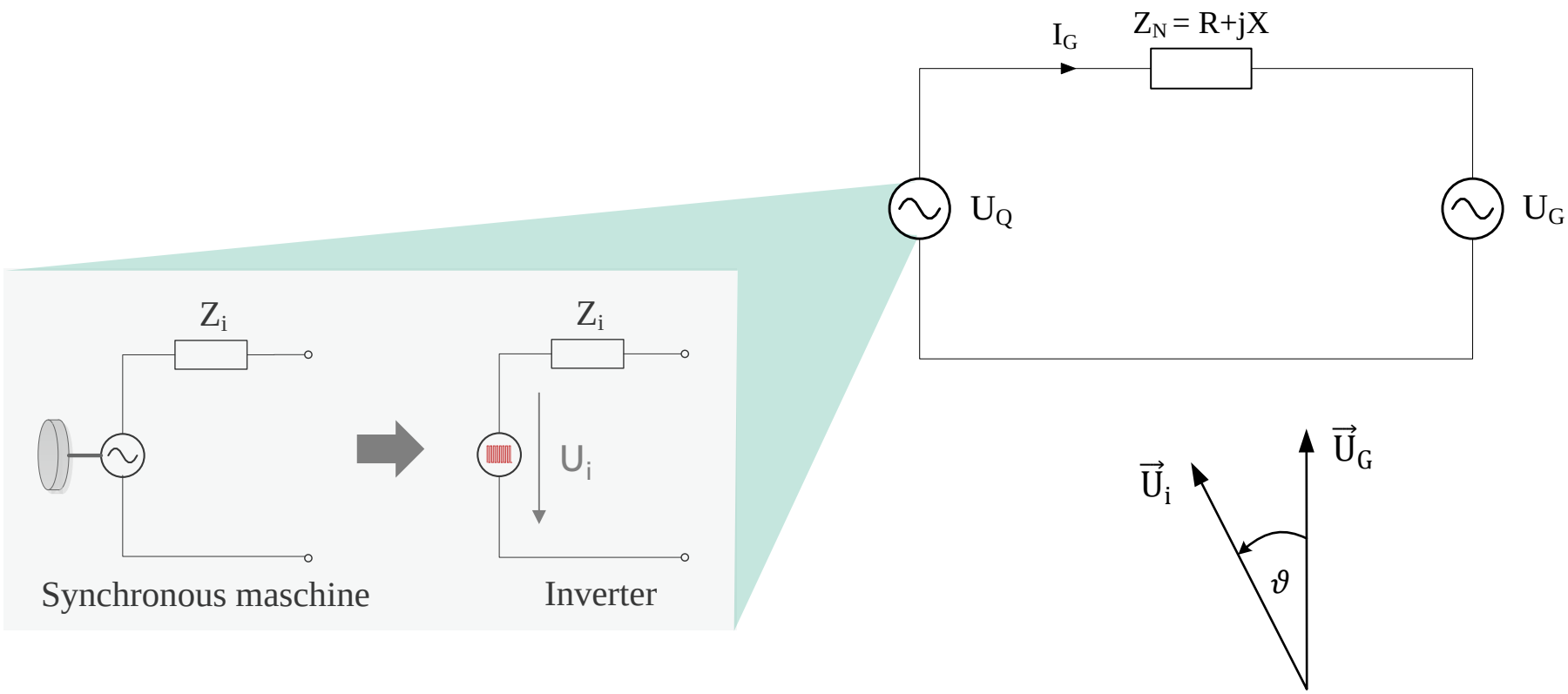
ADVANCED INVERTERS IN FUTURE POWER GRIDS

