Power-Hardware-In-The-Loop Validation of Air-Source Heat Pump for Fast Frequency Response Applications

PSCC 2024, Paris

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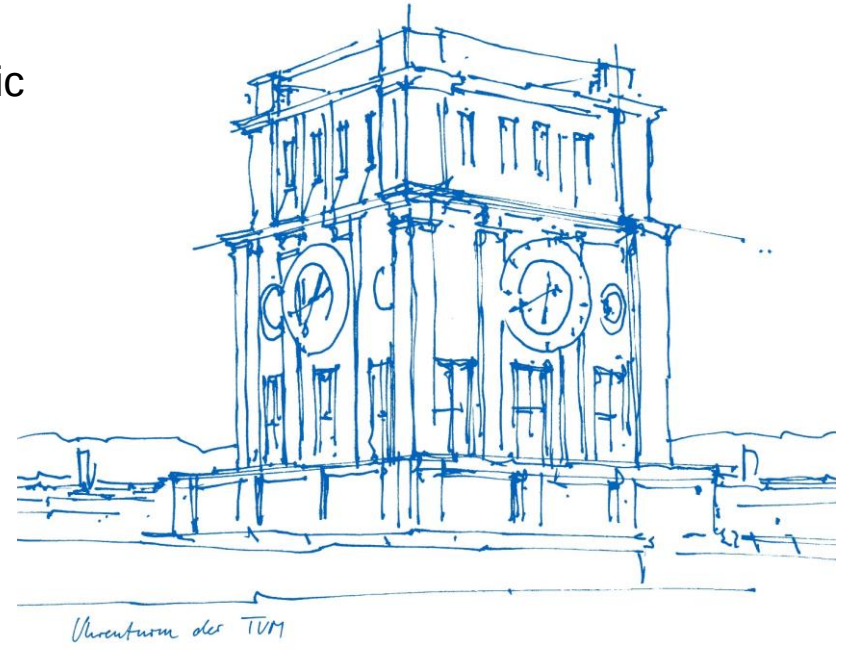
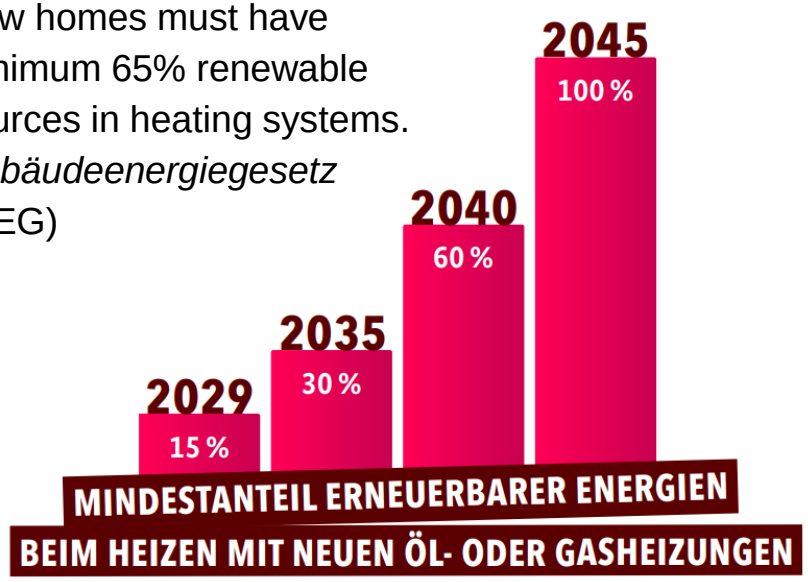


Motivation

- Heat pumps are key to decarbonization of heating sector

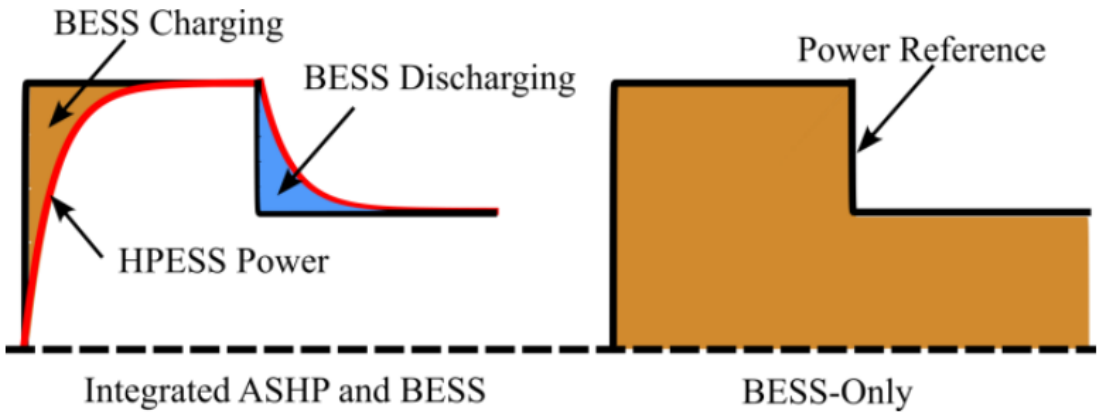
New homes must have minimum 65% renewable sources in heating systems. *Gebäudeenergiegesetz* (GEG)



https://www.energiewechsel.de/KAENEF/Redaktion/DE/Downloads/faktenblatt-geg-gebaeudeenergiegesetz.pdf

Motivation

- Heat pumps are key to decarbonization of heating sector
- Heat pumps can be used for frequency response services



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Review

Potentials of using electric-thermal sector coupling for frequency control: A review

