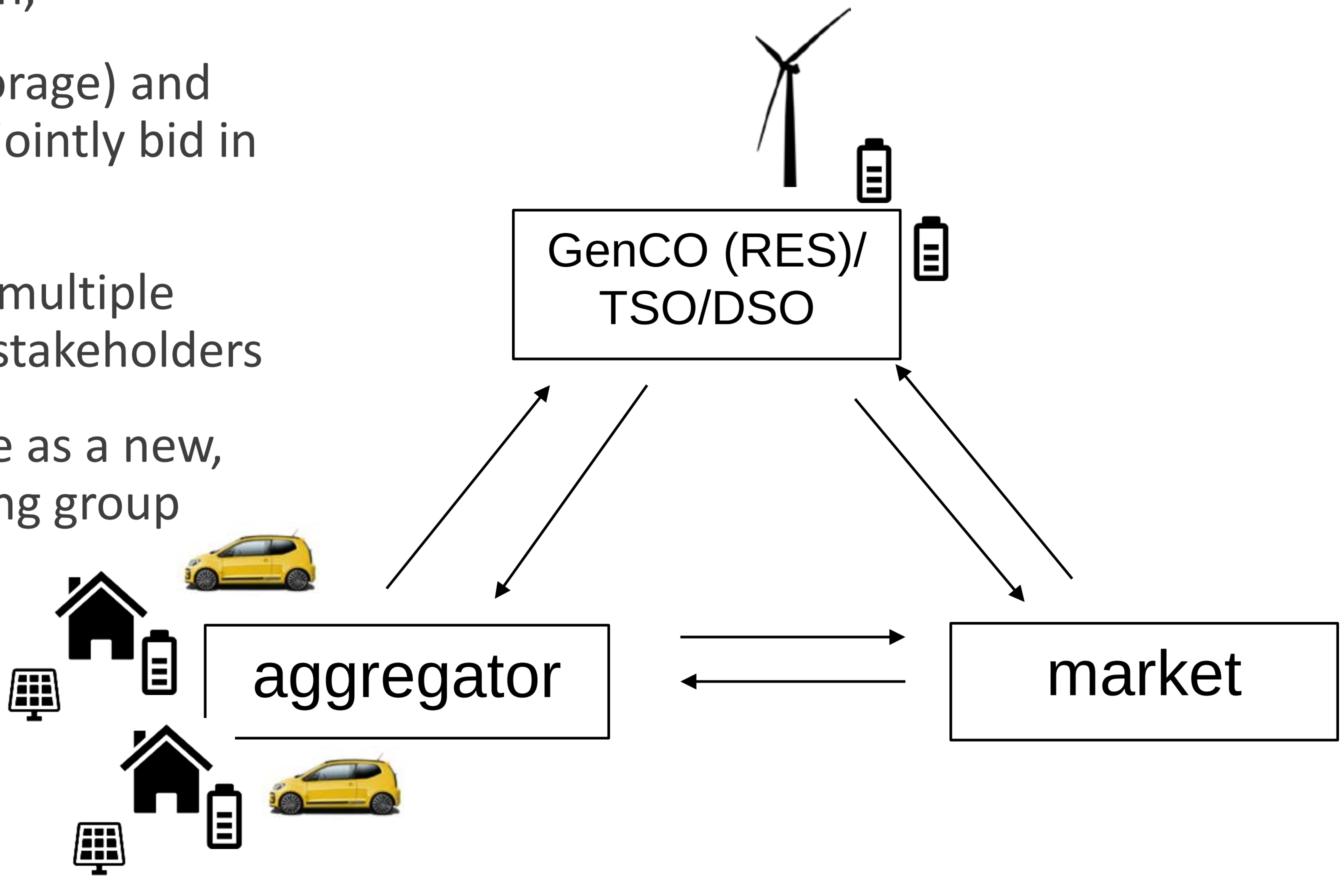
uGRIP

- Microgrids and cooperatives,
- Flexibility as a commodity,
- Modelling and laboratory testing of flexibility providers

Concept 1:
Prosumer owned battery storage and market participation

Energy cooperatives as balancing groups

- „Sharing" approach,
- Prosumers (PV+storage) and wind power plant jointly bid in the market,
- Multiple benefits, multiple services, multiple stakeholders
- Energy cooperative as a new, 100% RES, balancing group



Gržanić, Mirna; Capuder, Tomislav Bi-level Modelling Approach to Coordinated Operation of Wind Power Plant and PV-Storage Energy Community, IEEE Energycon (2018)

Modelling aspects

- Goals:
  - Maximize aggregators profit (portfolio of prosumers with PV and battery storage),
  - Minimize cost of the entire balancing group (aggregator of prosumers + wind power plant),
  - Minimize cost electricity for end-users,
- Questions:
  - Are there benefits of switching from traditional supplier to aggregator?
  - Are there benefits in dynamic pricing schemes?
  - Are there benefits in joined market participation?

