Rotating-Voltage-Vector Control for Wind Energy Plants providing Possibility for Ancillary Services

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Introduction

- conventional power plants supply instantaneous reserve using energy stored in rotating masses of the generators
- in case of a generation loss the drop of grid frequency is slowed down (Fig. 1, black line)
- grid self regulation effect (Fig. 1, blue line) and ancillary services supplied by power plants (Fig. 1, red line) will bring the grid frequency to a steady state

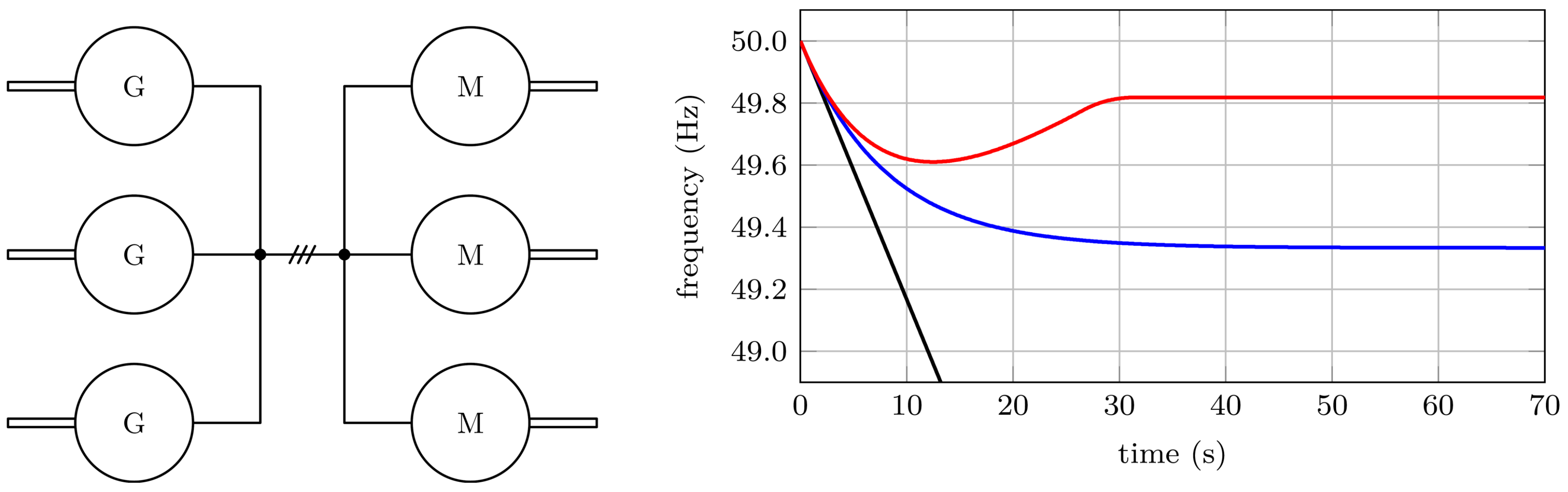


Fig. 1: current grid situation, frequency response to loss of generation

- just replacing conventional power plants by converter-based renewables will decrease the inertia in the grid
- renewables have to make contribution by participating in ancillary services
- providing virtual inertia to support frequency control
- grid-forming control schemes for grid-side converters to enable island grid operation and black start capability