Ruihao Song [a], Thomas Hamacher [a], Vladimir Terzija [b], Vedran S. Perić [a]

https://doi.org/10.1016/j.ijepes.2023.109194

Integrating Air-Source Heat Pumps into the Demand-side Fast Frequency Response Service: A Study Based on Thermal Dynamic Uncertainty

Ruihao Song, Vladimir Terzija, Thomas Hamacher, and Vedran S. Perić

https://www.techrxiv.org/doi/full/10.36227/techrxiv.21707870.v2

Motivation

- Heat pumps are key to decarbonization of heating sector
- Heat pumps can be used for frequency response services
- Heat pumps are a control nightmare in the field

Type		CHA-07	CHA-10
Performance range at A-7/W35	kW	1.6-6.8	2.2-9.8
A7/W35 Rated power / COP according to EN14511	kW / -	4.5 / 5.47	4.1 / 5.72
A2/W35 Rated power / COP according to EN14511	kW / -	5.15 / 4.54	5.75 / 4.65
A-7/W35 max. performance / COP according to EN14511	kW / -	5.88 / 2.73	7.97 / 2.88
max. lead time	°C	70	70
Sound pressure night max. (freestanding, 3m distance)	dB(A)	32	34
Refrigerant type / filling quantity / GWP	- / kg / -	R290 / 3.1 / 3	R290 / 3.4 / 3
Energy efficiency class room heating, low temperature	-	A++/A+++	A++/A+++
Energy efficiency class room heating, medium temperature	-	A++	A++

https://www.wolf.eu/de-de/produkte/waermepumpe-cha-und-chc-monoblock

SPIEGEL Business

Why heat pumps often consume too much electricity

They are intended to make residential buildings more climate-friendly and less dependent on gas. But many heat pumps are planned incorrectly, and customers are often left with high costs. What consumers should pay attention to.

By Henning Jauernig
18.03.2022, 13:00 • from DER SPIEGEL 12/2022

zdfheute

If the heat pump "costs" too much

by Sven-Hendrik Hahn 28.03.2023 | 11:04

Heat pumps are booming. According to the plan, from 2024 onwards, oil and gas heating systems will no longer be allowed in new buildings. But there are also risks involved in installing heat pumps.

Motivation

- Heat pumps are key to decarbonization of heating sector
- Heat pumps can be used for frequency response services
- Heat pumps are a control nightmare in the field

- How exactly should power system laboratories „research“ sector-coupling through heat-pumps?
  - Lack of expertise in heat-pump modelling
  - Lack of access to requisite real hardware
  - Unable to bypass any device safety features for fast control

Heat pump research at CoSES, TUM

- Various publications on modelling, control and operation of heat pumps

R. Song, G. Yon, T. Hamacher, and V. S. Peric, "Data-Driven Model Reduction of the Moving Boundary Heat Pump Dynamic Model", 2022 IEEE PESGM, 2022. doi: 10.1109/pesgm48719.2022.9916823.

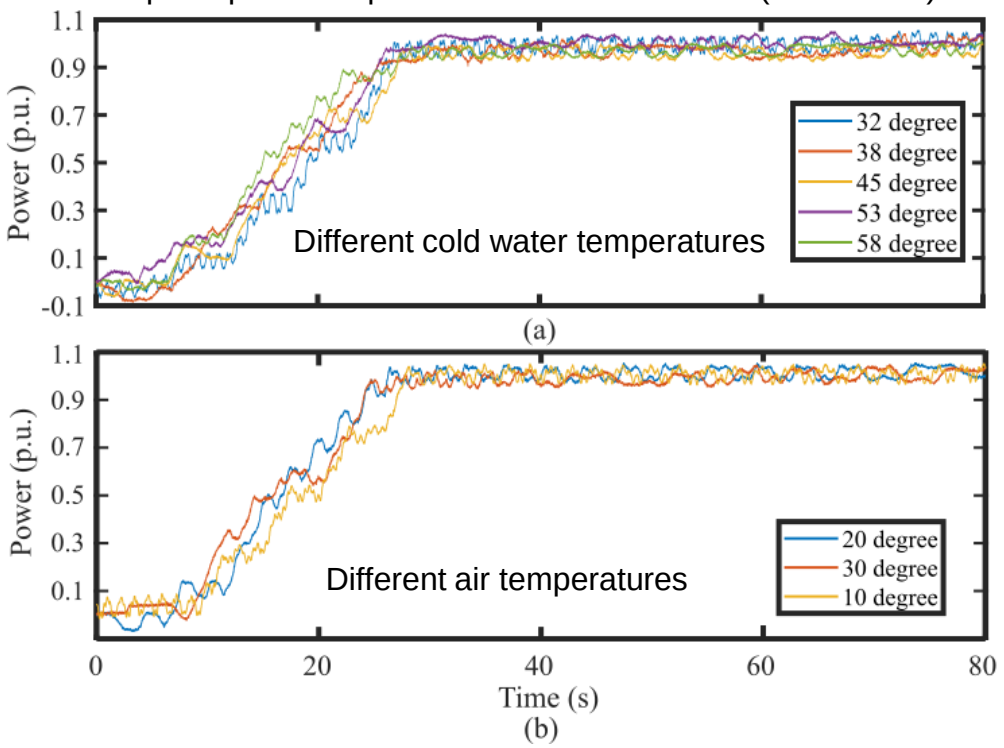
D. Zinsmeister et al., "A prosumer-based sector-coupled district heating and cooling laboratory architecture," Smart Energy, vol. 9. Elsevier, Feb. 2023. doi: 10.1016/j.segy.2023.100095.

