Investigation on Power Quality Parameters of Industrial 600V DC Microgrid Hardware

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Keywords

«DC power supply», «Active frontend», «Microgrid», «Power Supply»

Abstract

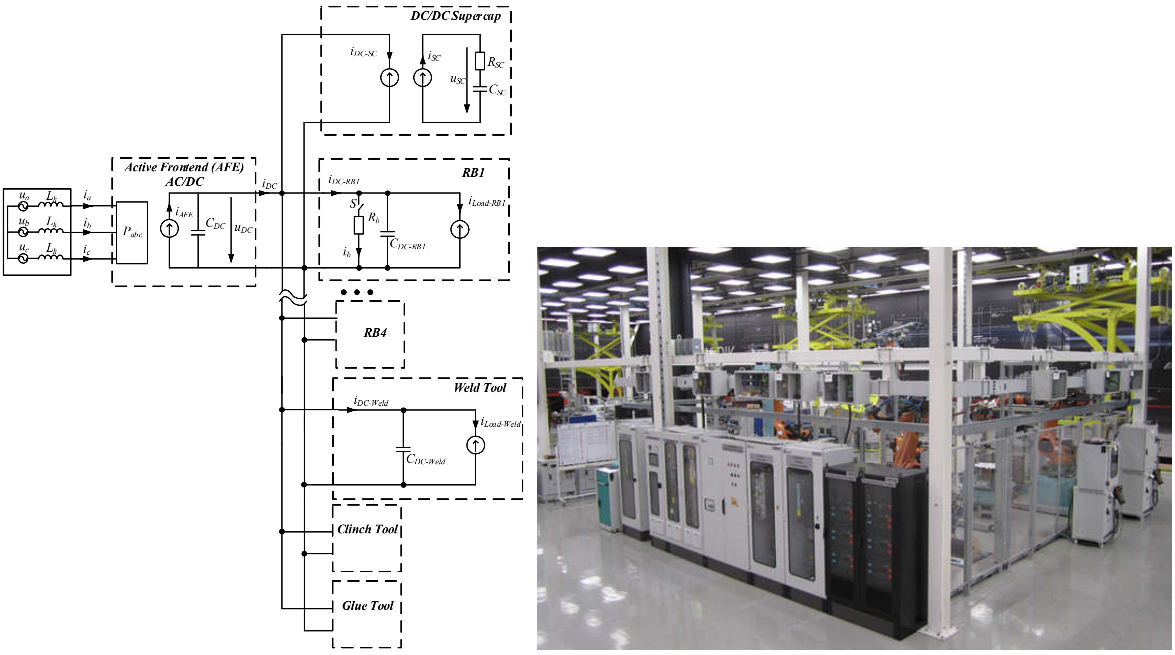
Paper describe physical DC microgrid realization for research and modelling tasks and its alignment with unique DC microgrid installation at automotive factory under real manufacturing conditions. Focus on key component modelling and verification such as bidirectional grid interface AC/DC frontend converter has been presented at real load conditions.

Introduction

Global trends to increase energy efficiency and rise of electricity costs has made an impact also to industrial electricity grids, fostering interest for implementation of renewable energy sources also at industrial factory level, as well as looking for new ways to save energy. Small scale electrical power supply infrastructure with given boundaries due to geographic, economical and other aspects can be observed in forms of grid structures referred as nano and microgrids. Typically separation from main power is related to lack or loss of grid connection or intrinsic nature of system that require supply of electrical energy and preferable type of voltage. In case of industrial manufacturing applications microgrid solutions of DC energy supply enable solutions of energy efficiency increase and storage for sustainable manufacturing. Also applications regarding household and office load supply in buildings has been considered recently. Several studies, like [1], [2], [3], [4] are presenting advantages of DC-grid transmission, as solar panels, fuel cells and Lithium-Ion or supercapacitor energy storage systems are DC-voltage based in their nature, thus it is logical choice to have DC-Grid connection between them, using DC/DC converters, as it would have less conversion stages. As modern industrial factory nowadays use high payload industrial robots, it is possible to re-use their braking energy, which is typically dissipated into braking resistors attached to converters DC-link, by means of storing that energy into capacitor banks or injecting into DC-Grid. Also carbon footprint reduction and product life cycle assessment leads to deeper research also within production process itself.
These initiatives lead to new developments and automated manufacturing infrastructure modifications, including DC microgrid as electrical energy supply concept (see Fig. 1.), with such elements as local PV generation, energy storage and industrial robots and their welding, clinching and gluing tools as

consumers. Furthermore such electrical installation using 600V DC microgrid within automotive manufacturing branch enables to operate such manufacturing cell in islanding mode for certain periods, create new power peak shaving options.