Peter Unruh, Fraunhofer IEE

Netzregelung 2.0

Advanced Inverters in Future Power Grids

Background



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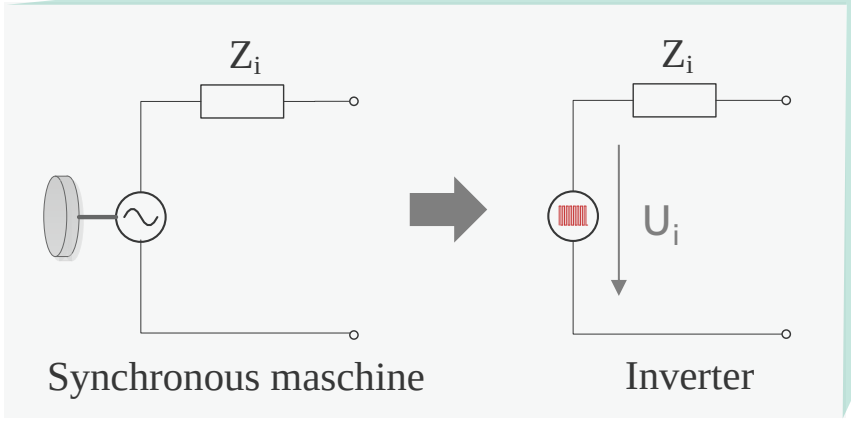
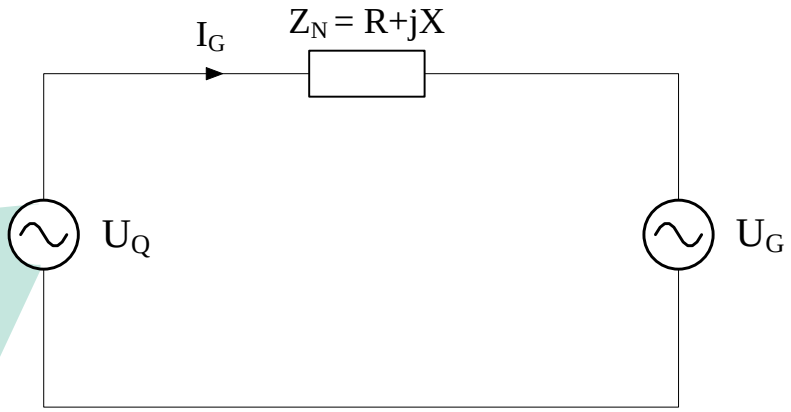
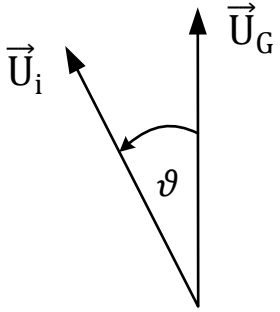
Background

- In inverter-dominated grids, there is a need for slow-acting voltage phasors







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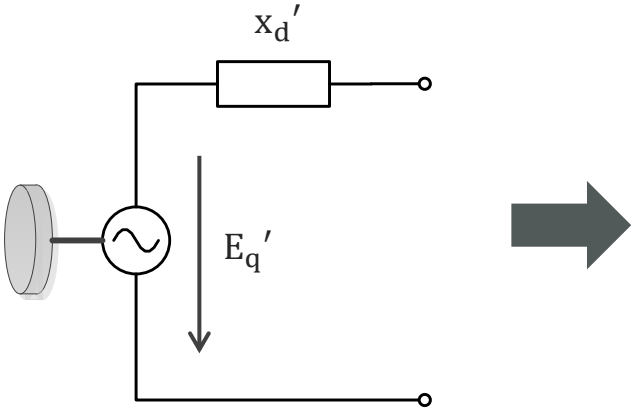
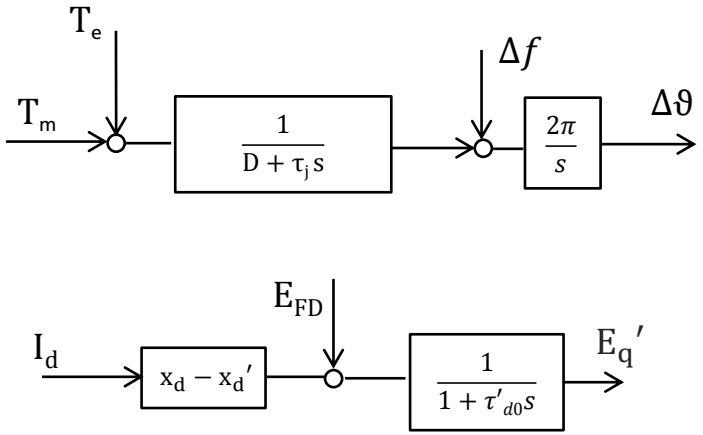
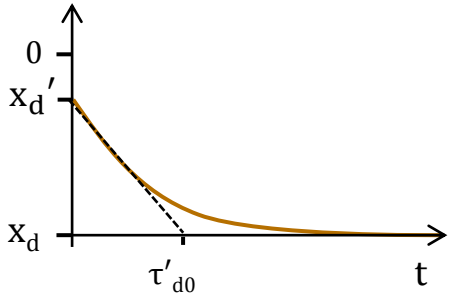
Modeling of the Synchronous Machine