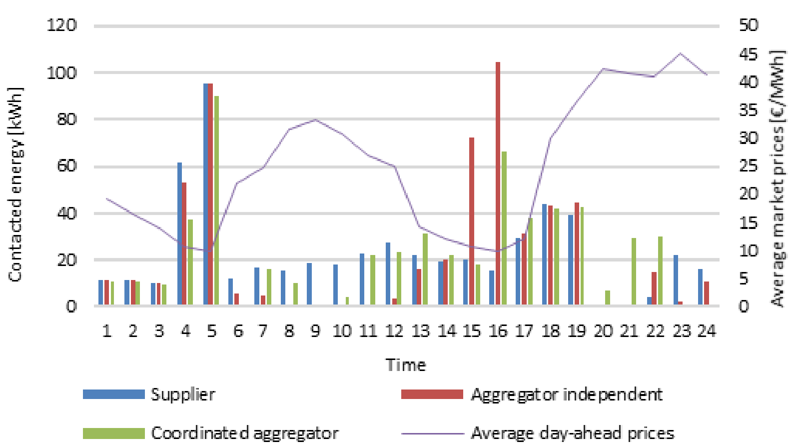
Initial results

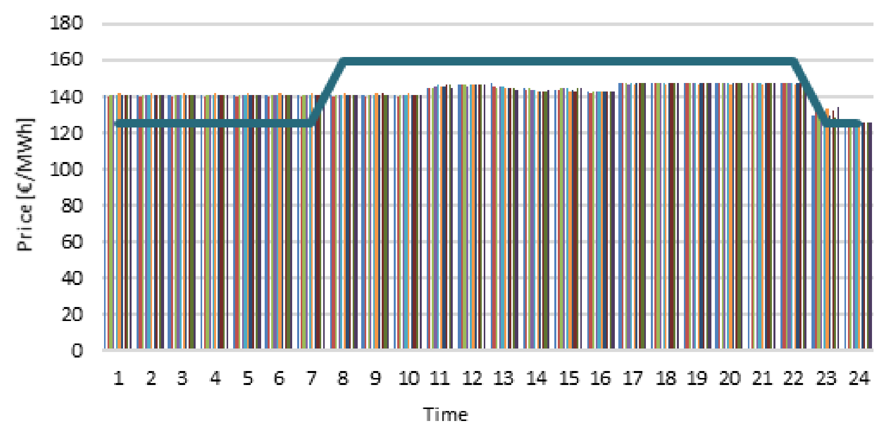
Prosumers with small PV capacity

	Supplier €	Individual €	Coordinated €
Total profit	67.35	69.38	67.58
Penalties	0.58	0.28	0.14
Cost for purchasing energy on the market	11.79	9.30	11.47
Conumers cost of electricity	79.72	78.96	79.19

Prosumers with large PV capacity

	Supplier €	Individual €	Coordinated €
Total profit	43.02	46.5	44.70
Penalties	0.92	0.44	0.24
Cost for purchasing energy on the market	8.11	6.71	8.79
Conumers cost of electricity	52.05	53.65	53.73





Key exploitable results

- Benefits and beneficiaries:
  - Coordinated operation (new BG) always results in *lower deviations/penalties* as compared to individual market participation –> entire power system,
  - Options for WPP after FiT period –> joining flexible RES based BG,
  - Diverisity of aggregators portfolio could create benefits for p2p trading –> end-users

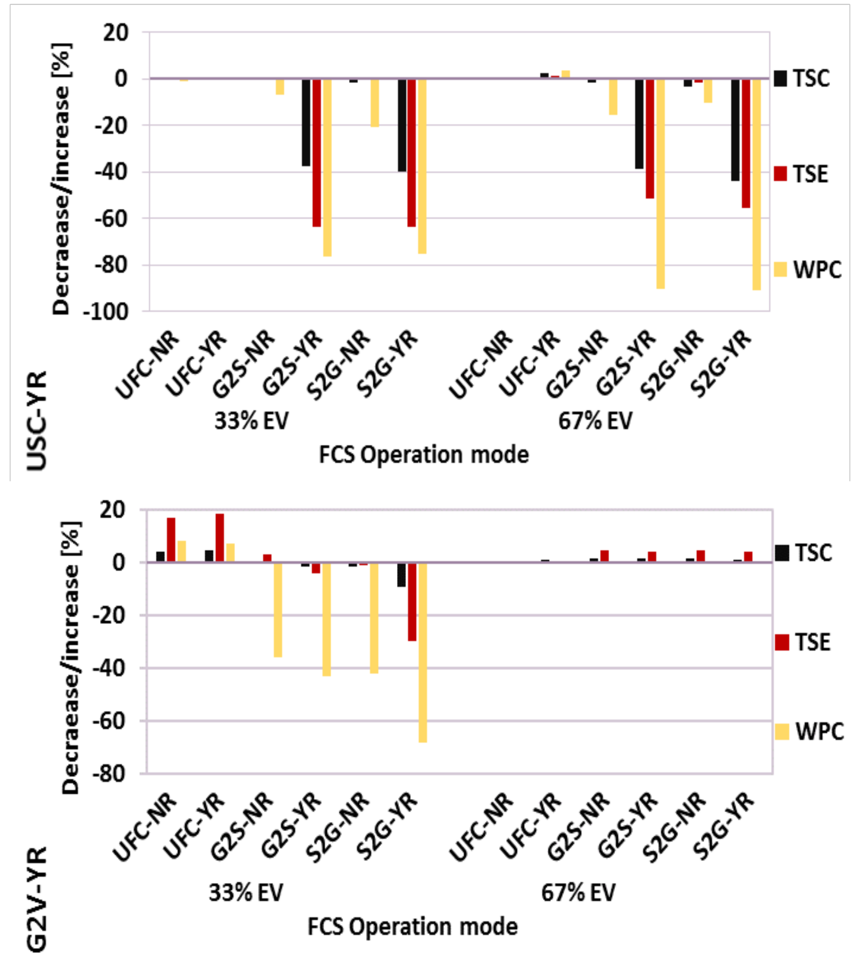
Challenges, barriers, lessons learned

- Challenges:
  - Who could benefit from p2p trading? How would aggregator's strategic behavior change (and would it) in case of p2p trading?
  - More accurate battery modelling (results of EVBASS) and demand response modeling -> laboratory testing needed,
  - Develop comprehensive models, define value of different services,
- Barriers:
  - Regulatory framework for aggregators is missing (or why else are there so few aggregators) -> how to validate the results of modelling (and business cases)?
- Lessons learned:
  - Coordinated operation -> as higher profit and lower penalties,
  - Flexible balancing groups -> path towards 100% RES system

Concept 2:
Battery storage as suport to fast charging EV integration

Power System Level

- Comparing slow and fast charging,
- System level UC model,
- With flexible fast charging:
    - Total operational costs are reduced
    - Total emissions are reduced
    - Significant reduction in RES curtailment
    - Peak load reduction
    - **Power plant efficiency increasing**



Pavić, Ivan; Capuder, Tomislav; Kuzle, Igor.
A Comprehensive Approach for Maximizing Flexibility Benefits of Electric Vehicles. // IEEE Systems Journal. (2017)