Practical realization of 600V DC-microgrid structure (Fig. 1.a.) is done at Daimler AG factory in Germany as presented in Fig.1.b. System has central AC/DC bidirectional converter (Active Front End) with rated power of 450 kW. Load group is combined of 4 industrial robots and related tools for material joining by spot welding, glue dispensing and punch riveting methods as well as rotating conveyor for part exchange. As auxiliary systems electrolytic capacitor bank of is directly connected to main DC bus as well as LiIon storage and photovoltaic panel array with respective DC/DC power converters. Nevertheless it was a great challenge to create such system, due to lack of electrical component portfolios of typical suppliers with respect to state of the art AC electrical technology, also there is a need for updated and new DC standards for such application. Insight of research activities covering both software and hardware modifications with focus on energy efficient robotic manufacturing has been presented by [2], [5]. If looking more widely real DC-Grid infrastructures enable various practical researches in the field of grid power control and management [6],[7], safety issues [8], and voltage quality issues [9]. If looking into frequency domain like described [10], or measuring [11], [12] it can help to identify equipment faults, thus enabling new approach in the field of equipment and system maintenance. Nevertheless such industrial DC-Grid infrastructure is not widely available, due to high prototype and custom design equipment costs, therefore detailed mathematical models must be created, that are based on real experimental measurements.



a) Matlab model of 600V DC-Grid structure b) industrial production cell hardware realization

Fig. 1. Structure and realization of 600V DC microgrid for automotive manufacturing application.

For this purpose a special 600V DC-Grid laboratory with real equipment is created in Riga Technical University (see Fig.2.), that uses same architecture, but same time is scalable to the industrial production cell described in Fig.1.

Overview of 600V DC Grid testing infrastructure in Riga Technical University (RTU) laboratory

An experimental laboratory electrically representing a manufacturing work cell is necessary to complete the research objective and demonstration to develop a DC power supply system in which energy could be exchanged, harvested, stored and recovered at a factory level. The main loads in the laboratory have to be several industrial robots, however, due to financial and spatial limits, only one DC powered industrial robot will be implemented. Therefore, a system has been developed which can recreate the dynamic DC bus power flow of an industrial robot. RTU DEMO laboratory layout is shown in Fig.2., where number (1) – Active Front-End AC/DC rectifier unit (55kW), number (2) and (3) universal robot load emulator stands (23kW), able to replicate energy consumption signature of any industrial robot also with combination of robot tools, input is AC, but output is DC (can be switched to AC if necessary), number (4) is prototype Lithium Ion battery energy storage system (BESS) 16-22kW, number (5) is prototype supercapacitor storage system (30kW), number (6) is 600V DC-Robot prototype and DC-Cabinet (7) with load 2kW, number (8) is Master PLC controller (Cell controller), (9) is prototype solar DC/DC converter (3-4kW) for 3.3kW solar panel array, (10) is optional wind energy emulator stand.

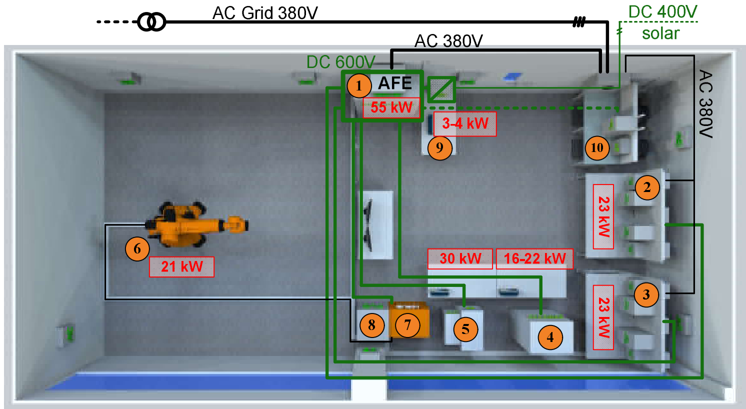


Fig.2. DC-Microgrid layout plan and grid connections at RTU laboratory

Evaluation and modelling of AC/DC interface converter unit.

Regarding DC microgrid structures DC link voltage is often utilized as key parameter for overall system coordination and control. The currents in DC link are directly related to power flows within system. Often by modelling of systems and large scale analysis waveforms of voltage and current are considered to follow idealized DC type quantities. However application central AC/DC grid tied converter or active frontend as important subsystem for DC microgrid supply would require closer analysis regarding actively modulated power electronics and related effects within DC link. Analytical approach discussing DC link behavior related to inverter topologies has been presented by [13]. Rectifier application has been discussed by [14],[15]. The effects of higher harmonics within DC link is also matter of lifetime of capacitor elements as discussed [16].

Evaluation of real AC/DC bidirectional converter operation at laboratory microgrid arrangement has been made possible by dynamic power flow emulation units utilizing coupled electrical machines as presented in Fig.3. and feeding of power back into AC grid. Such arrangement allow to replicate both bidirectional power flow as industrial robots and tools as well as load grid with constant loading conditions.