Based on: Power System Control and Stability, P.M. Anderson and A.A. Fouad, S.141



Transient development of the impedance after a current step (see Elektrische Energieversorgung I, V. Crastan S.244)

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Virtual Synchronous Machines – Synchronverter

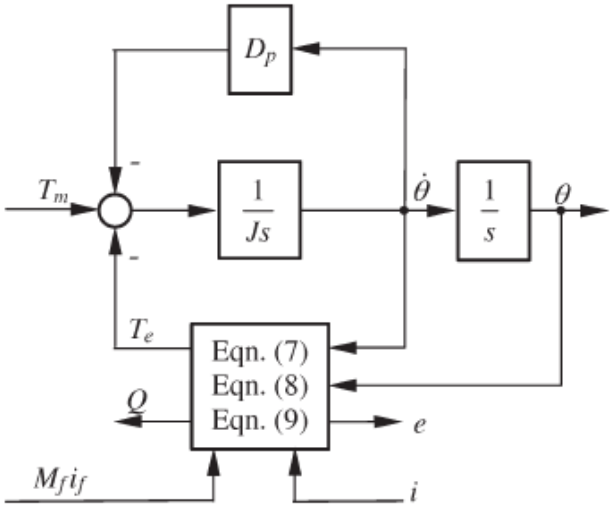

Image taken from [10]

- Proposed by Zhong/Weiss [10]
- Mimics the dynamic behavior of the 2. order of the synchronous machine
- stator/rotor-linkage are described by algebraic equations (7)-(9)

$$T_e = -M_f i_f \left\langle i, \frac{\partial}{\partial \theta} \widetilde{\cos}\,\theta \right\rangle = M_f i_f \langle i, \widetilde{\sin}\,\theta \rangle .^{*} \qquad (7)$$

$$e = \dot{\theta} M_f i_f \widetilde{\sin}\,\theta . \qquad (8)$$

$$Q = -\dot{\theta} M_f i_f \langle i, \widetilde{\cos}\,\theta \rangle .^{*} \qquad (9)$$

* < , > denotes the three-dimensional scalar product

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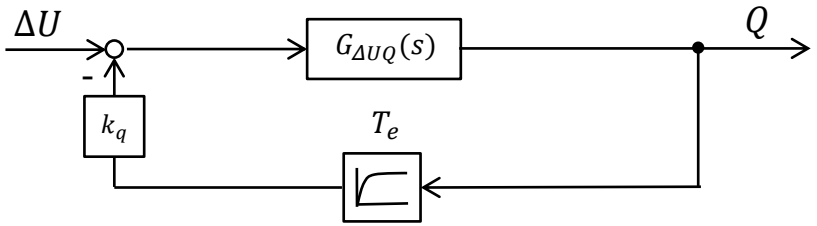
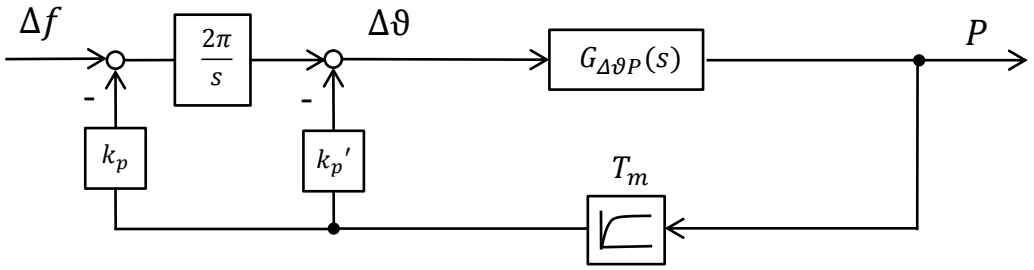
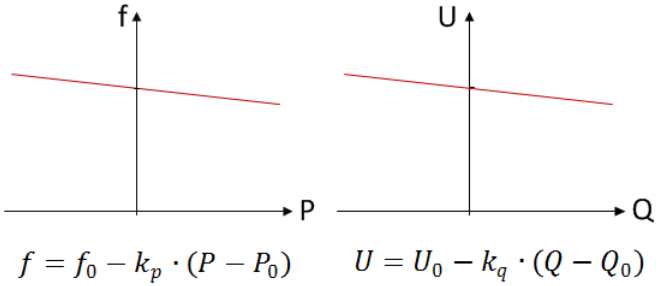
Droops – SelfSync [3]



