Investigation of Load Transitions Between Loaded and Load Free Conductor Segments in Industrial Conductor Systems

Jan-Niklas Koch, Raphael Otte, Tim Stuckmann, Slavi Warkentin, Holger Borcherding – UAS Lemgo

1 Industrial DC Grids

- Energy efficiency and use of renewable energy sources are crucial for modern industrial production
- Energy consumption and production processes have to be optimized in order to stay competitive
- Industrial DC grids are well equipped to address the needs
- Participants in the DC grid are divided into **DC sectors** and fused by **smart DC breakers**:
  - **Drives**, **passive loads** and **auxiliary supplies** are coupled via the DC bus
  - Bidirectional energy flow of participants
  - Energy supply by **infeed converters** and **renewable sources**
  - **Energy storage units** for peak load reduction, save shut down and short time bridging of power failures

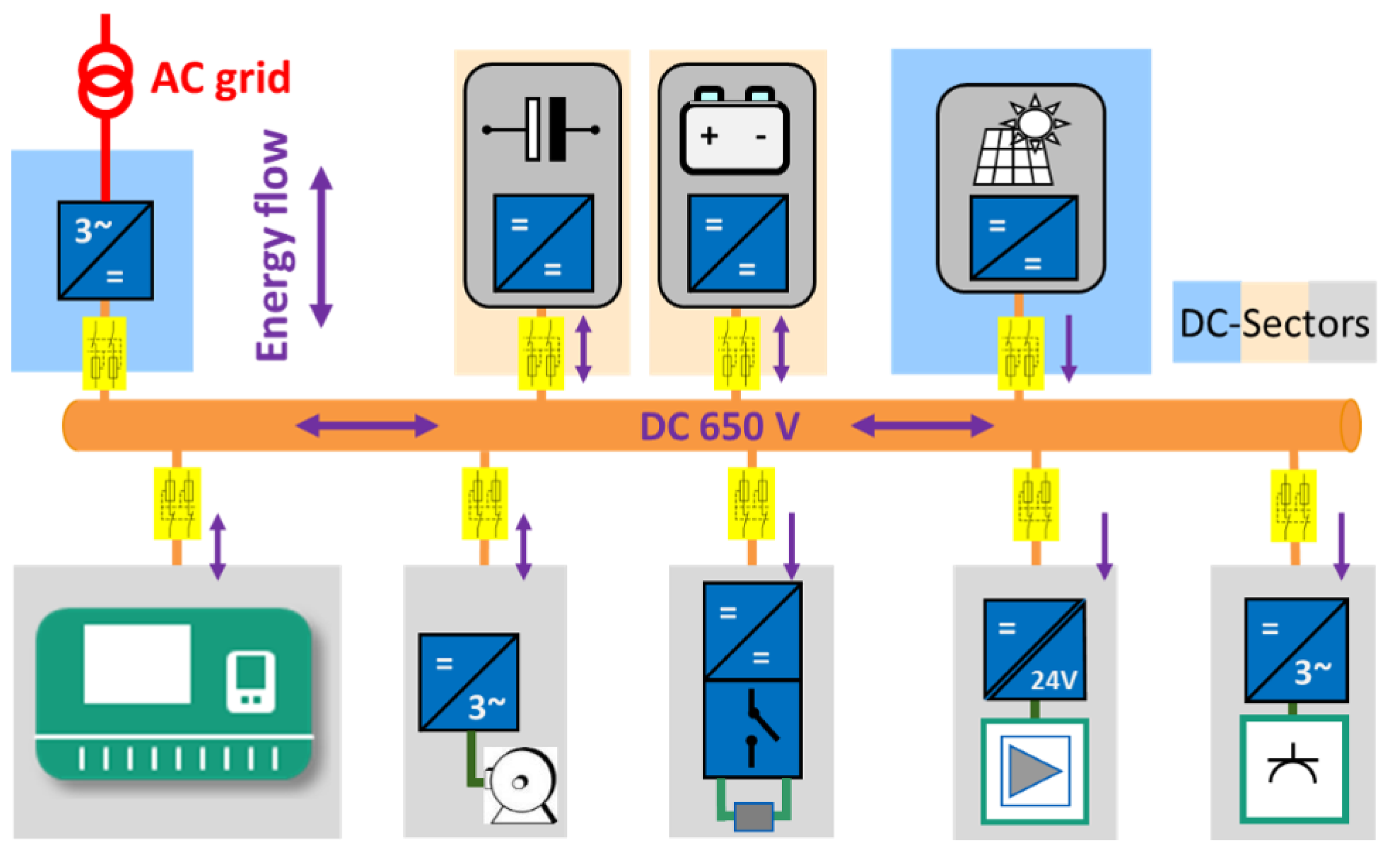

Fig. 1: Concept for an open industrial DC grid with several devices located in DC sectors

- **Voltage droop control** is used for prioritization of energy sources and load management
- Requires all infeed converters to operate as current-controlled voltage sources
- DC bus voltage is load dependent, higher loads result in a lower DC bus voltage
- No further communication between infeed converters is needed
- information about load state of the system is transmitted via the DC bus voltage