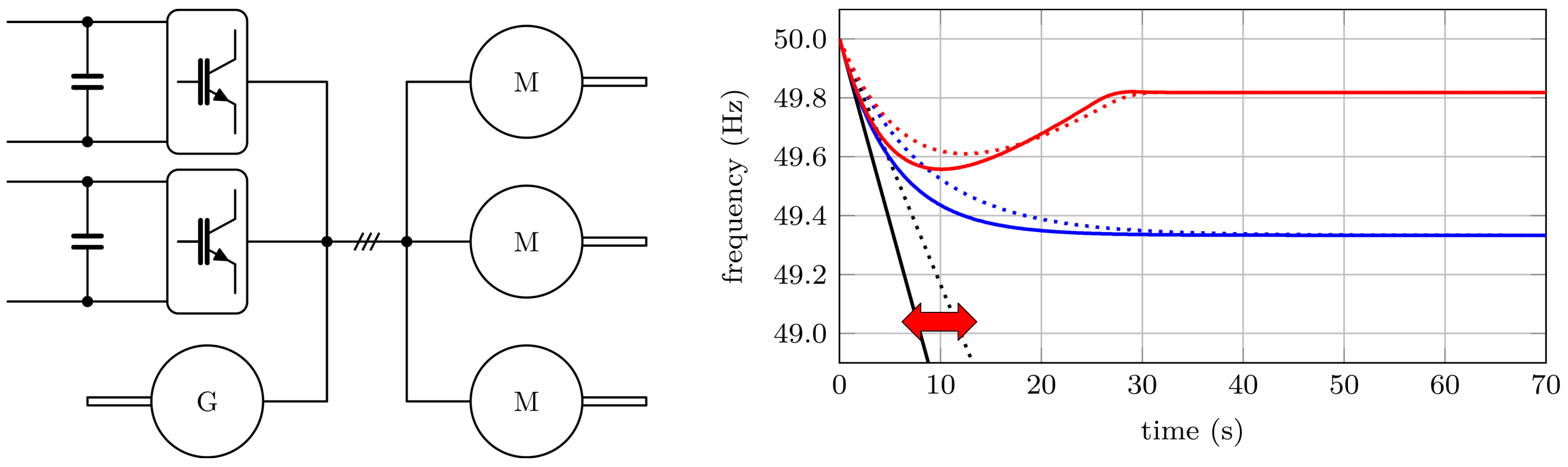
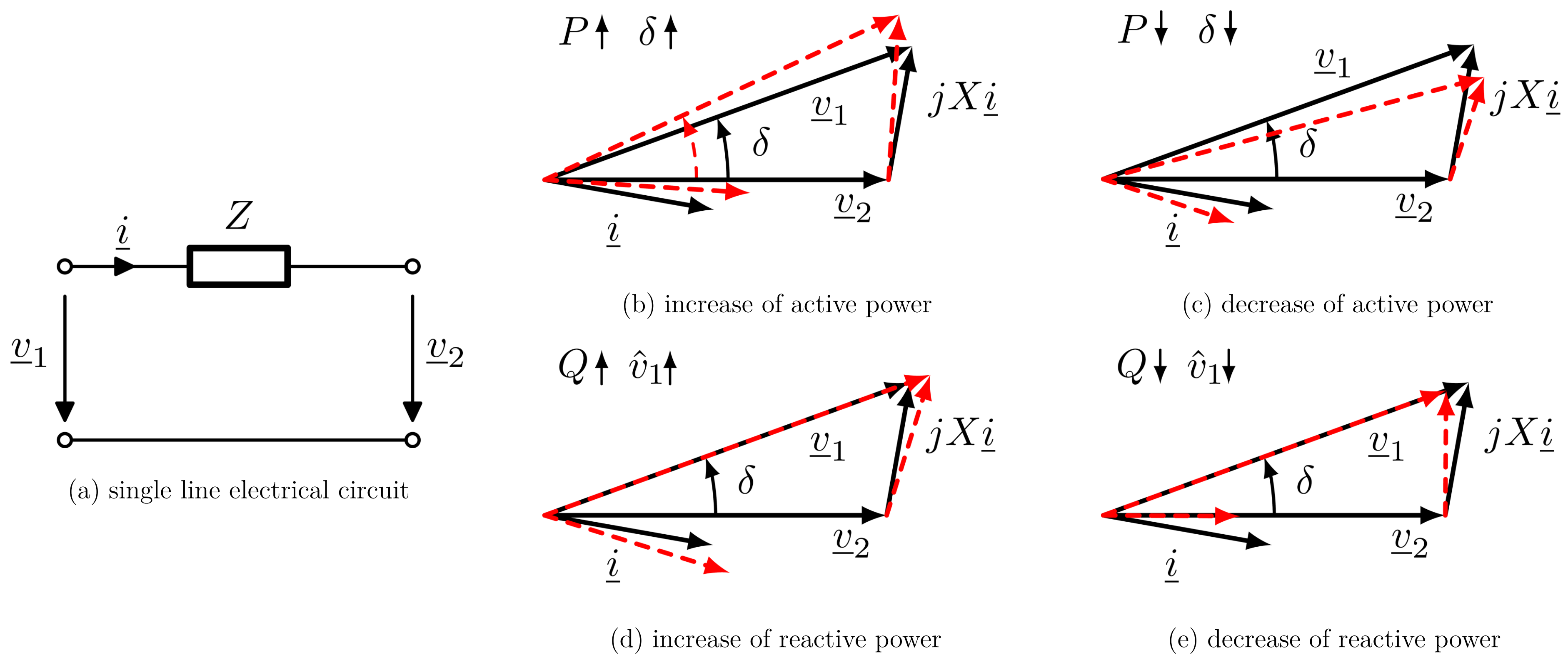