O. Angelidis, D. Zinsmeister, et al., "5th Generation District Heating and Cooling Modelica Models for Prosumer Interaction Analysis," Proceedings of the 15th International Modelica Conference 2023, Aachen, doi: 10.3384/ecp204607.

R. Song, D. Zinsmeister, et al., "Adaptive Control of Practical Heat Pump Systems for Power System Flexibility Based on Reinforcement Learning", International Conference on Power System Technology (PowerCon). IEEE, 2023. doi: 10.1109/powercon58120.2023.10331231.

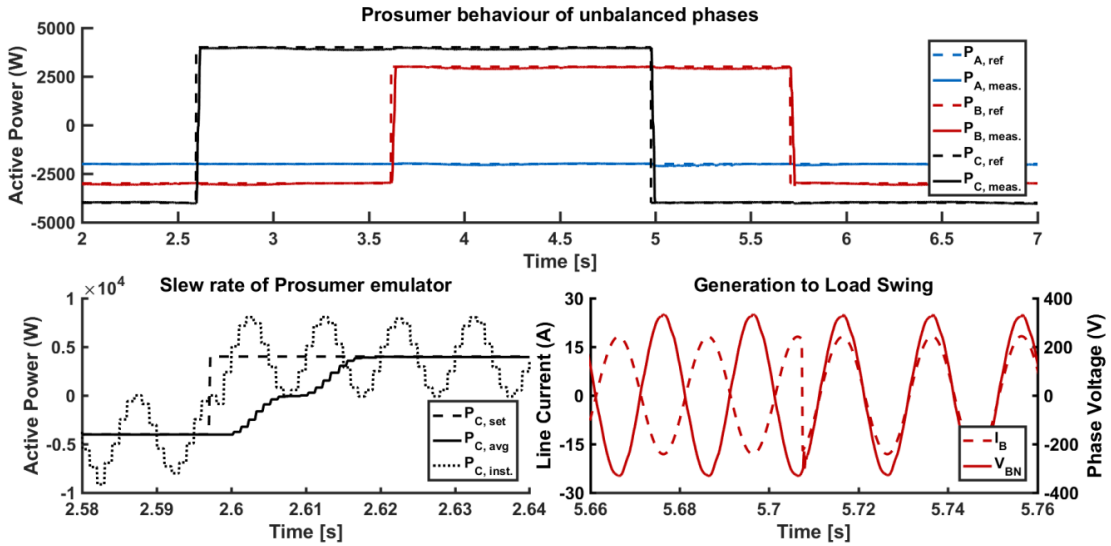
Wolf Air Source Heat Pump
(19 kW_{heat}, 9 kW_{cold})
+
HVAC climate generator

Speed-power response of the CoSES ASHP (normalized):



Heat pump research at CoSES, TUM

- High bandwidth PHIL emulation



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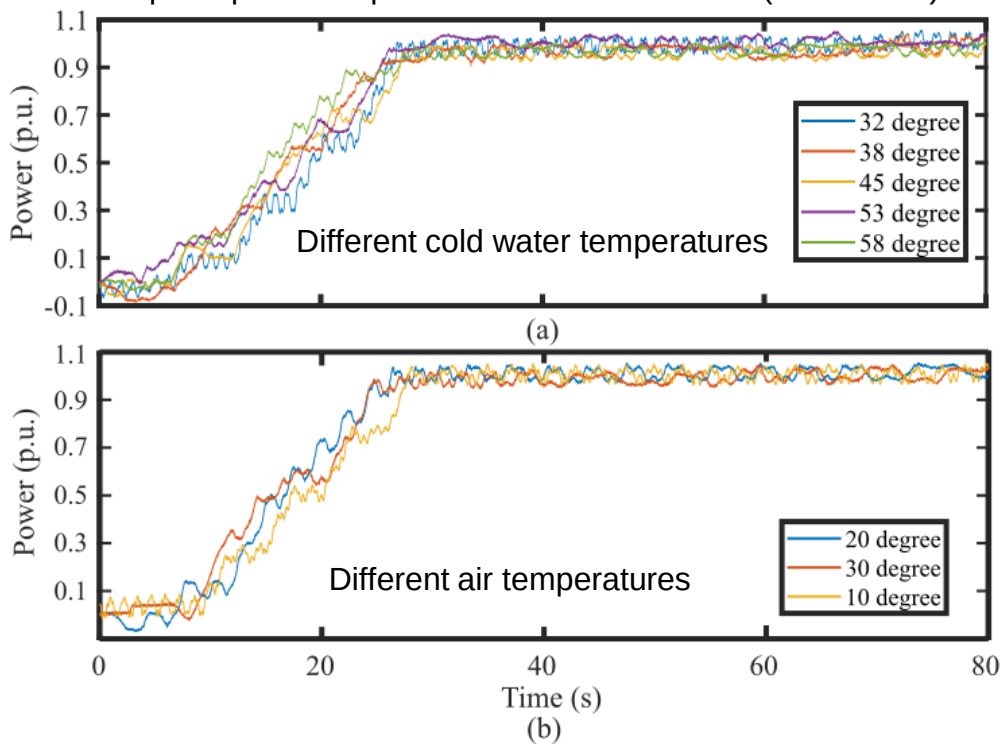

*A. Mohapatra, T. Hamacher, and V. S. Peric, “PHIL Infrastructure in CoSES Microgrid Laboratory,” IEEE PES Innovative Smart Grid Technologies Conference Europe, Novi Sad, IEEE PES, 2022, doi: https://doi.org/10.1109/ISGT-Europe54678.2022.9960295