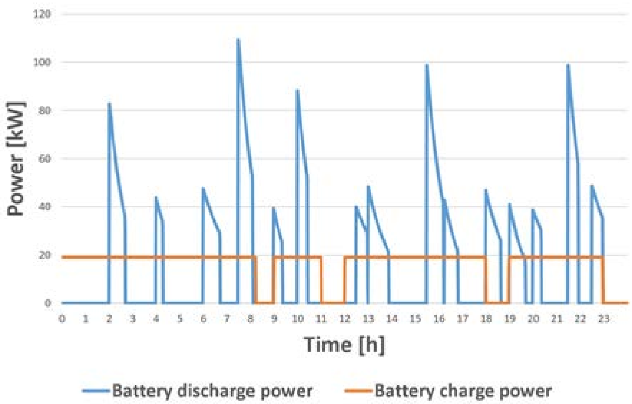
The idea of FSC + BSS

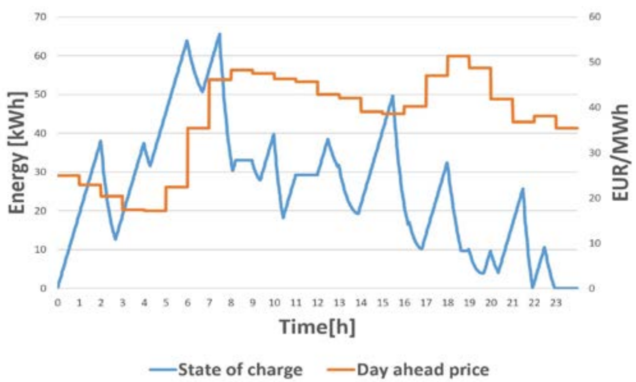
- Battery storage system serves as a buffer,
- Bussiness cases:
  - energy arbitrage,
  - charging of peak power
- End-user receives the desirved QoS, the system does not see „unforcasted” peak loads (or overbuilds the network).

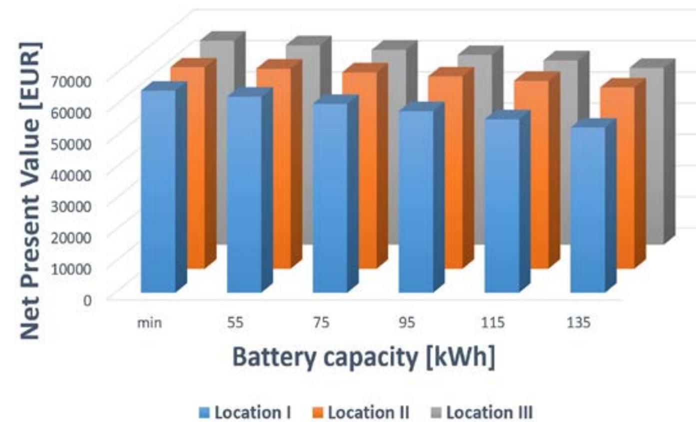
Requested QoS (50kW, 150kW) Limit to 20kW charging

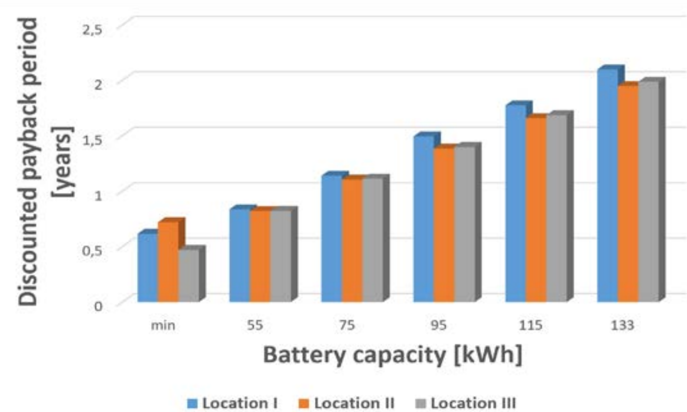
Initial results

- Battery storage with FCS avoids paying for peak power.
- Minimum size is the most feasible (around 30kWh).





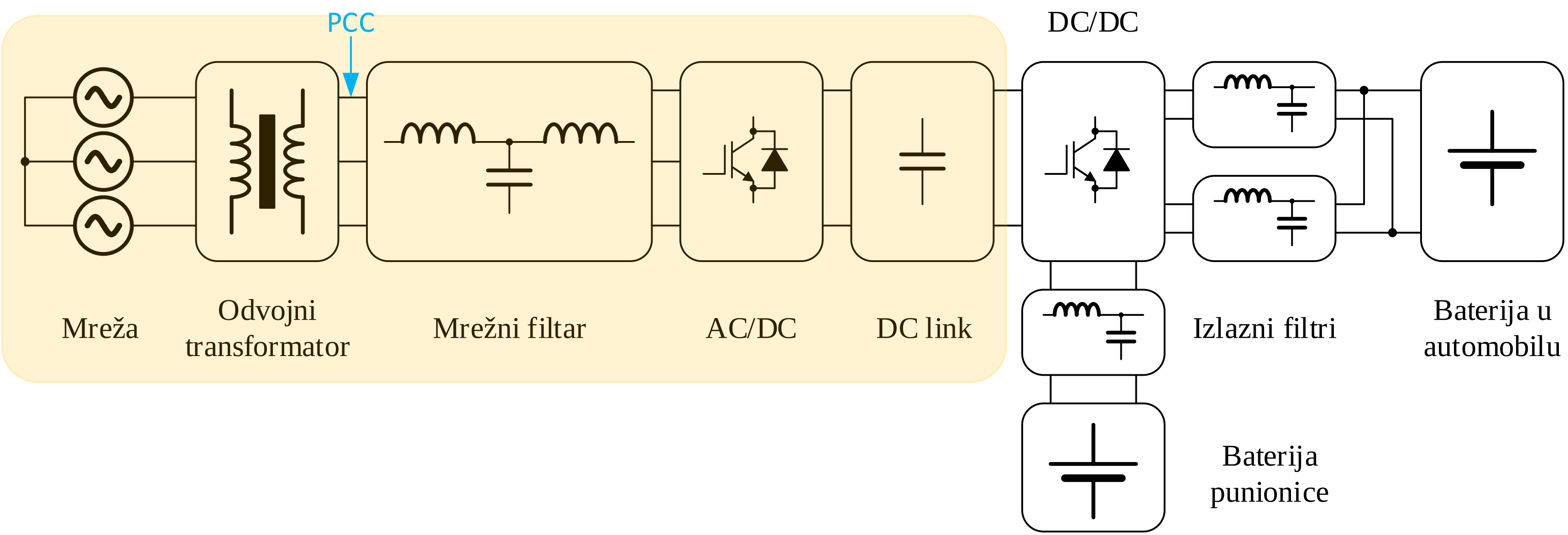




Salapić, Vjekoslav; Gržanić, Mirna; Capuder, Tomislav;.
Optimal Sizing of Battery Storage Units Integrated Into Fast Charging EV Stations. // IEEE Energycon 2018.