Fig. 2: change of grid situation, loss of inertia due to replacing power plants by converters

Operating Principle of Rotating-Voltage-Vector Control

- operation of a converter on the grid can be described by single line electrical circuit (Fig. 3a)
- converter $\underline{v}_1$ and grid $\underline{v}_2$ are connected via impedance Z
- active power P is primarily dependent on angle $\boldsymbol{\delta}$
- reactive power Q is primarily dependent on voltage difference $\hat{v}_1 - \hat{v}_2$
- power flow between grid and converter can be controlled by adjusting fundamental phase $\boldsymbol{\varphi}_1$ and amplitude $\hat{v}_1$ of the converter voltage relative to the grid voltage



(a) single line electrical circuit

(b) increase of active power

(c) decrease of active power

(d) increase of reactive power

(e) decrease of reactive power

Fig. 3: operating principle of RVVC

Control Structure of Rotating-Voltage-Vector Control

- instantaneous active and reactive power are calculated from measured grid voltage $\underline{v}_2$ and grid current $\underline{i}$
- reference value P' is specified by superordinate control loop of the DC-link voltage, which is intended to guarantee a constant DC-link voltage V_{DC}
- reference value Q' is set according to external requirements
- a decoupling network ($D_{\hat{v}}$ and D_{φ}) is used to cancel the cross-coupling between P and $\hat{v}_1$ as well as Q and $\boldsymbol{\varphi}_1$
- initial value of the angular frequency is set according to the desired grid frequency, usually 50Hz