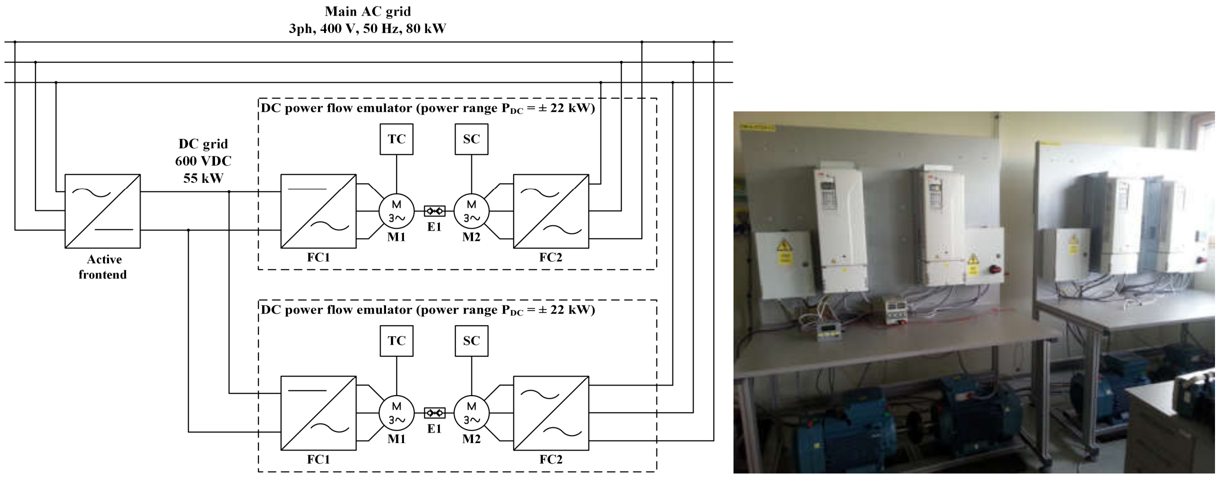


Fig. 3. Principal electric schematic of AC/DC active frontend converter testing with 2 robot load emulator stands.

Initially generalized model of AC/DC frontend converter has been developed and verified against dynamic load changes according to Fig.4 as described in [17] with main focus of converter efficiency estimation and replication as well as behavior on AC grid side during dynamic operation.

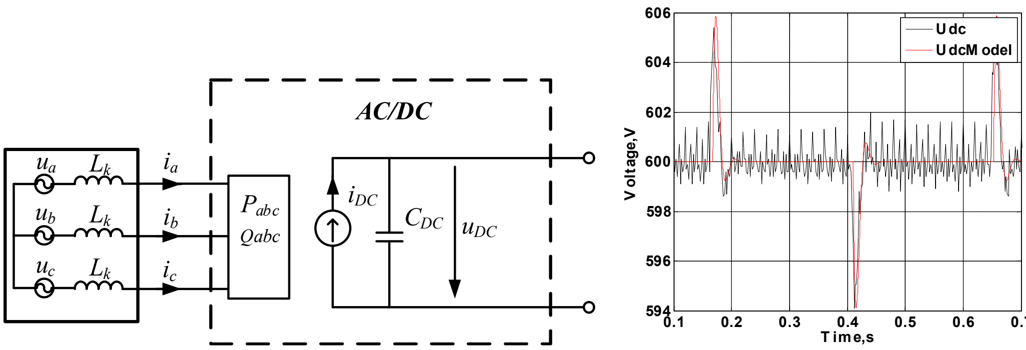


Fig. 4. Generalized model of bidirectional AC/DC converter and simulated DC link voltage behavior of 7 kW load step change.

Higher frequency experimental evaluation for model modification.

As discussed before utilization of actively commutated converters interfaced with microgrid DC link also present effects of higher frequency content within DC power flow. In order to obtain data for electrical system modelling voltage and current data has been obtained with frequency of 41 kHz thus presenting frequency related analysis within range up to 20 kHz. Such frequency range is considered sufficient for electrical mode iteration since it provide insight of fundamental switching frequency of AC/DC converter being 8kHz and its second harmonic. The following pictures represent obtained experimental measurement data of DC link voltage being controlled according to setpoint value of 600V by active frontend converter under several steady load conditions. Four operation conditions have been depicted: simple AC/DC converter operation without DC link (AFE only), operation with load emulators switched on at no load, load of 44kW being consumed from DC microgrid and recuperation of 33kW via active frontend to AC mains. Fig.5 represents voltage and current waveforms at selected conditions at AC/DC converter DC terminals.