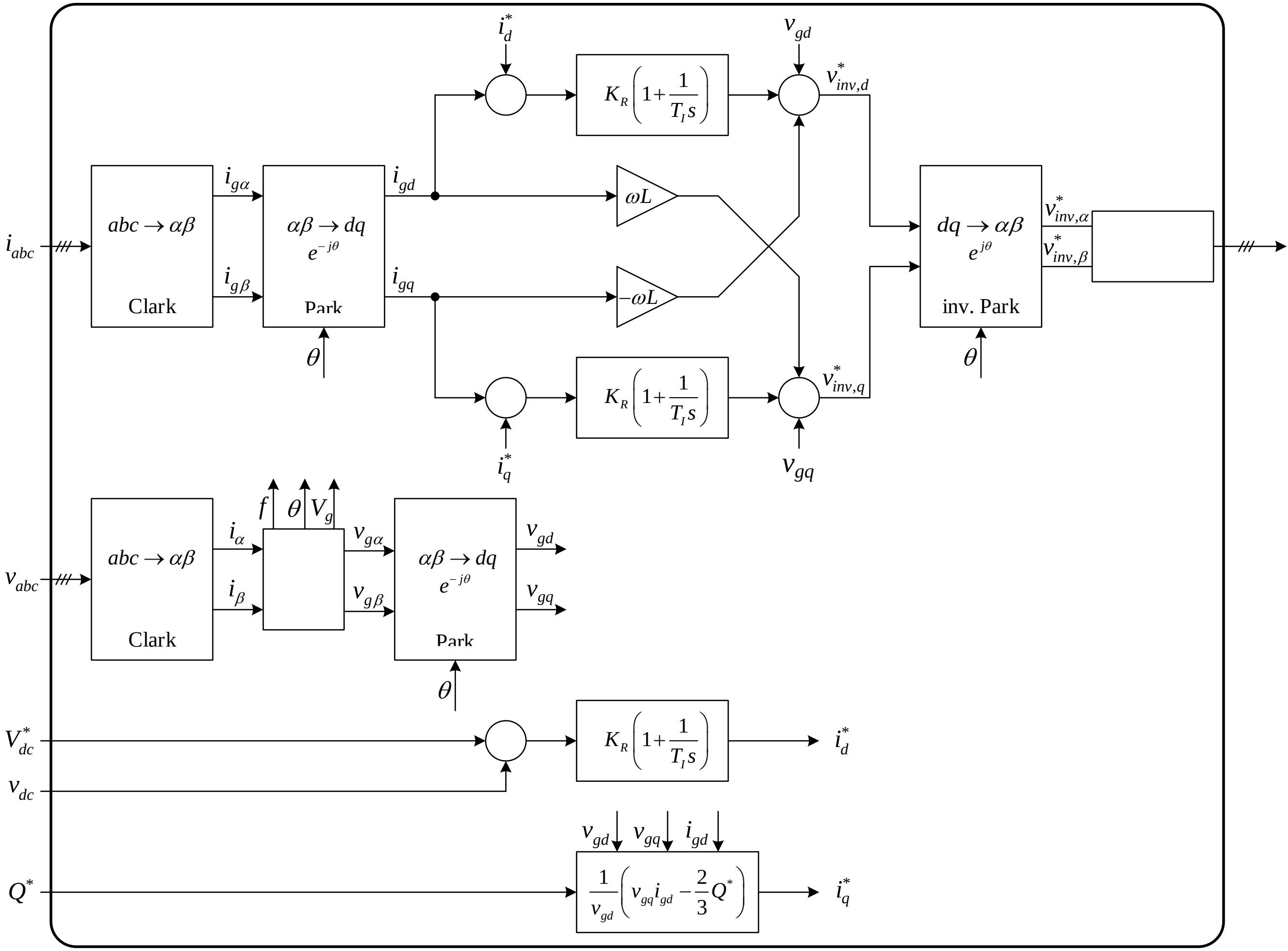
Prototype charging station

- Practical aspect:
  - Model and design FCS with battery storage,
  - Construct and integrate into FER SmartGrid laboratory,
  - Test and validate the benefits,
- Nominal power on the grid side: 20 kVA (400 V, 29 A)
- Nominal power on the DC side : 2x50 kW, 500 Vdc, 100 Adc