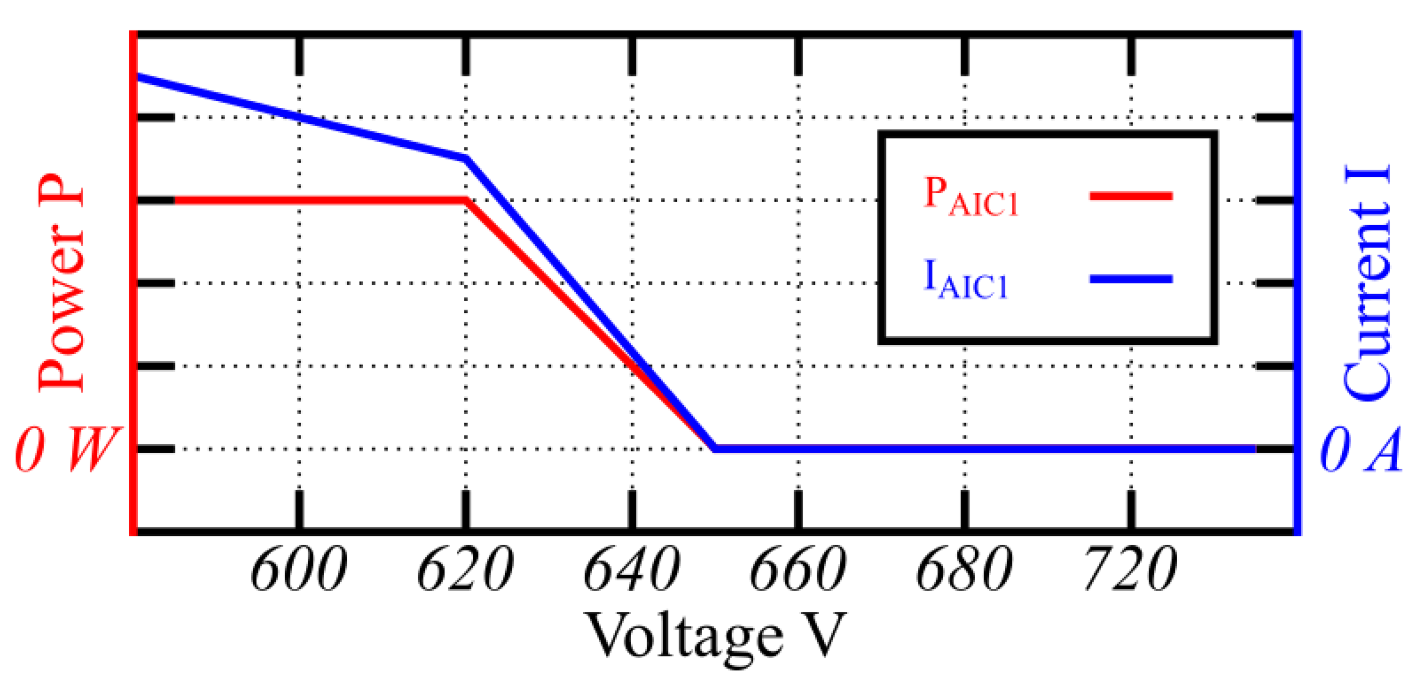

Fig. 2: Exemplary I-V and P-V voltage droop curves of a unidirectional infeed converter

2 DC Conductor Systems

- Conductor systems are an integral part of many industrial facilities such as cranes, sliding stages and elevators, rack storage and monorail conveyer systems
- Industrial production needs safe and reliable operation of conductor systems
- In addition to energy saving potential a reduction of copper usage of 50% and more can be achieved
- **Separating points** are required for track switches, multiple feed in for voltage drop reduction and enabling maintenance areas
- Crossing of separating points is a major challenge in industrial DC grids