Heat pump research at CoSES, TUM

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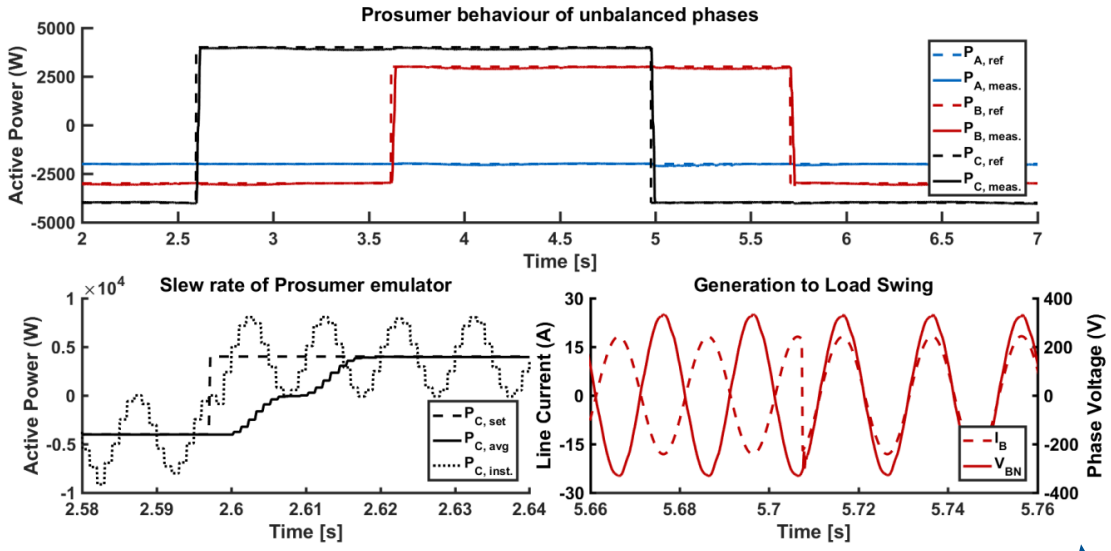

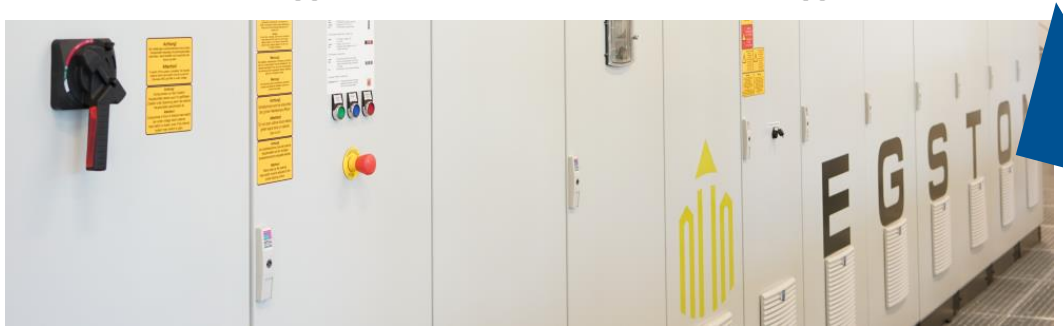

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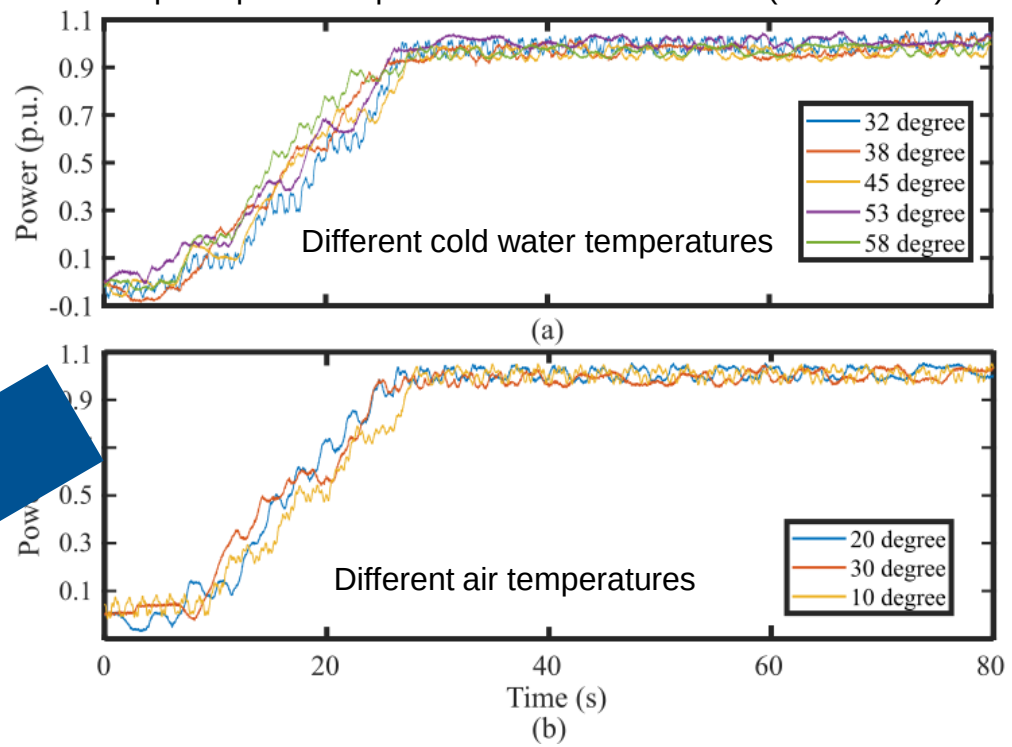