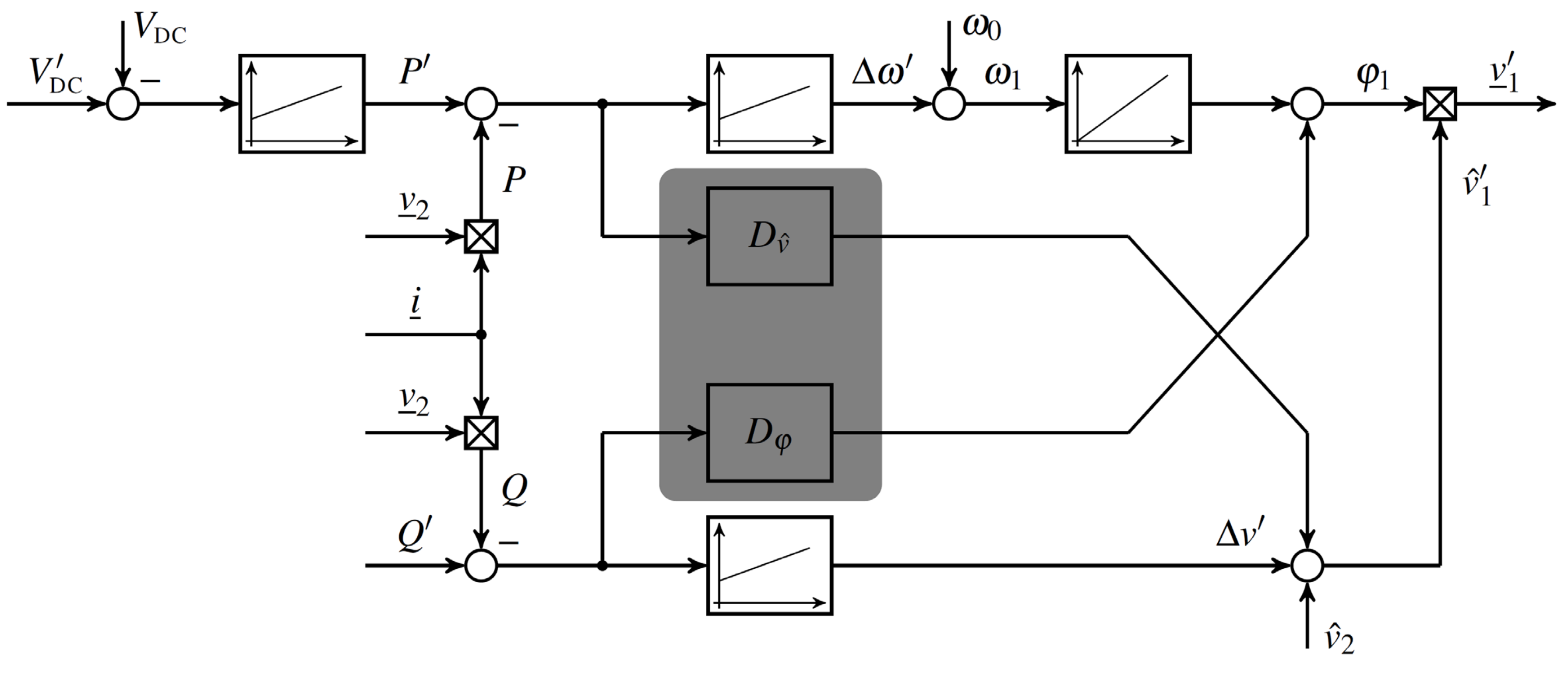


Fig. 4: control structure of RVVC

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Response to Changes in Active and Reactive Power

- VOC can track the changes of P and Q without problems
- active power control of RVVC shows a comparable behaviour
- reactive power control is slower, controller design may be inadequate and needs to be improved
- high proportion of low-frequency harmonics in active and reactive power
- drops of V_{DC} are compensated quickly for VOC and RVVC