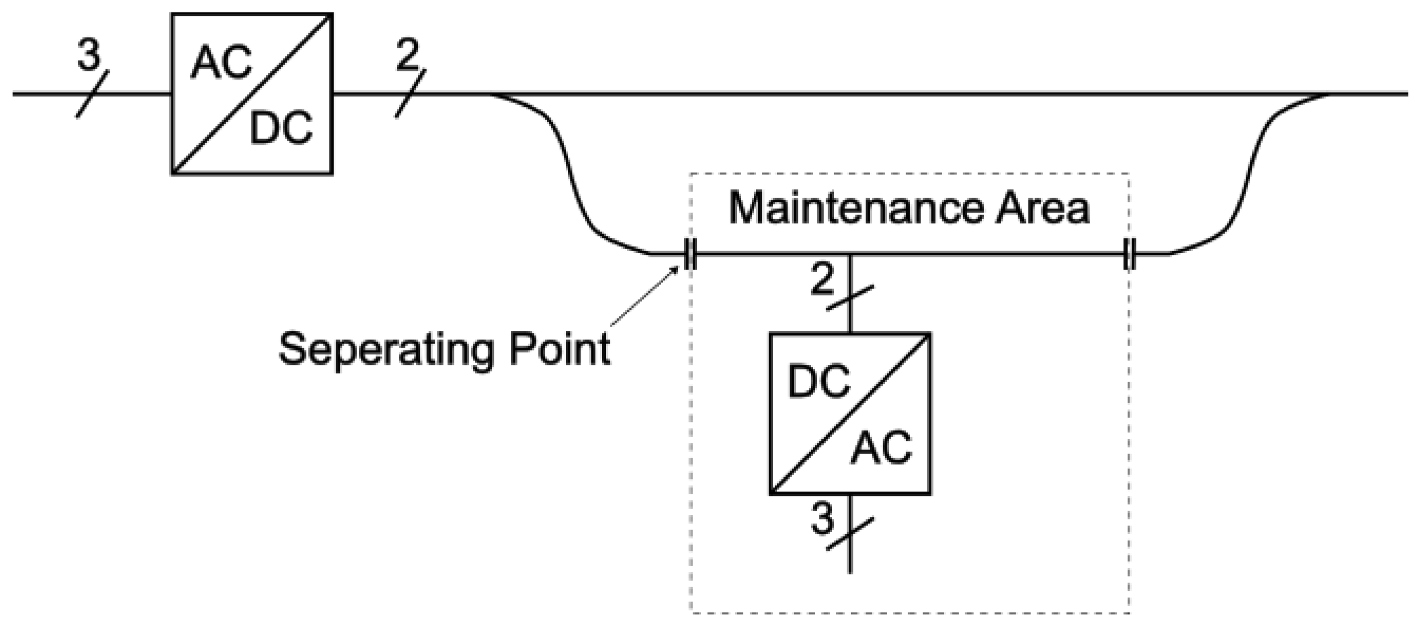

Fig. 3: Example of a separated maintenance area

- Load situation on both sides of a separating point can be different, resulting in different voltage levels
- Crossing a separating point stresses the infeed converters, because they are connected in parallel for a short amount of time
- Voltage difference between the segments has to eliminated without causing oscillations
- Parallel operation of infeed converters can lead to circulating currents

3 Circulating Currents

- Connecting infeed converters in parallel without dedicated filters can cause **circulating currents**
- Over-currents, power de-rating and life-time reduction of components may occur

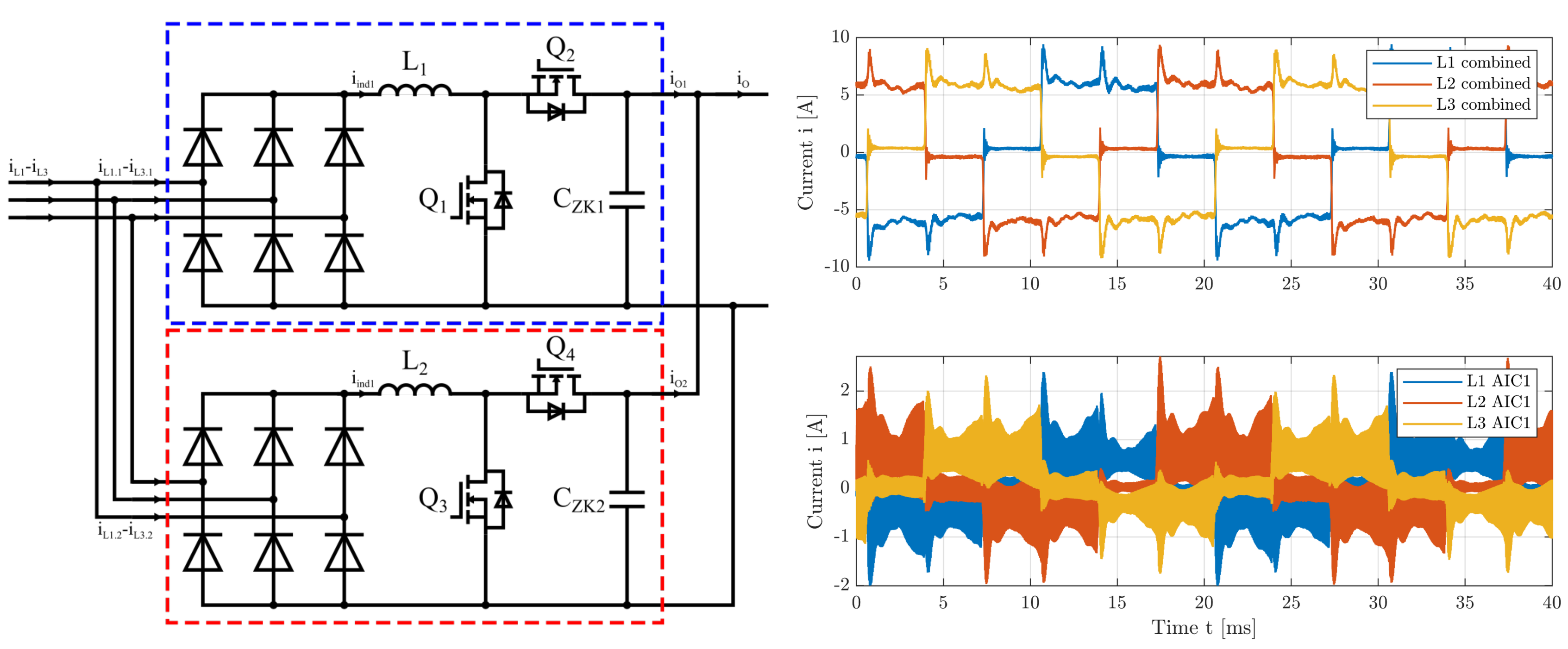

Fig. 4: Parallel connection of three-phase Boost PFC converters (right) and measurement of circulating currents in the mains connection

4 Modular Test Bench

- Main objective of the modular test bench investigation of load shifts between conductor segments with different load condition
- Test bench consists of two conductor segments, a separating point and a movable load
- Each conductor segment is fed by an infeed converter