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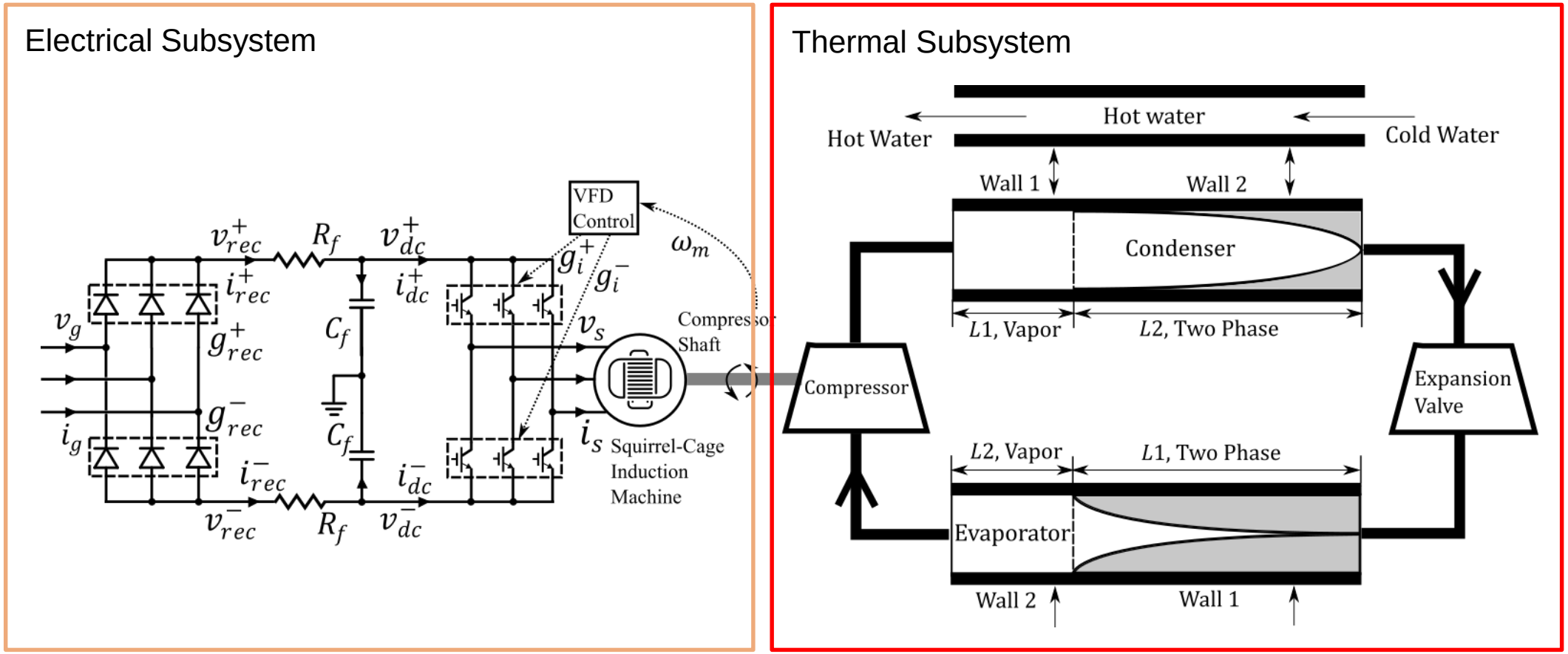
Virtual heat pump on PHIL emulator

- Remove all the internal safety control gains and delays.
- Reflect important non-linear dynamics based on physics principles (for rapid control validation).
- Establish our “virtual PHIL Heat Pump” in a real grid environment.