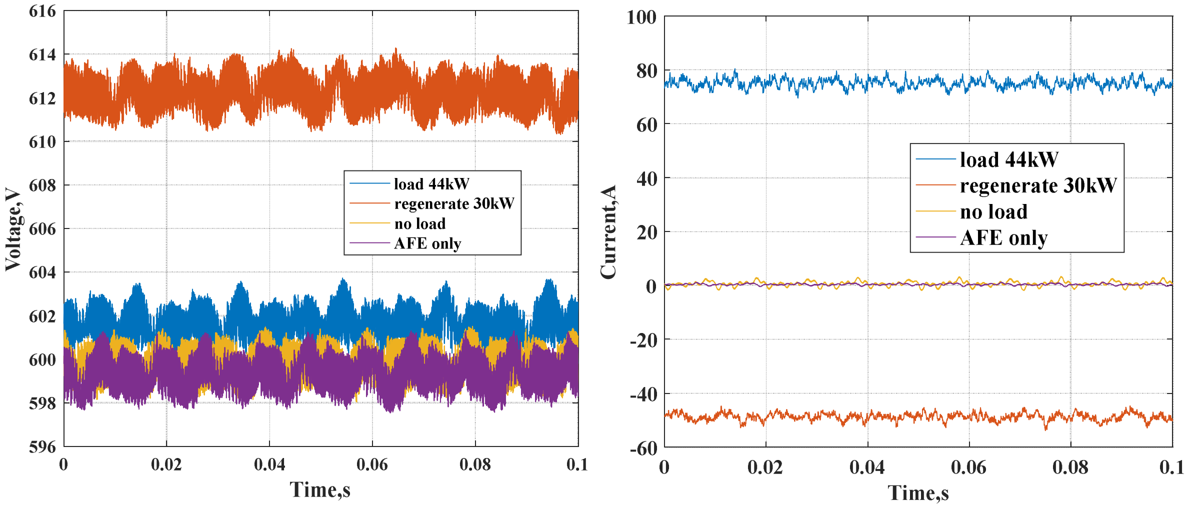


Fig.5. DC link voltage and current waveforms at DC link terminals of AFE converter.

By means of frequency content analysis significant frequencies and relative variation under changing load conditions has been obtained as shown in Fig.6.

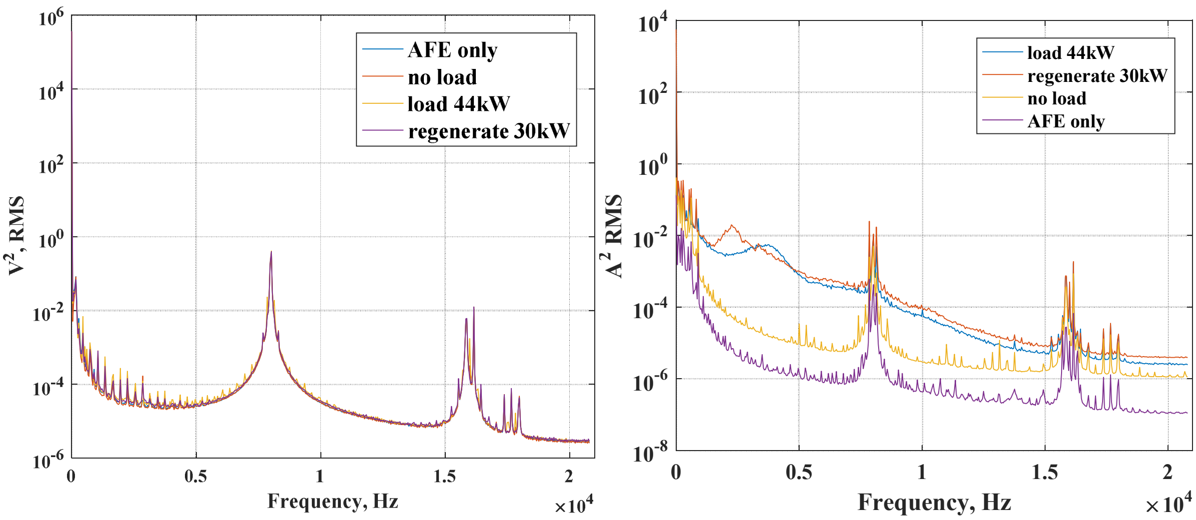


Fig.6. Frequency content analytical results of DC terminal voltage and current at various load states.

Conclusions and future work.

Obtained experimental results of real AC/DC converter operation interfacing DC microgrid and mains with bidirectional power flow capability allow improvement of existing mathematical models. The behavior of higher frequency components at DC link voltage and currents during real load power situations enable detailed design of microgrid electrical subsystems such as dynamic buffering and storage units and their controllers. It has been verified experimentally that voltage harmonic content is less prone to deviate under load conditions as current waveforms when central AC/DC unit is utilized under voltage control approach.

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