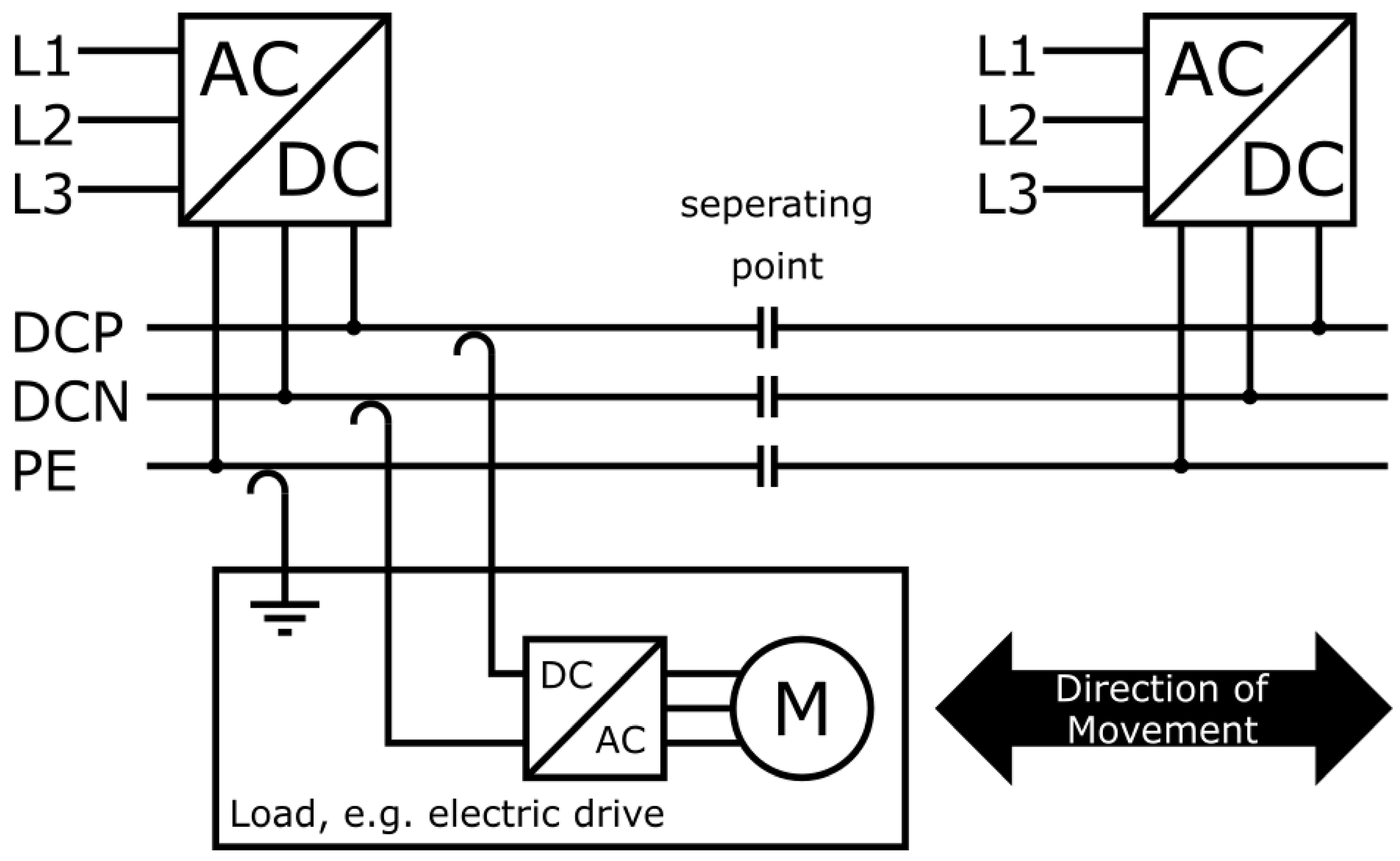

Fig. 5: Concept for the setup of the test bench

- **Test Scenarios:**
  - **Improper Installation:** separating point can be shifted horizontally and vertically, contact pressure of the current collector can be adjusted
  - **Conductor Length:** The distance between infeed converter and separating point can be adjusted
  - **Transition Speed:** A speed-controlled linear axis can move the current collector across the separating point at different speeds
  - **Load Type:** The load and load type connected to the current collector can be varied