- U(Q)- and f(P)-droops
- PT_1 low-pass filter
- Angle feedforward





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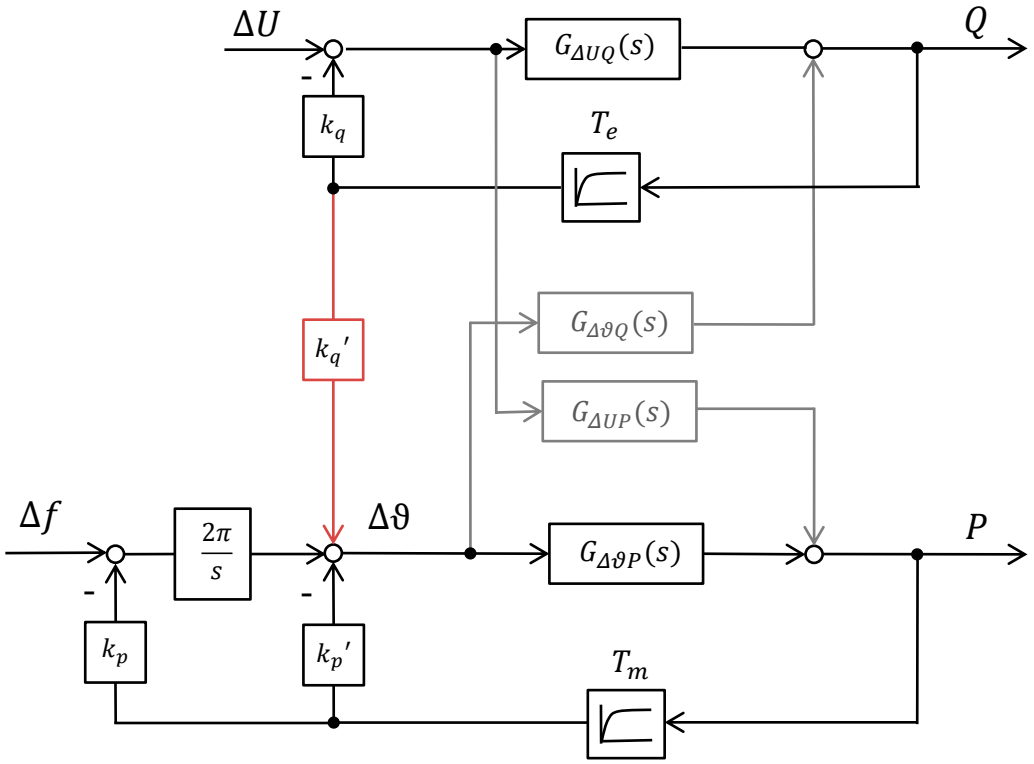
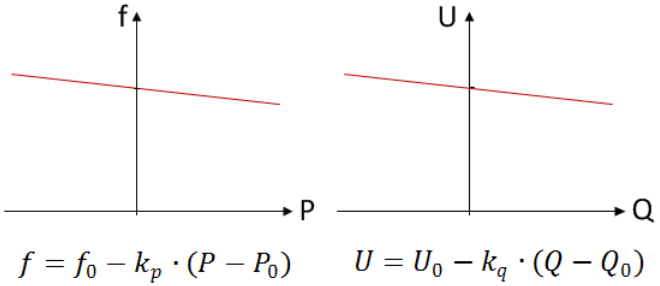
Droops – SelfSync + [4]



- U(Q)- and f(P)-droops
- PT_1 low-pass filter
- Angle feedforward



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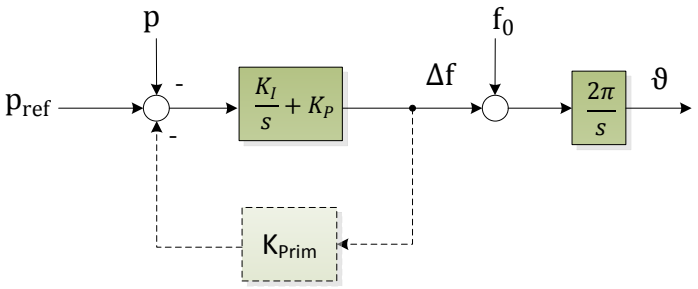
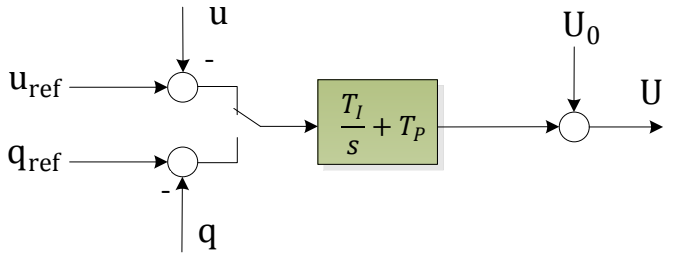
Voltage Controlled Inverter