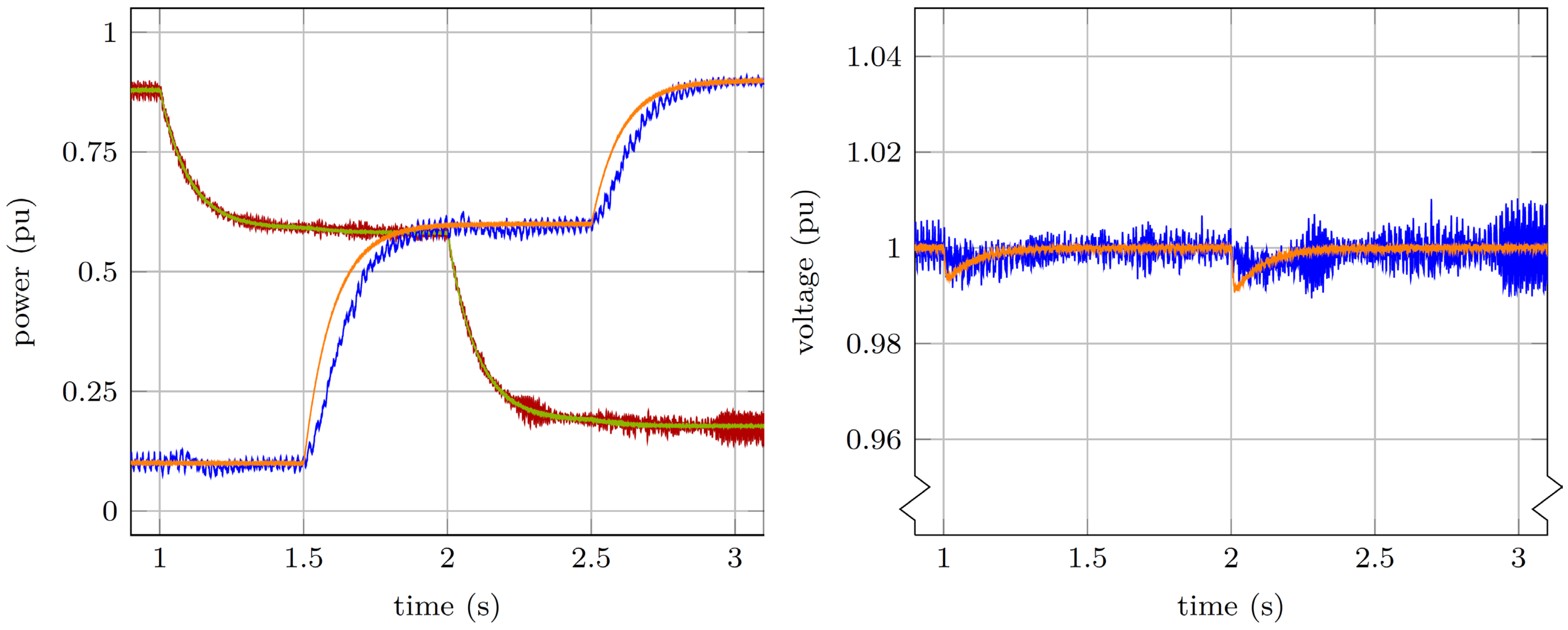


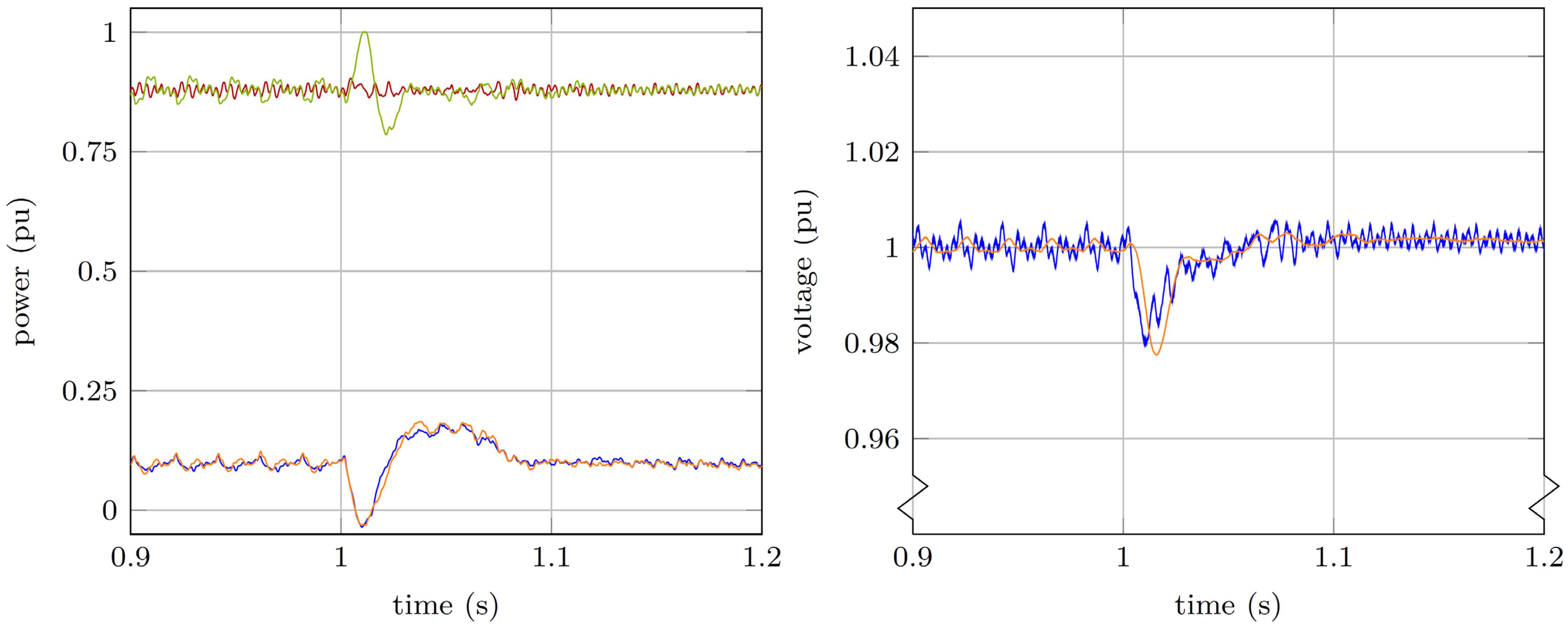
Fig. 5: RVVC: P (red), Q (blue), VOC: P (green), Q (orange)

Fig. 6: RVVC: V_{DC} (blue), VOC: V_{DC} (orange)

Fig. 7: response to changes in active and reactive power

Response to Changes in Frequency and Voltage Amplitude of the Grid

- RVVC provides additional active power for short time in case of frequency drop
- amount of active power depends on stored energy in the DC-link
- DC-link voltage is reduced as generation does not change
- afterwards less active power is available to obtain reference value
- variation of the C_{DC} does not influence the courses of Q and V_{DC}