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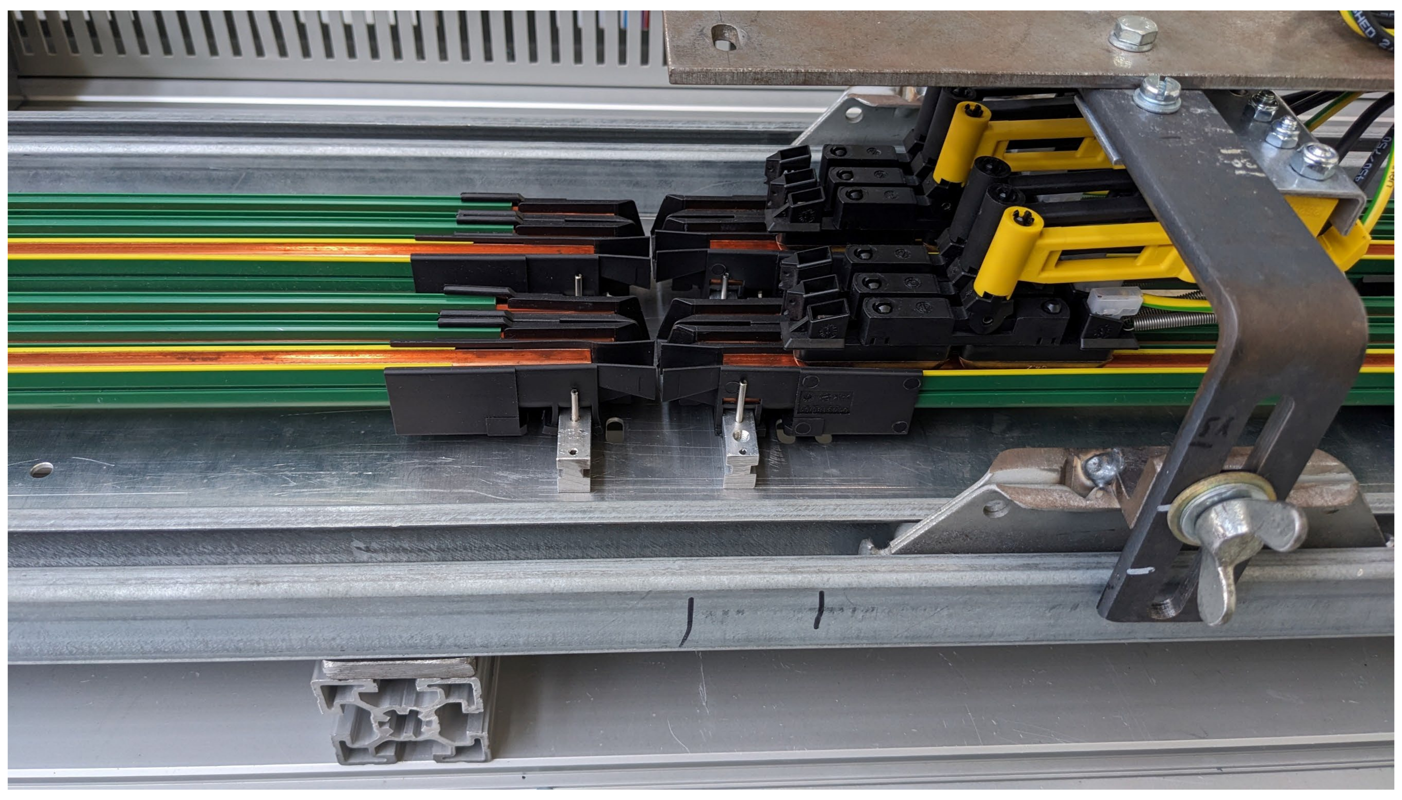


Fig. 6: Test bench with separating point and current collector

5 Controller Implementation

- Voltage droop control is used and implemented for three-phase Boost-PFC converter
- Dynamics are mainly determined by the slope of the voltage droop curve and the inductor of the boost converter

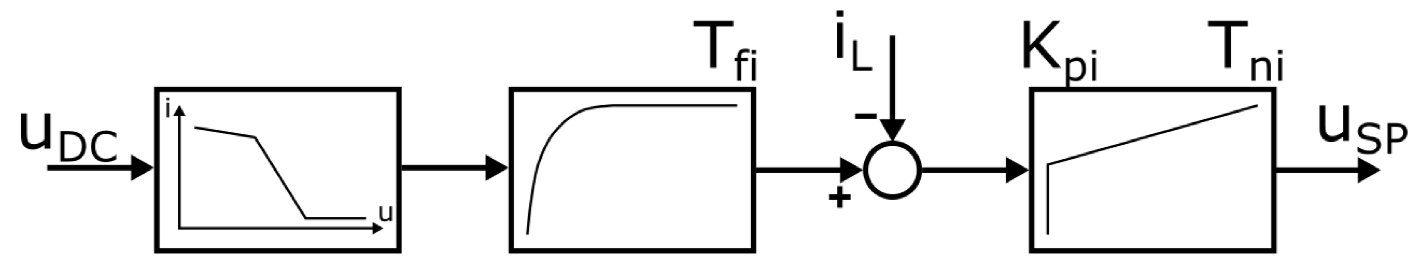
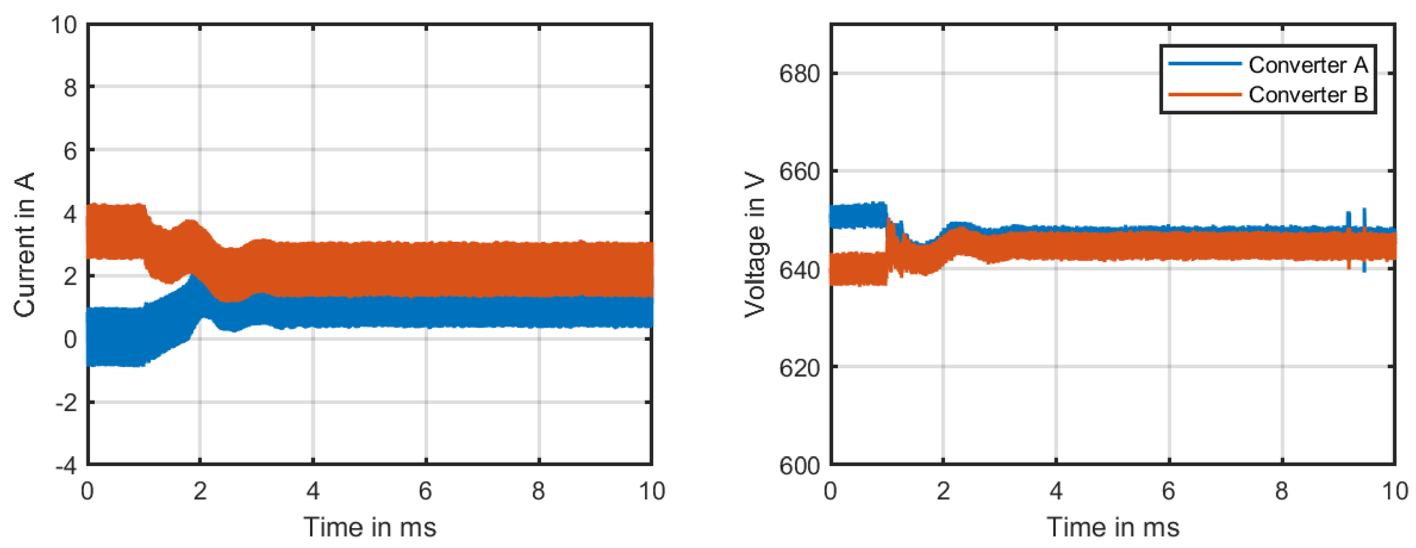


