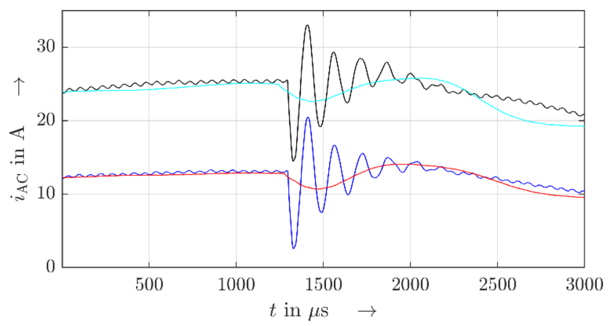

Fig. 6: $i_{AC\ noImp\ HP}$ (blue), $i_{AC\ Imp\ HP}$ (red) $i_{AC\ noImp\ FP}$ (black), $i_{AC\ Imp\ FP}$ (cyan)

While Fig. 6 shows the current, the voltage during the same transient process is shown in Fig. 7. It becomes visible, that the grid-impedance, even if not changed, has a significant impact on the dynamic behavior.

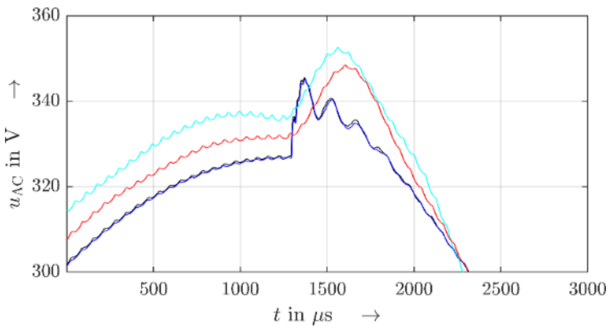

Fig. 7: $u_{AC\ noImp\ HP}$(blue), $u_{AC\ Imp\ HP}$(red), $u_{AC\ noImp\ FP}$(black), $u_{AC\ Imp\ FP}$(cyan)

For PV-inverters, the DC-power level is seen to have an impact on the admittance characteristic, i.e. the stationary behavior that can affect the system stability [10]. For the dynamic behavior, first measurements seem to indicate, that the DC-power level is not of importance for the dynamic behavior, as can be seen in Fig. 6. If the time constants of MPPTs in PV-inverters are much larger than the dynamic process, the DC-side can be considered decoupled from the AC-side for photovoltaic inverters. This measurement has not been done yet to finally proof the decoupling for the studied PV-inverters.

5. Conclusion

The study presents a framework for the measurement-based characterization of the dynamic behavior of power electronic devices. The results of the measurements can be used to determine the “grid-robustness” of the devices, e.g. PV inverter, and can serve as prerequisite to develop new black-box modeling approaches to model the dynamic behavior for large scale simulations. Initial measurements for PV inverters have shown that the transient response is significantly different between different makes.

The slew rate of the step change is at the moment mainly determined by the grid-simulator in the laboratory, but the impact of the slew rate itself has to be studied in future work. The proposed impact factors are also relevant for three-phase systems but need some adaptation, such as considering balanced and unbalanced conditions. It is also left to future work to choose suitable models in time domain models, to fit the collected data into new models that can represent the dynamic behavior of power electronic devices in low-voltage grids.

Acknowledgment

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 360497354.

References

[1] Blaabjerg, F. ; Yang, Y. ; Yang, D. ; Wang, X.: Distributed Power-Generation Systems and Protection. In: *Proceedings of the IEEE* Bd. 105, Institute of Electrical and Electronics Engineers (IEEE) (2017), Nr. 7, S. 1311–1331.

[2] Teodorescu, R. ; Liserre, M. ; Rodriguez, P.: Grid Converters for Photovoltaic and Wind Power Systems : Wiley-IEEE Press, 2011 — ISBN 9780470057513.

[3] Sun, J.: Impedance-Based Stability Criterion for Grid-Connected Inverters. In: *IEEE Transactions on Power Electronics* Bd. 26, Institute of Electrical and Electronics Engineers (IEEE) (2011), Nr. 11, S. 3075–3078.

[4] Wang, X. ; Blaabjerg, F.: Harmonic Stability in Power Electronic Based Power Systems: Concept, Modeling, and Analysis. In: *IEEE Transactions on Smart Grid*, Institute of Electrical and Electronics Engineers (IEEE) (2018), S. 1.

[5] Stiegler, R. ; Meyer, J. ; Schori, S. ; Höckel, M. ; Drápela, J. ; Hanzlík, T.: Survey of network impedance in the frequency range 2-9 KHZ in public low voltage networks in AT / CH / CZ / GE. In: *25th International Conference on Electricity Distribution*, 2019, S. 3–6.

[6] Kaufhold, E. ; Meyer, J. ; Schegner, P.: Modular White-Box Model of single-phase Photovoltaic Systems for Harmonic Studies. In: *13th IEEE PES PowerTech Conference*. Milano, Italy, 2019.

[7] Cobben, S. ; Kling, W. ; Myrzik, J.: The Making and Purpose of Harmonic Fingerprints. In: *19th International Conference on Electricity Distribution* (2007), Nr. 0764, S. 21–24.

[8] Liserre, M. ; Teodorescu, R. ; Blaabjerg, F.: Stability of photovoltaic and wind turbine grid-connected inverters for a large set of grid impedance values. In: *IEEE Transactions on Power Electronics* Bd. 21, Institute of Electrical and Electronics Engineers (IEEE) (2006), Nr. 1, S. 263–272.

[9] Langella, R. ; Testa, A. ; Meyer, J. ; Moller, F. ; Stiegler, R. ; Djokic, S.Z.: Experimental-Based Evaluation of PV Inverter Harmonic and Interharmonic Distortion Due to Different Operating Conditions. In: *IEEE Transactions on Instrumentation and Measurement* Bd. 65 (2016), Nr. 10, S. 2221–2233 — ISBN 9781479909483.

[10] Kaufhold, E. ; Meyer, J. ; Müller, S. ; Schegner, P.: Probabilistic Stability Analysis for Commercial Low Power Inverters Based on Measured Grid Impedances. In: *2019 9th International Conference on Power and Energy Systems*. Perth, Australia, 2019.

[11] Enslin, J.H.R. ; Heskes, P.J.M.: Harmonic Interaction Between a Large Number of Distributed Power Inverters and the Distribution Network. In: *IEEE Transactions on Power Electronics* Bd. 19, Institute of Electrical and Electronics Engineers (IEEE) (2004), Nr. 6, S. 1586–1593.