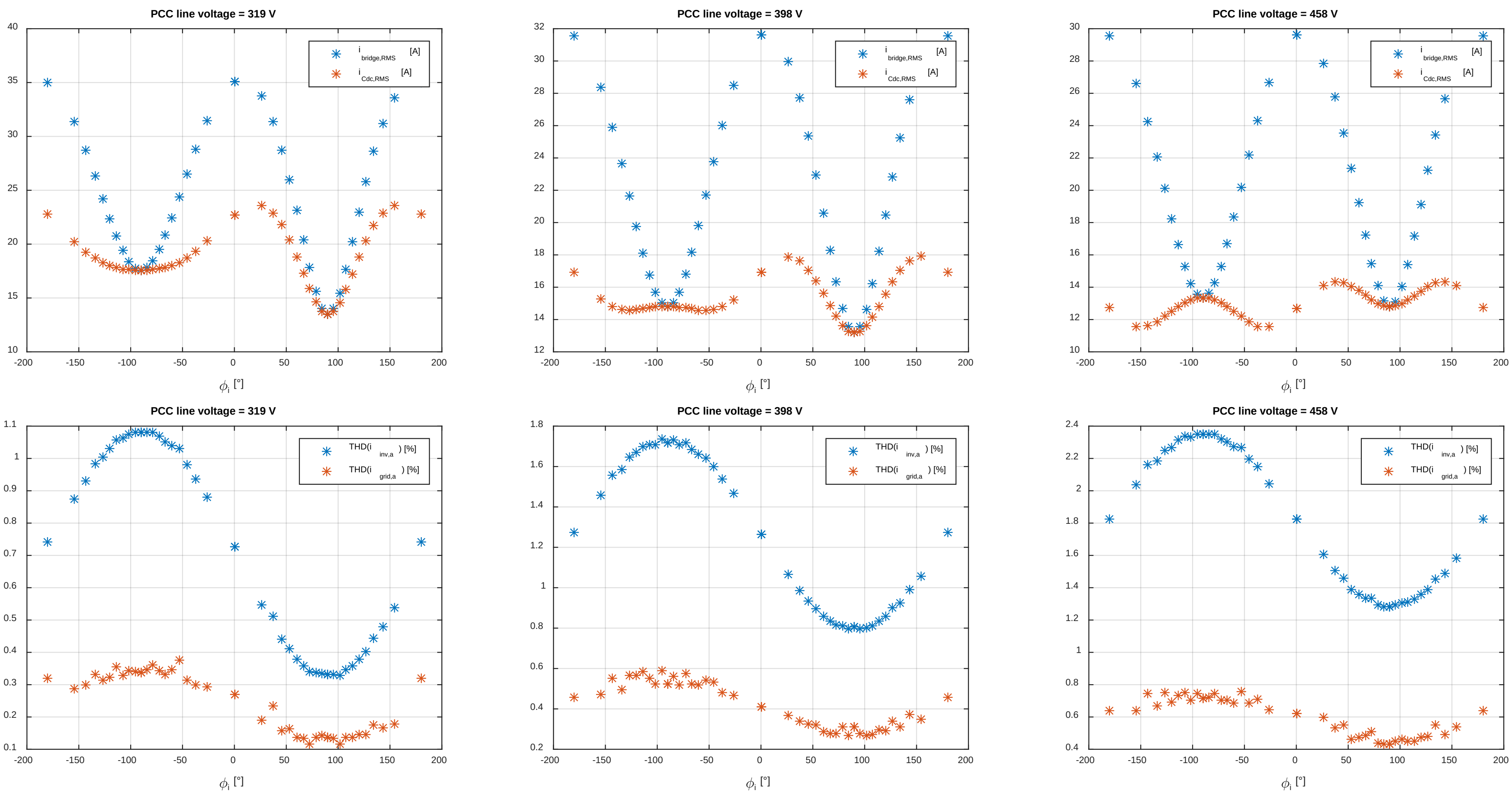


Modelling of 3-phase inverter

- The inverter has to:
  - Be synchronized with the network
  - Be robust during operation
  - Be capable of regulating DC voltage
  - Be capable of regulating active/reactive power at the interface with the network



Simulation results



Key exploitable results

- Benefits:
  - Benefits for the power system: reduced curtailment, lower operational costs, lower CO2 emissions;
  - Benefits for the charging station owners/operators – lower operational costs, acceptable investment return rate;
  - Potential benefits for the DSO – avoiding unneccessary network investments.

Challenges, barriers, lessons learned

- Challenges:
  - Demonstration project of battery storage as a buffer (for implementation see CEF project NEXT-E) -> pilot projects (4 locations),
  - Develop drediction/forecasting of EV requirements -> project bigEVdata,
  - Construct and integrate a prototype of fast charging station with integrated battery storage in FER SGlab;
  - Develop models for assessing „sharing" opportunities (correlation with concept 3 of SUCCESS project) – utilizing battery storage for multiple services;

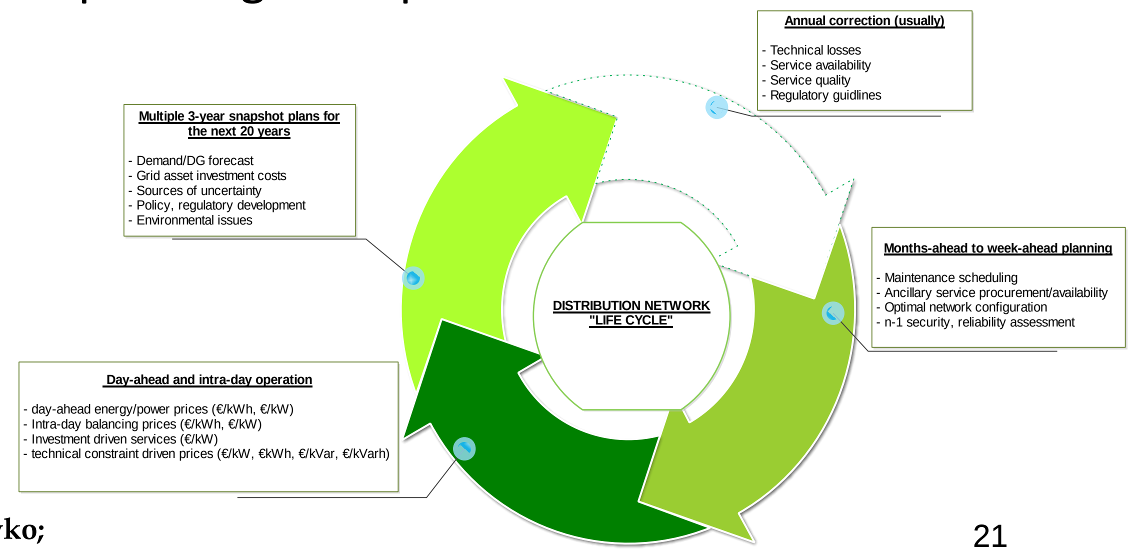
Challenges, barriers, lessons learned

- Barriers:
  - Unavailable EV data for modelling (synthetic data used such as that of todays traffic or generated by models), missing sufficient amount of data, slow EV uptake to test the methods in reality..
  - Low interest in FCS+BSS charging stations.
- Lessons learned:
  - Batteries are expensive (for research and pilot projects) – costs of up to 1000€/kWh for key-in-hand (BMS, power electronics, wiring, installations…),
  - Very few available flexible solutions (both in terms of batteries and power electronics).

Concept 3:
Battery storage sharing between prosumers and DSO

Prosumer - DSO cooperation

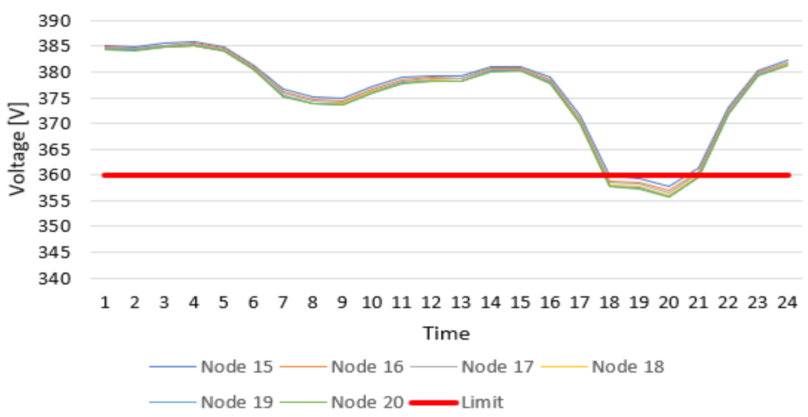
- Main idea:
  - DSO utilizes prosumers storage for more efficient network operation and planning,
- Modelling aspects:
  - Maximize prosumers profit, minimize DSO operational cost (non-convex problem),
  - Challenge: interaction of planning and operational horizon.