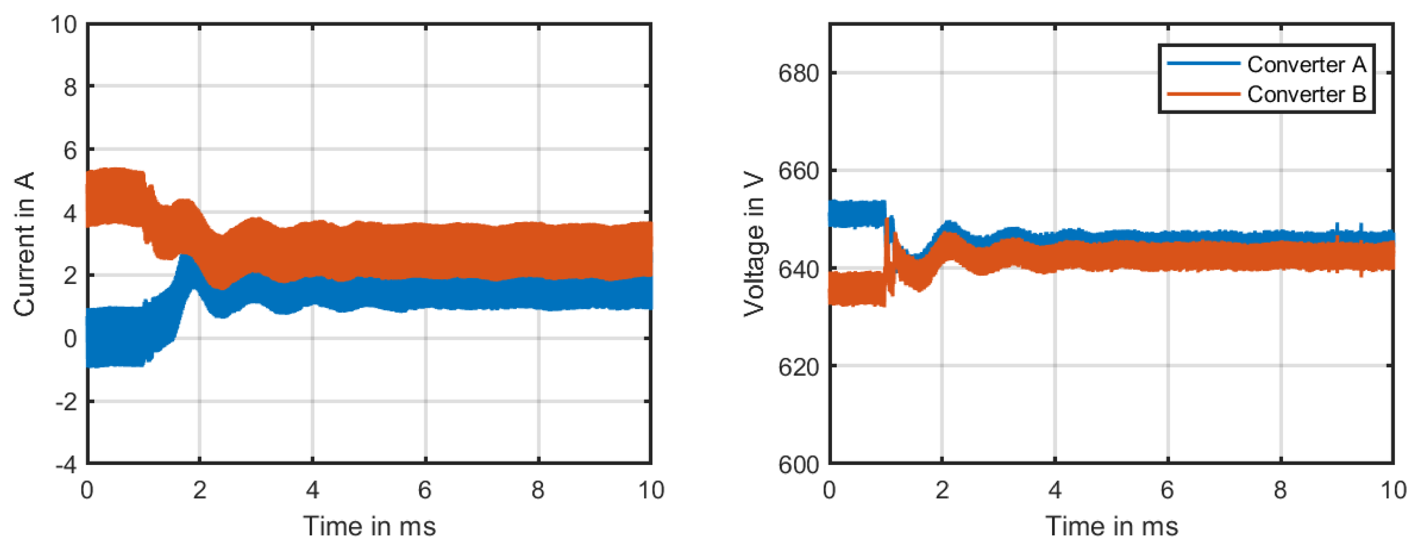
Fig. 7: Droop curve and PI current controller

- Control structure consists of the voltage droop curve, a preliminary filter and a PI current controller