Typical air-source heat pump schematic

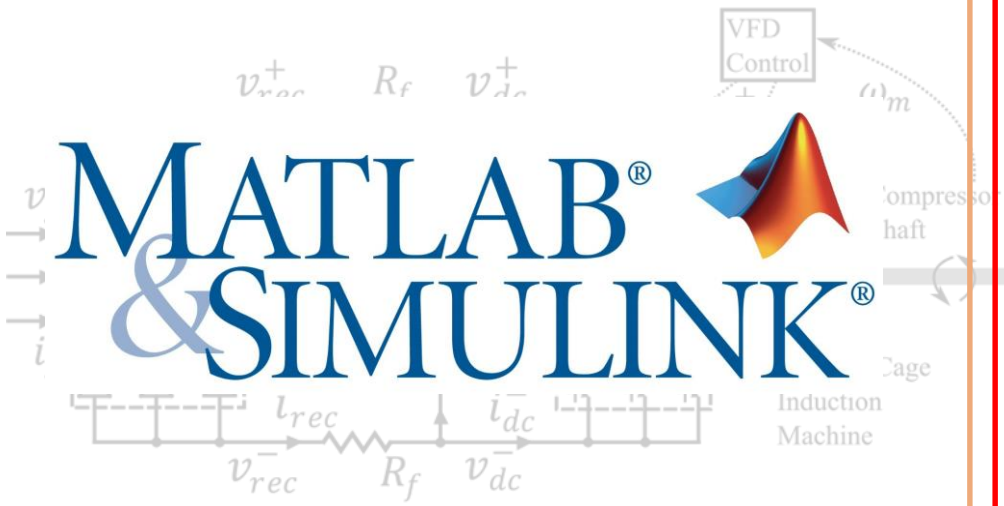
- Heat pump modelling



Typical air-source heat pump schematic

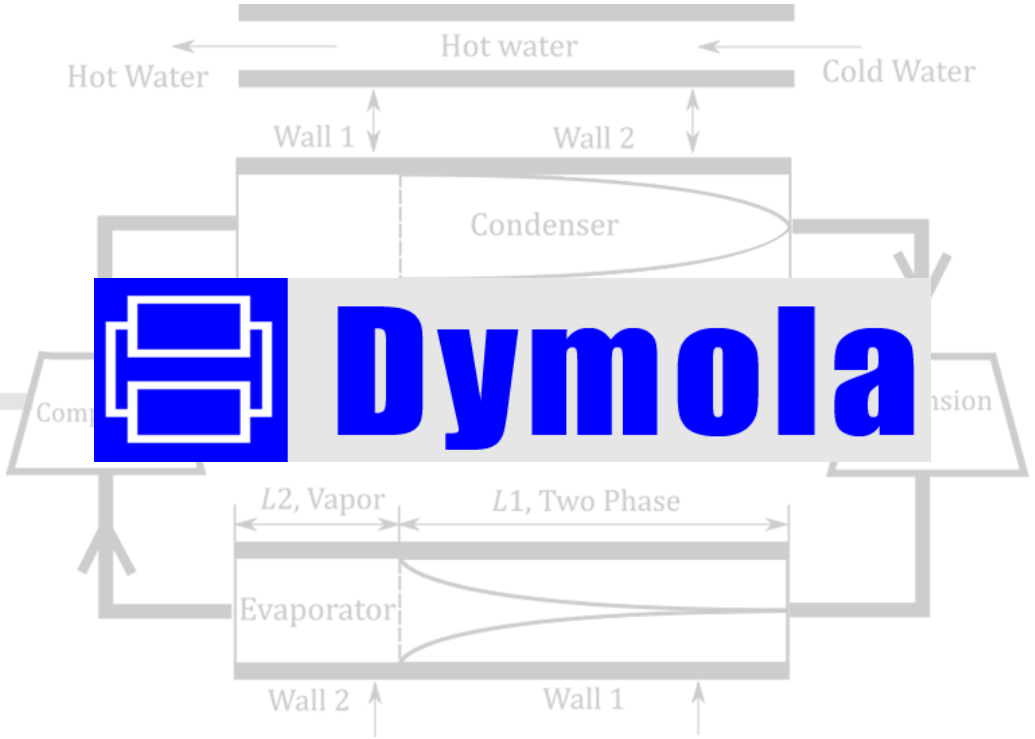
- Heat pump modelling

Electrical Subsystem



MATLAB® & SIMULINK®

Thermal Subsystem



Dymola

PHIL modelling caveats

- Real time computation load must be managed
- Model the Rectifier + Filter stage as *purely Math* model, NOT Physical model

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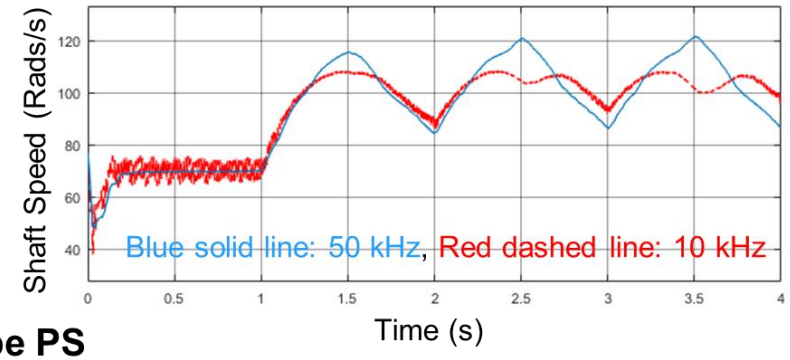
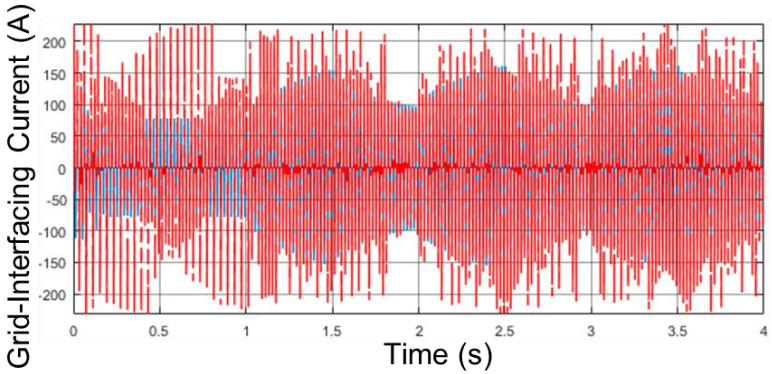
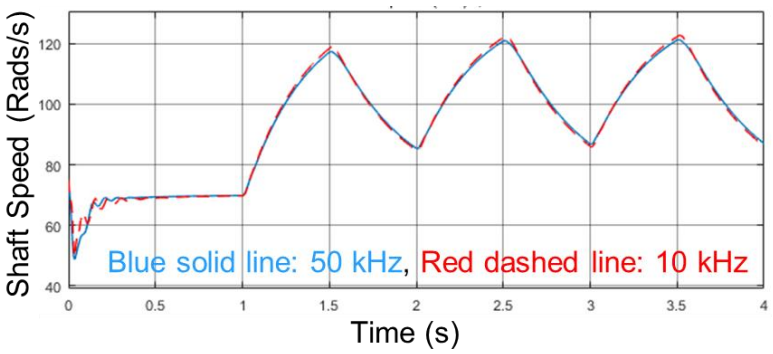
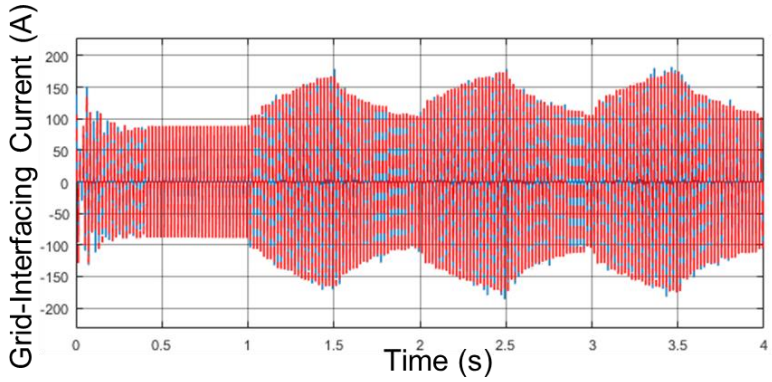
Simscpe PS