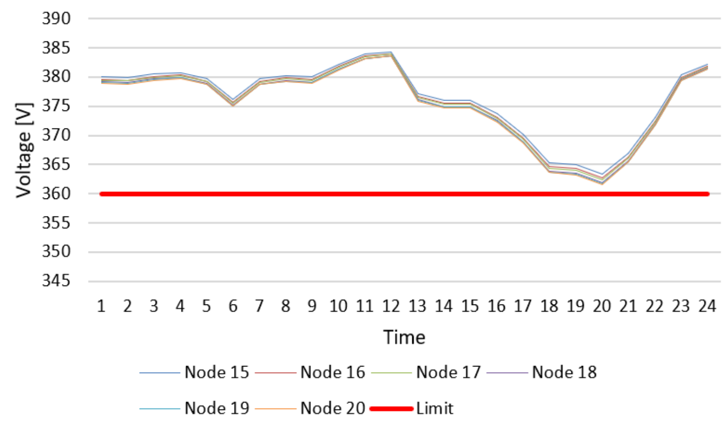


Gržanić, Mirna; Capuder, Tomislav; Krajcar, Slavko;
DSO and Aggregator Sharing Concept for Distributed Battery Storage System // EEEIC 2018.

Initial results

- DSO, instead of building new lines, „rents” storage service from end users;





Consumer	Energy cost without battery storage €	Energy cost with battery storage €	Cost including battery investment €
7	498.98	469.78	654.46
13	535.25	506.05	690.73
15	661.75	632.55	817.23
16	399.74	370.54	555.22
20	416.94	387.74	572.42

Consumer	Cost for energy €	Cost with battery investment €	Savings €
7	296.69	481.37	17.32
13	319.39	504.07	31.18
15	385.90	570.58	91.16
16	183.75	368.43	31.31
20	200.01	384.69	32.25

Key exploitable results

- Outcomes:
  - The DSO could alleviate technical issues by utilizing consumer side flexibility – this enhances the business case for end-users as well (e.g. battery storage);
  - Long-term planning tool developed for defining resevation and utilization cots/prices -> connection to Interreg Danube project 3Smart (http://www.interreg-danube.eu/approved-projects/3smart).

Challenges, barriers, lessons learned

- Challenges:
  - The need for „better” definition of DSO flexibility costs/prices,
  - TSO-DSO coordination -> system flexibility from distribution system resources and how does it impact the DSO operation
- Barriers:
  - Scallability of models
  - How and where to test the provision of flexibility to DSO -> project 3Smart.
- Lessons learned:
  - Does DSO need additional flexibility -> Current results in Croatia, BiH, Hungary, Austria suggest that most distribution networks are „strong enough” (overbuilt and over invested),

Thank you for your attention

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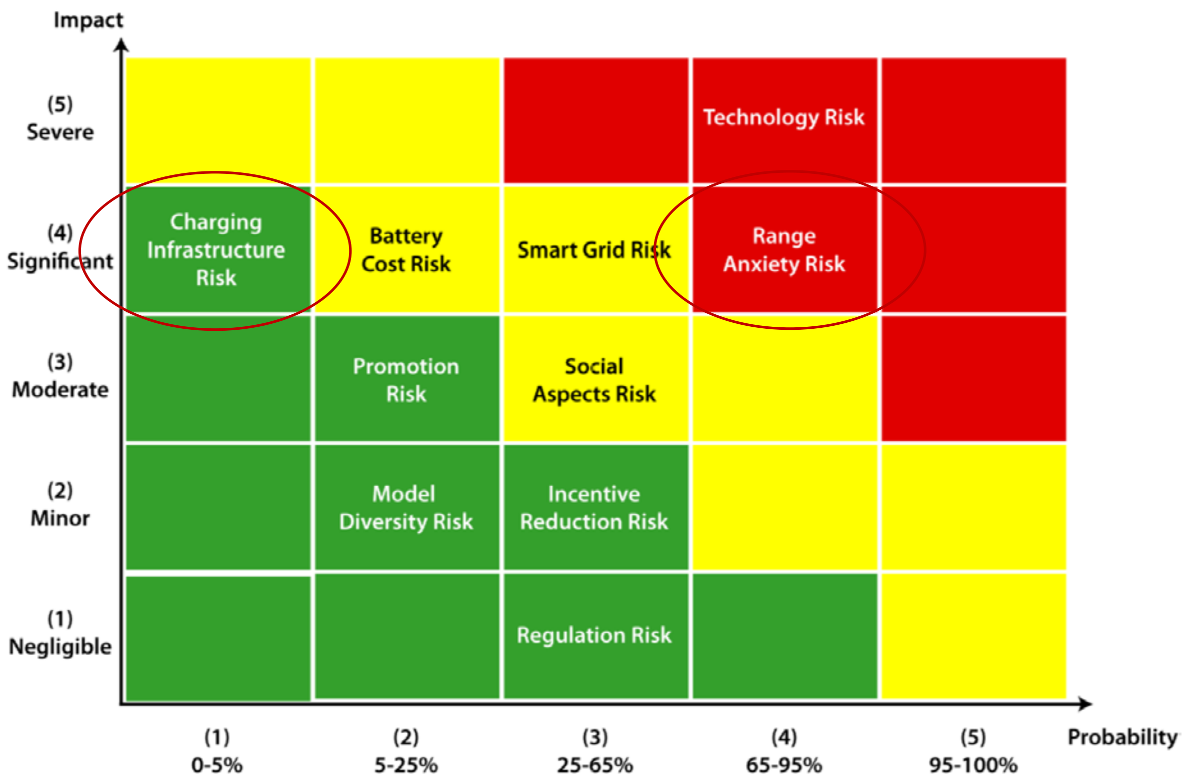
APPENDIX 1
Concept 2: Battery storage as suport to fast charging EV integration

Research approach to EV

- Multiple areas intersecting:
  - Role and modelling of batteries -> EVBSS
  - How does relaying on FCS impact the power system operation –> SUCCESS/EVBASS
  - Business/optimization models for EV aggregators (EVBA concept) -> SUCCESS/EVBASS
  - Integrating batteries with FCS -> SUCCESS/EVBASS

Future of EV - IRM analysis



- More chargers -> lower charing infrastructure risk,
- More chargers -> lower Range anxiety risk,
- (Super)fast chargers as a way of increasing EV driver comfort