f/P control loop



U/Q control loop



- Introduced by TU Braunschweig [8]
- By restructuring, P/f-control loop equivalent to the Selfsync
- Voltage controller eliminates the inner impedance instead of causing a „drooping“

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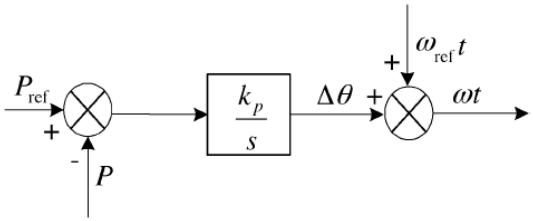
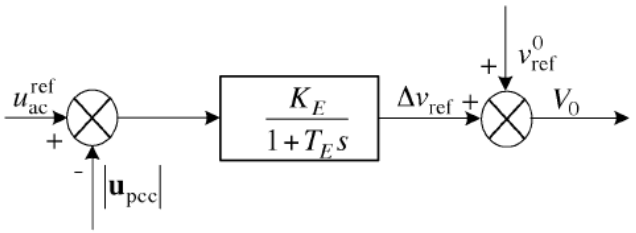
Power Synchronization Loop

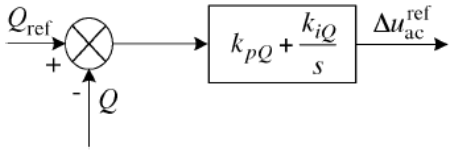
f/P control loop



U/Q control loop



- Introduced by ABB [9]
- f/P control loop equals droop control
- Also the proportional voltage controller corresponds to a „drooping“ character
- … but in opposite direction



Pictures taken from [9]

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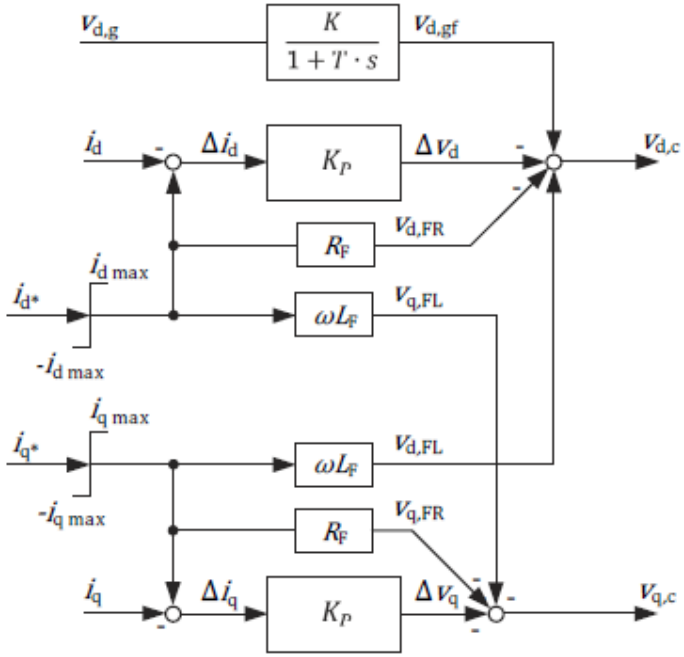
Softened current controller – DQ-voltage control



Picture taken from [7]

- Realization by Wrede/Winter [7]
- Voltage feedforward is low-pass delayed
- Current controller is reduced to a proportional controller
- Acts transiently as an ohmic damper