Math Model



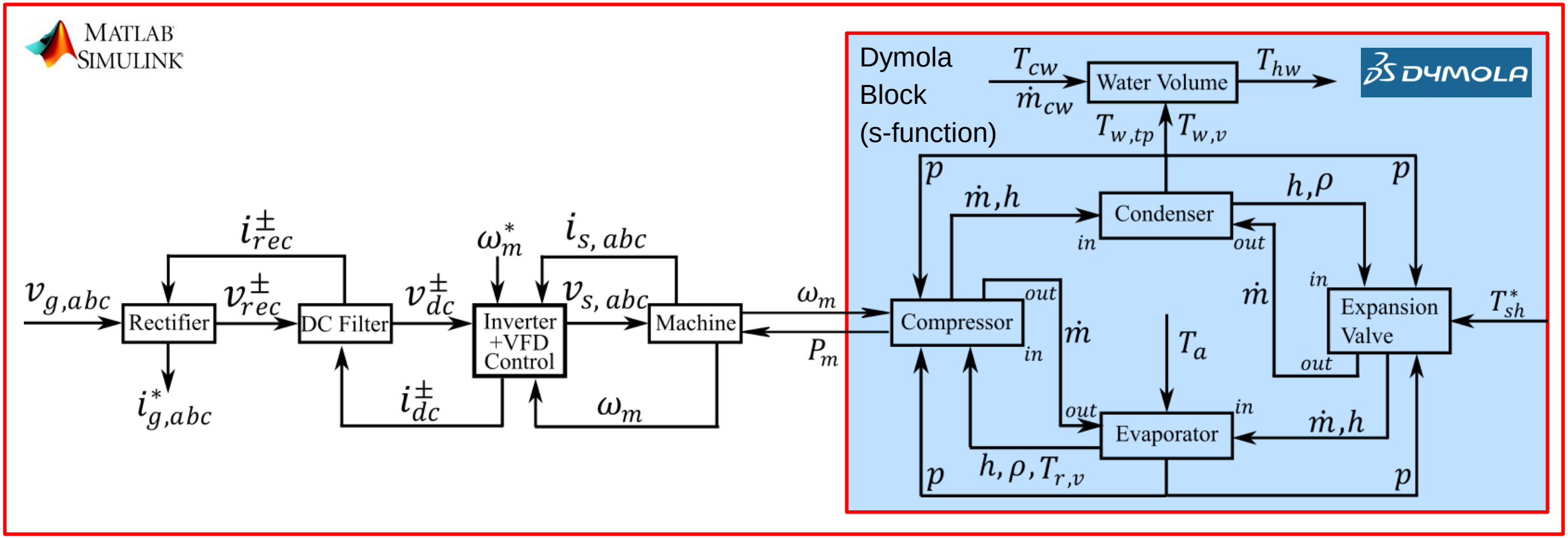


PHIL modelling caveats

- Real time computation load must be managed
- Model the Rectifier + Filter stage as *purely Math* model, NOT Physical model
- Model the thermal system as –
  - ODE relaxations of phase-shifting heat exchanger PDEs
  - Standard isoentropic compression
  - Standard expansion valve as per Bernoulli’s equation
  - PI controller for superheating