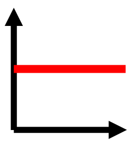
Fast EV chargers

- Installation of FCS as a strategy in reducing drivers concern of range insufficiency:
  - Tesla superchargers
  - CEF (Connecting Europe Facility) projects: fastE, EAST-E, NEXT-E -> massive installations of FCS on highways,
  - Ionity -> joint effort of BMW, Mercedes, Ford and VW
  - Ultra – E -> joint effort of Allego, Audi, BMW, Magna, Renault, Hubject, and others
  - ……

Power System Level

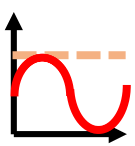
Flow — energy — service

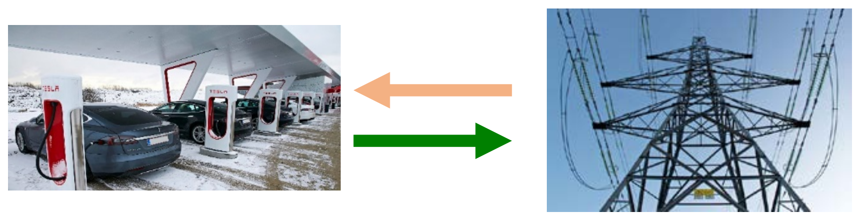
Fixed UFC charging



More flexibility needed

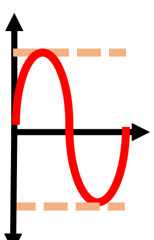
Single direction G2S charging

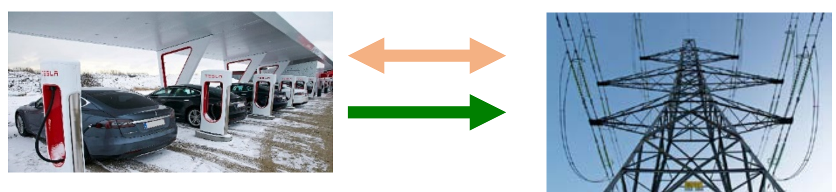




Providing flexibility

Two-way G2S charging

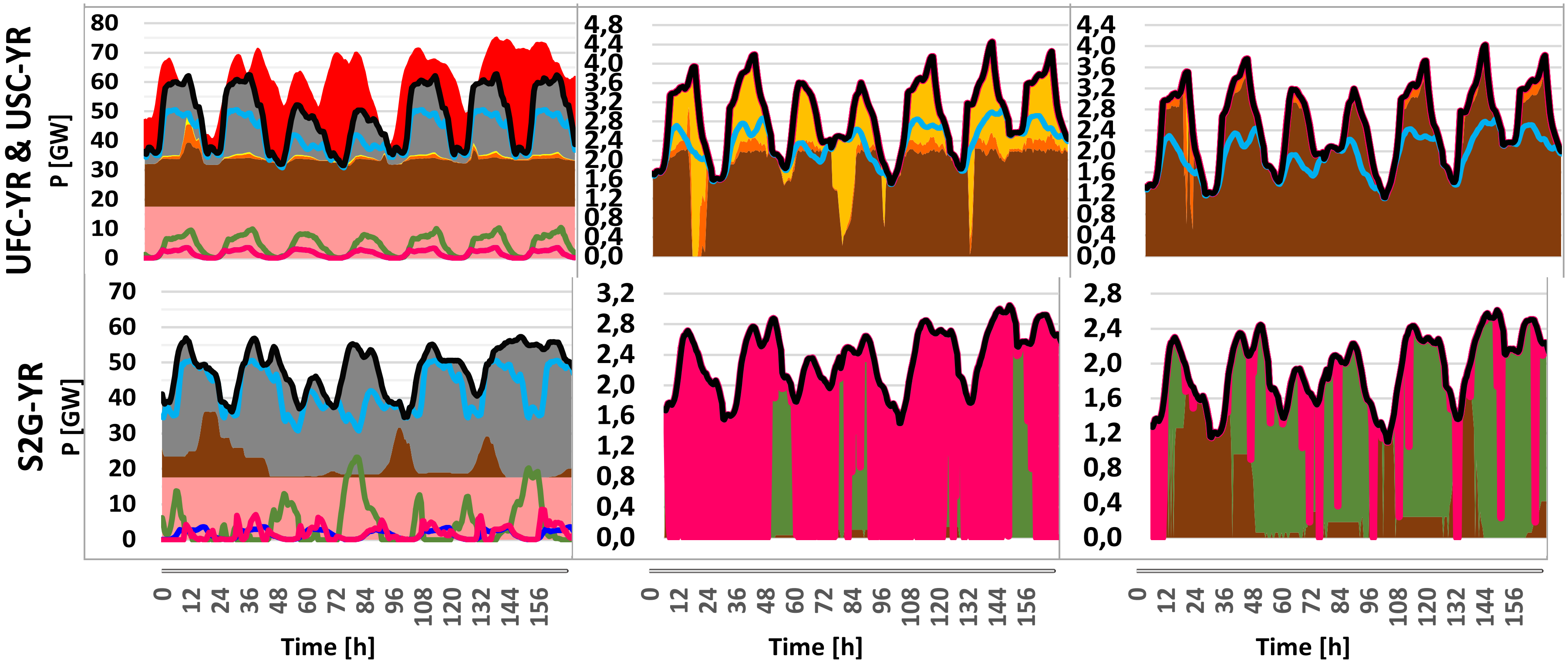




Providing flexibility

Power System Level

- Peak power increased, more flexibility needed (Curtailment), more reserve needed, higher operational costs



Pavić, Ivan; Capuder, Tomislav; Kuzle, Igor.
Fast charging stations — Power and ancillary services provision // IEEE Manchester PowerTech. (2017)