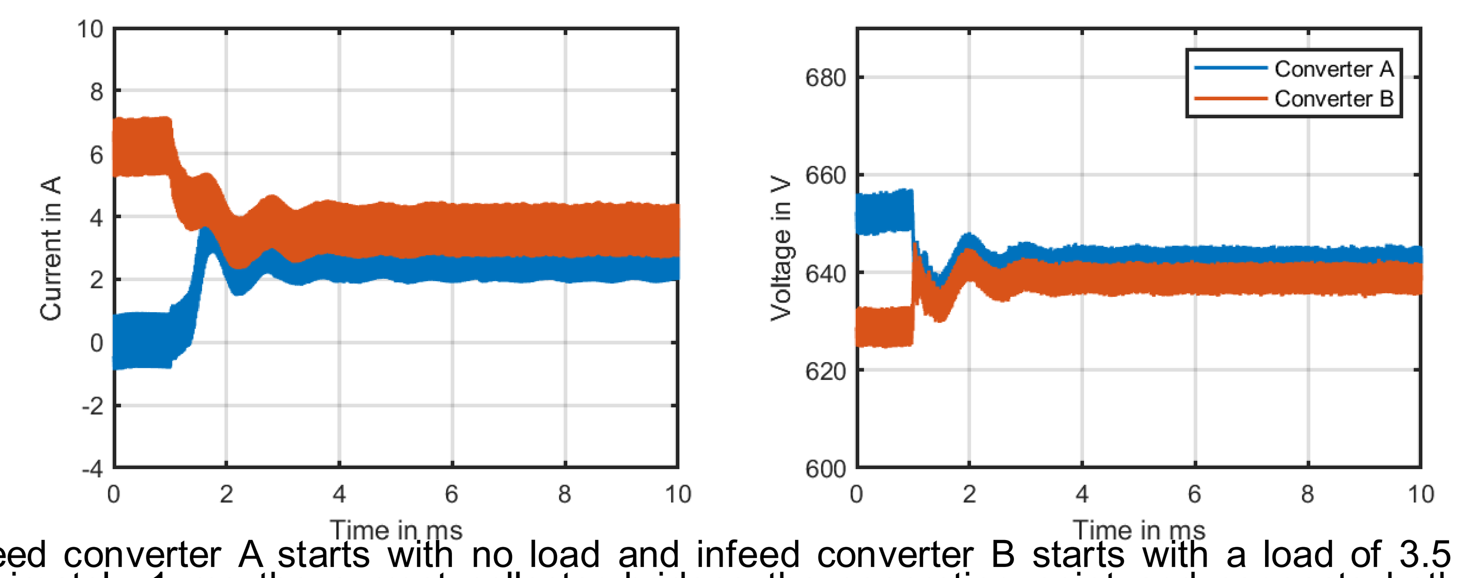
6 Measurements



a) Infeed converter A starts with no load and infeed converter B starts with a load of 2 kW; at approximately 1 ms the current collector bridges the separating point and connects both infeed converters

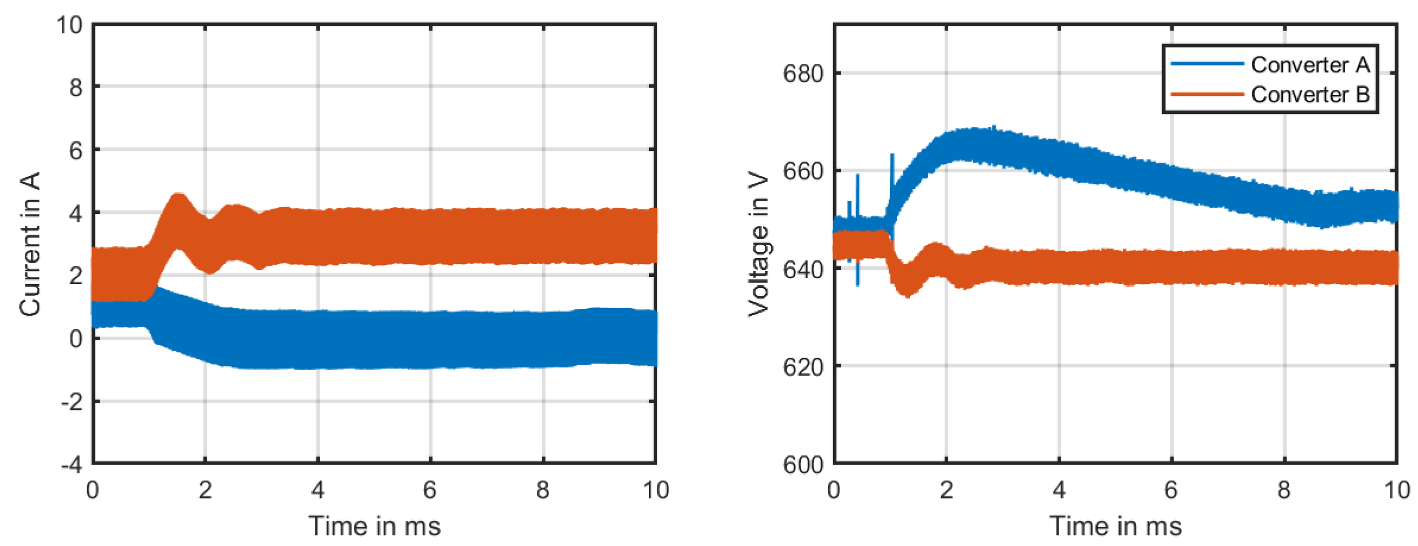


b) Infeed converter A starts with no load and infeed converter B starts with a load of 2.5 kW; at approximately 1 ms the current collector bridges the separating point and connects both infeed converters