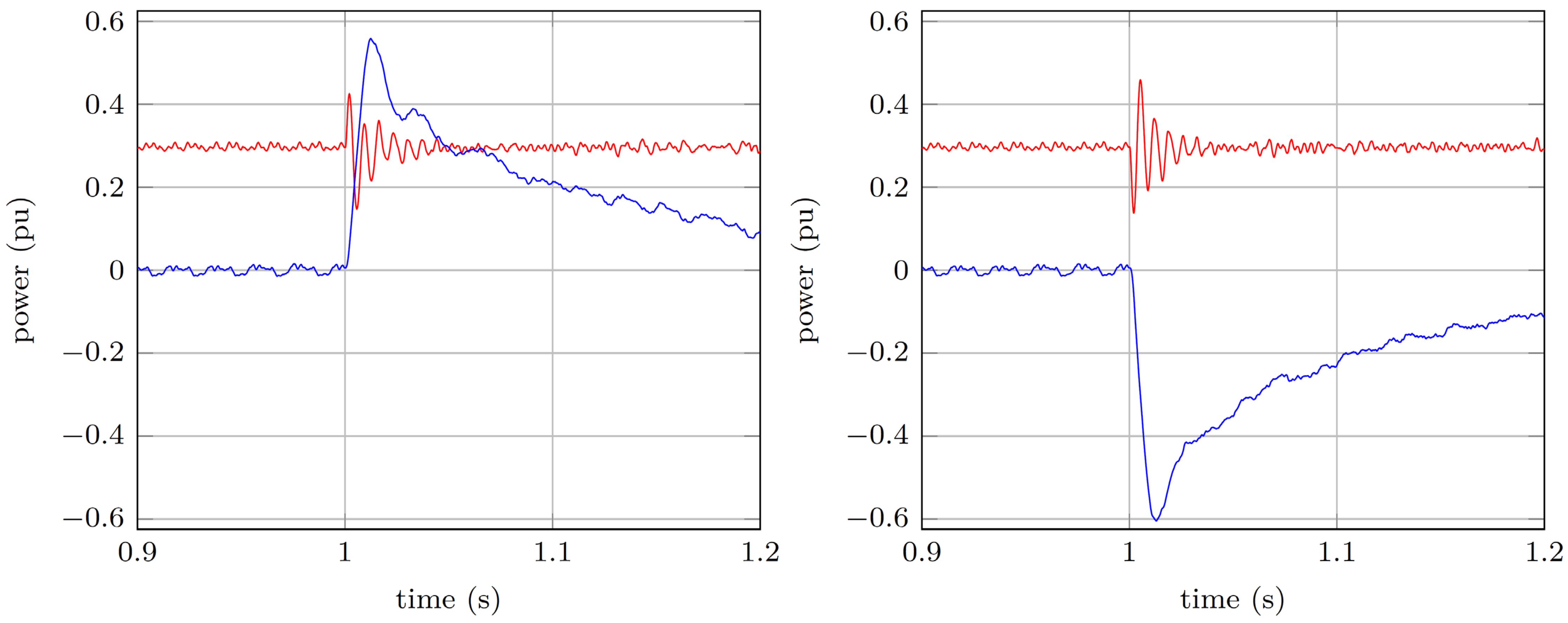


(a) P: C_{DC} (red), 10·C_{DC} (green), Q: C_{DC} (blue), $10 \cdot C_{DC}$ (orange)

(b) V_{DC}: C_{DC} (blue), $10 \cdot C_{DC}$ (orange)

Fig. 7: response of active power to changes in grid frequency with variation of the DC-link capacitance

- grid-supporting behaviour during drop or rise of the grid voltage
- as the grid voltage drops, higher capacitive reactive power is needed
- as the grid voltage rises, higher inductive reactive power is needed
- RVVC is grid-supporting and feeds positive resp. negative reactive power
- active power shows a short-term oscillation but quickly returns to the reference value



(a) voltage drop, active power (red), reactive power (blue)

(b) voltage rise, active power (red), reactive power (blue)

Fig. 7: response of reactive power to changes in amplitude of the grid voltage by 5%

Conclusion

- RVVC offers inherent short-term possibilty of grid-supporting behaviour due to its internal structure
- RVVC is particularly suitable for decentralised regenerative feeders since it does not require grid synchronisation
- RVVC also enables island grid operation
- comparable results achieved with regard to state-of-the-art control schemes

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