Modelling behind FCS+BSS

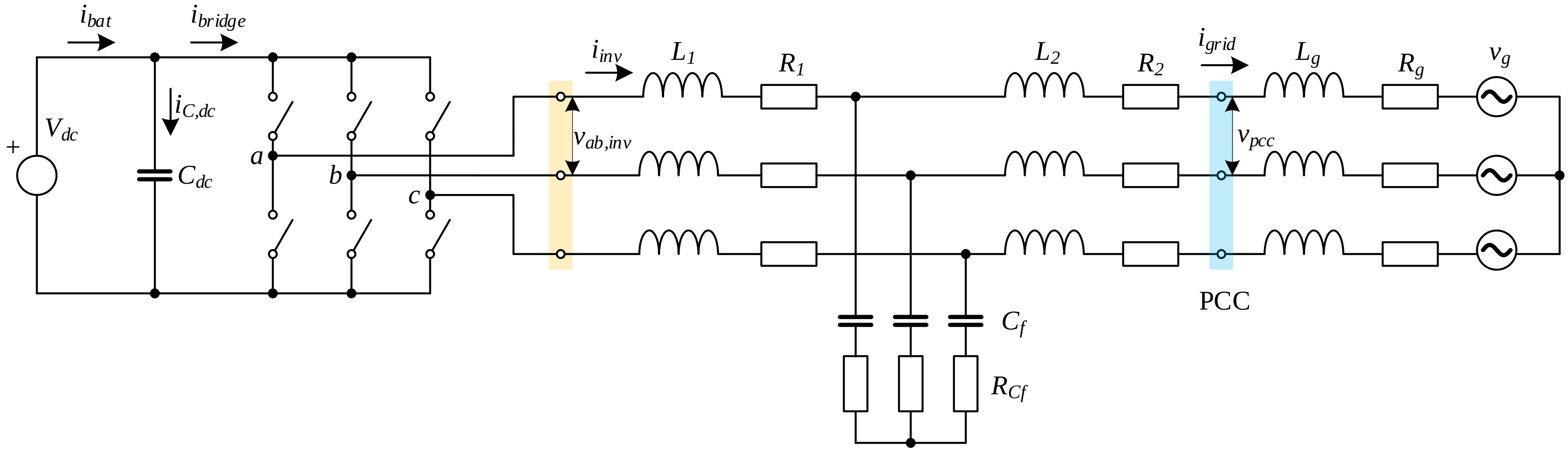
- Objective function -> best investment choice (optimal benefit between operational cot reduction and initial investment. s.t.:
  - Arrival time, departure time
  - SOC at the time of arrival, SOC at end
  - Type of car, location (3 locations: highway, shopping centre, parking lot), frequency of charging....

- All uncertanties modelled as stochastic variables (SOC, arrival/departure time, prices...)
- Decision: optimal size of battery storage unit to be integrated into FCS

Salapić, Vjekoslav; Gržanić, Mirna; Capuder, Tomislav;.
Optimal Sizing of Battery Storage Units Integrated Into Fast Charging EV Stations. // IEEE Energycon 2018.

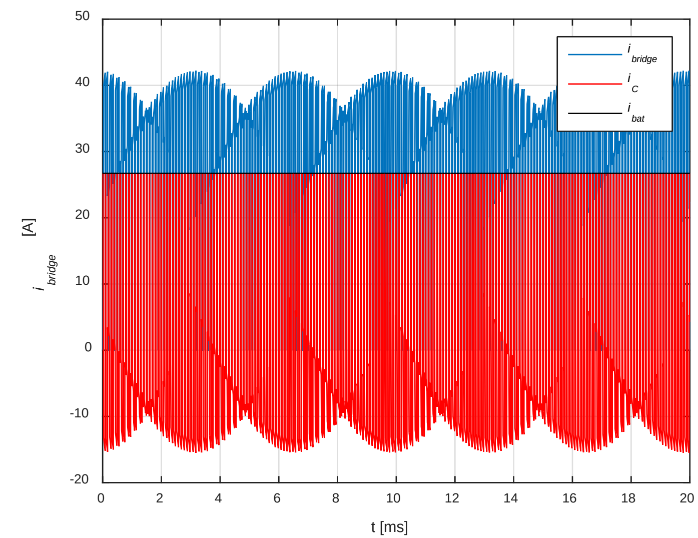
Modelling of prototype FCS

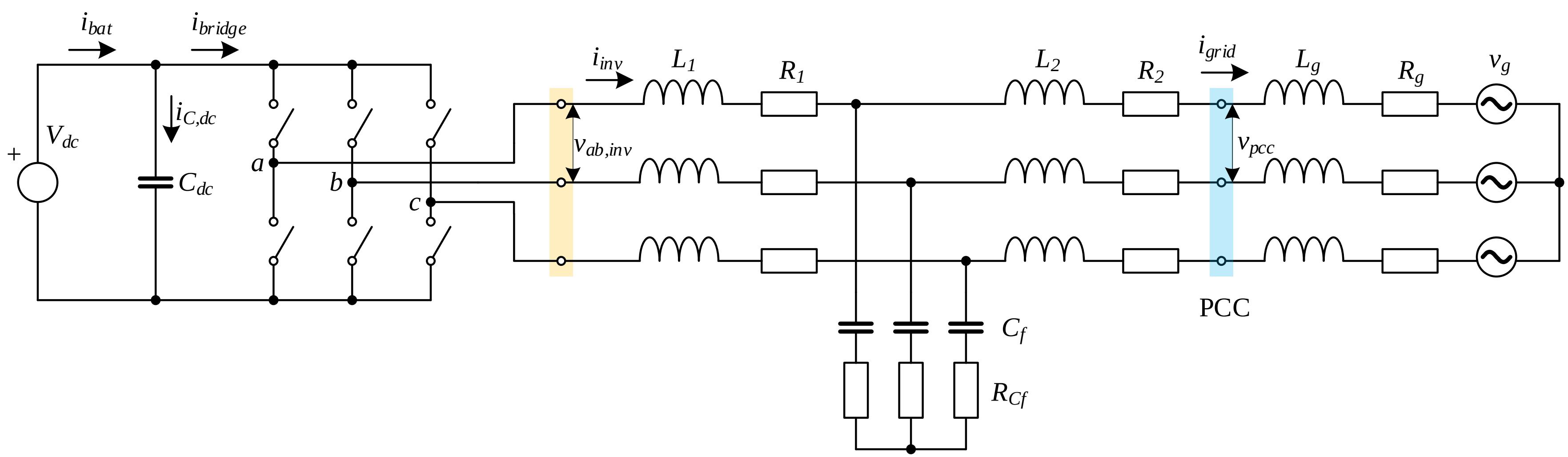
- Controllable AC voltage source:
  - Generates AC voltage:
    - Any requested amplitude (maximum line voltage amplitude ($v_{ab,inv}$ in Figure) is equal to the DC link amplitude, V_{dc})
    - The frequency is equal to the network frequency (needs to be synchronized)



Simulation results

- DC side currents i_{bat}, $i_{C,dc}$ i i_{bridge}
- $\cos(\varphi_v - \varphi_i) = 1$





Simulation results

- DC side currents i_{bat}, $i_{C,dc}$ i i_{bridge}
- $\cos(\varphi_v - \varphi_i) = 0$