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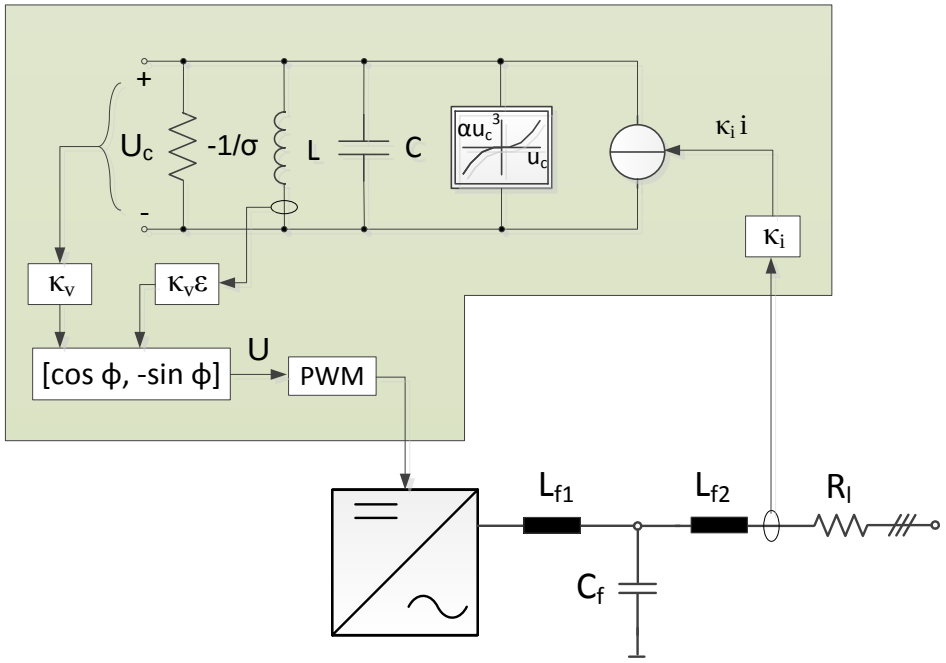
Virtual Oscillator Circuit



- Developed by B. Johnson (former NREL) [5]
- Sinusoidal implementation in time domain
- Nonlinear Van der Pol oscillator
- Resonance frequency is set equal to the nominal frequency

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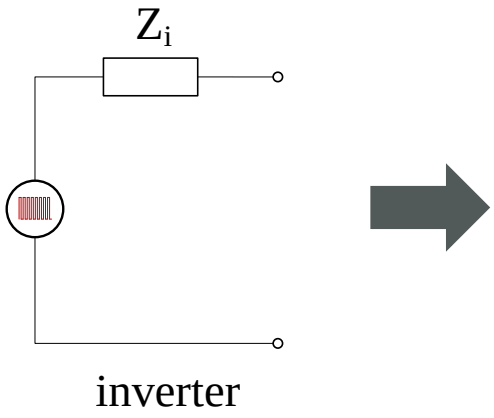
Conclusion



Advanced inverters means…

- Inverters should provide slow-acting voltage phasors
- A synchronization mechanism according to the swing equation is preferable
- Damping of rotor oscillation is needed and can be realized appropriately in inverters

Grid-forming Inverters and Synchronous Machines

References

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[4] P. Unruh and T. Gühna, “Distributed grid-forming inverters in power grids”, PV Integration Workshop 2017

[5] B. Johnson, M. Rodriguez, M. Sinha, and S. Dhople, “Comparison of virtual oscillator and droop control” in 2017 IEEE 18th Workshop on Control and Modeling for Power Electronics (COMPEL): Stanford University, Stanford, California, USA, July 9-12, 2017, Stanford, CA, USA, 2017, pp. 1–6.

[6] Duckwitz et. al., „Experimental Short-Circuit Testing of Grid-Forming Inverters in Microgrid and Interconnected Mode“, NEIS Conference, September, 2018, Hamburg

Grid-forming Inverters and Synchronous Machines

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[7] P. Winter and H. Wrede, “Impact of Power Converter Control on Transient Stability of Power Systems”, NEIS Conference, 2018

[8] S. Laudahn, J. Seidel, B. Engel, T. Bulo, and D. Premm, “Substitution of synchronous generator based instantaneous frequency control utilizing inverter-coupled DER,” *7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG),* 2016

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[10] Q. Zhong, G. Weiss, “Synchronverters: Inverters That Mimic Synchronous Generators”, IEEE Trans. On Industriell Electronics , 2011

Grid-forming Inverters in the Power System

Funding reference

Supported by:

on the basis of a decision
by the German Bundestag

The project underlying this report was funded by the Federal Ministry for Economic Affairs and Energy under grant number 0350023A. The responsibility for the content of this publication lies with the authors and does not necessarily reflect the opinion of the consortium of the project Netzregelung 2.0

Advanced Inverters in Future Power Systems

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