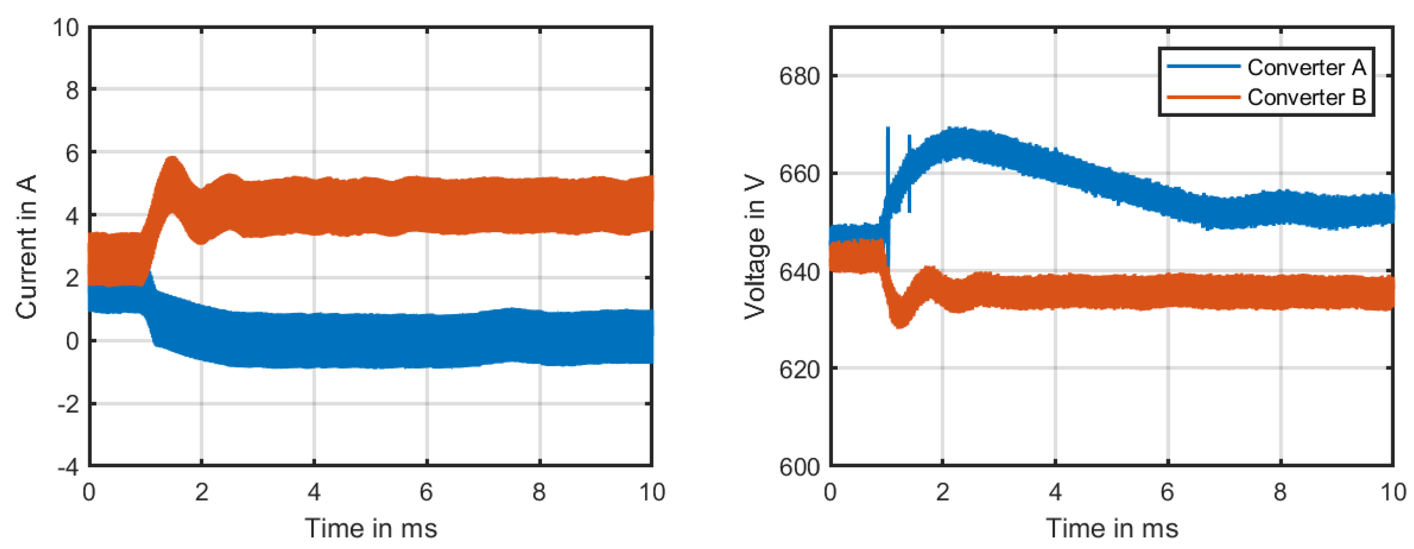


c) Infeed converter A starts with no load and infeed converter B starts with a load of 3.5 kW; at approximately 1 ms the current collector bridges the separating point and connects both infeed converters

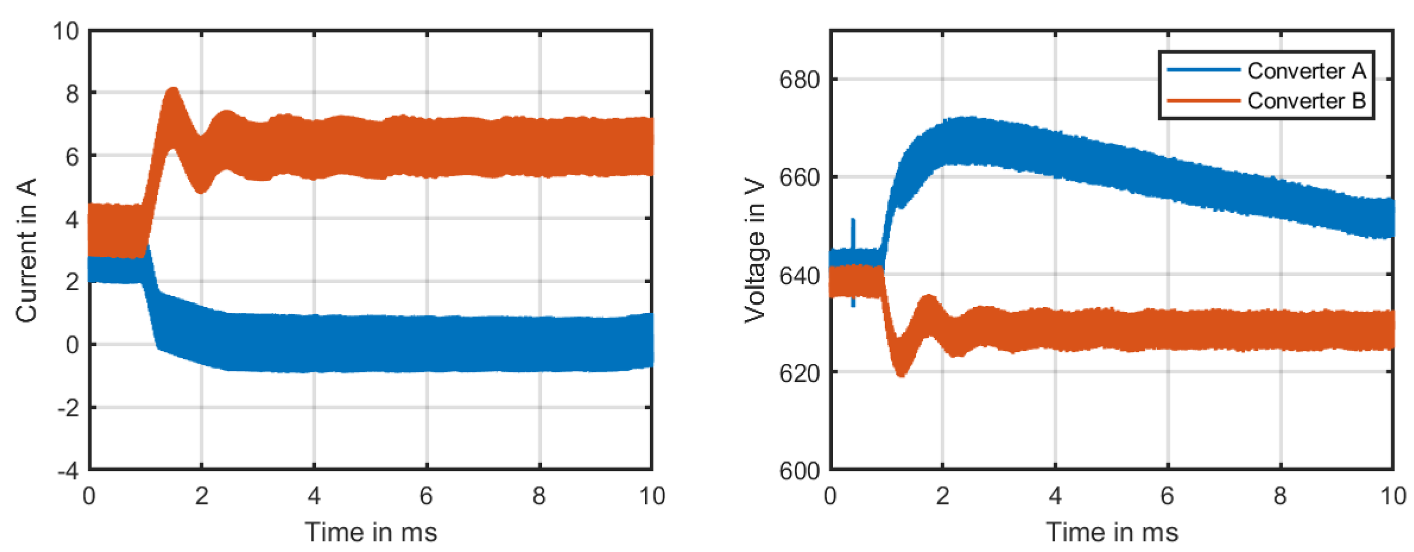
Fig. 8: Loaded current collector (ohmic load) connecting two separately fed conductor segments; DC output voltage (left) and inductor current (right) waveforms of the two infeed converters



a) Infeed converter A and B divide a load of 2 kW according to their droop settings; at approximately 1 ms the current collector leaves the separating point and disconnects the infeed converters



b) Infeed converter A and B divide a load of 2.5 kW according to their droop settings; at approximately 1 ms the current collector leaves the separating point and disconnects the infeed converters



c) Infeed converter A and B divide a load of 3.5 kW according to their droop settings; at approximately 1 ms the current collector leaves the separating point and disconnects the infeed converters

Fig. 9: Loaded current collector (ohmic load) releasing separately fed conductor segments; DC output voltage (left) and inductor current (right) waveforms of the two infeed converters