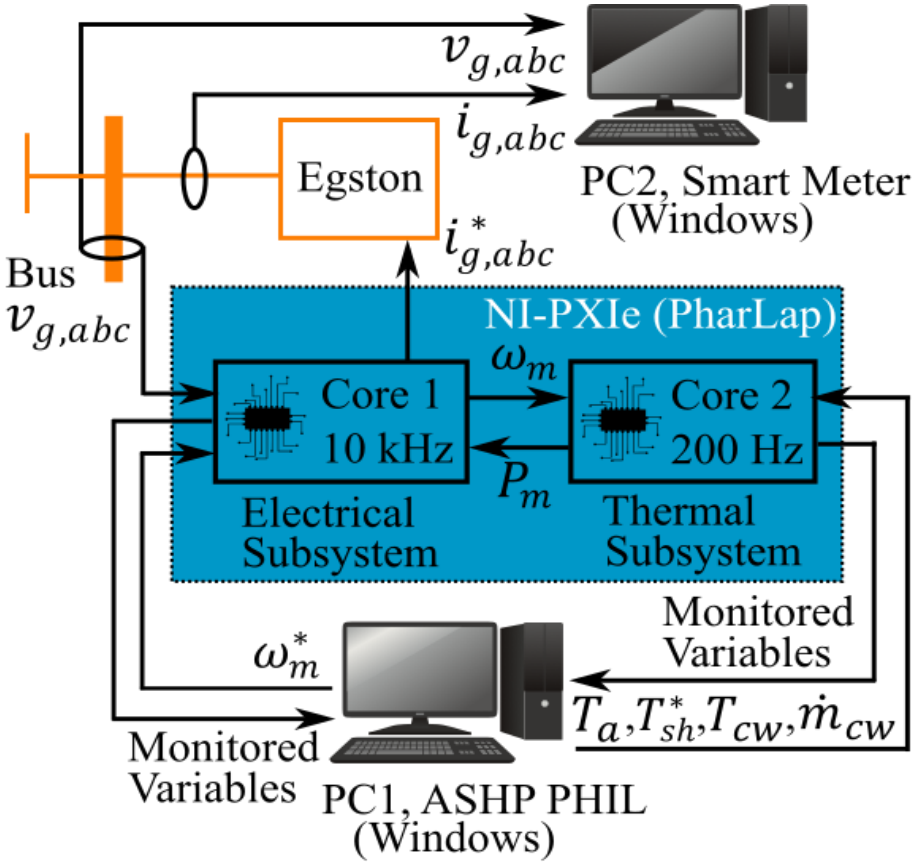
PHIL modelling caveats

- PHIL ready heat-pump model



PHIL results

- Two simulation models on two cores
  - To apply different execution frequencies
- Execution order: thermal → electrical.
  - Check individual model stability in advance
- Two models have an information exchange
  - shaft speed (electrical → thermal)
  - mechanical power (thermal → electrical)



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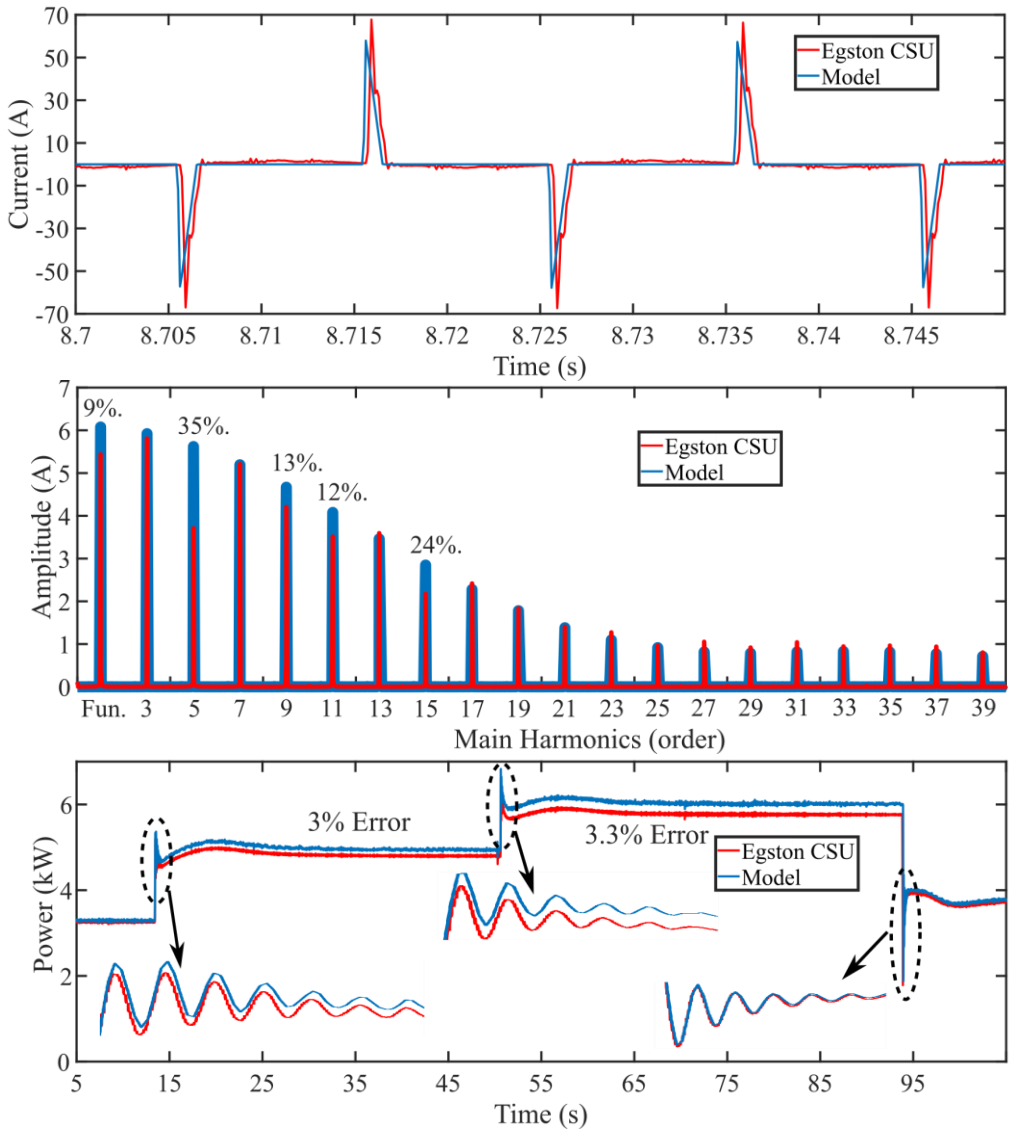

Conclusion

- Heat pumps are key component for sector-coupling research
- Most power system laboratories lack knowledge and test beds for heat pump modelling and control

- PHIL emulator ready “Virtual Air Source Heat Pump” was developed
- Can be used for PHIL validated sector-coupling research in power system laboratories

- Minor changes to modelling approaches might be needed based on specific PHIL setups.