A NEW DC POWER SUPPLY SYSTEM FOR ROBOTIC MANUFACTURING INDUSTRY HAS BEEN DEVELOPED AND DEMONSTRATED

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A novel DC power supply system has been developed and demonstrated for saving electrical energy in robotic production plants with significant contribution of researchers from the Institute of Industrial Electronics and Electrical Engineering (IEEI) of Rīga Technical University (RTU). Although it included some earlier developments of IEEI, the proposed DC-grid supply system was mostly developed within three years' time in the course of the FP7 project "Automation and Robotics for European Sustainable Manufacturing" (AREUS), which involved ten partners from six countries of Europe – Latvia, Italy, Germany, Sweden, Finland, and Denmark. The system was developed and tested in close cooperation with car manufacturer Daimler AG for use in Mercedes-Benz car manufacturing plants in Germany. The DC supply system improves energy efficiency by exploiting architecture benefits of DC power supply grids. This has been a large step towards the concept of smart factories of the future [1], where innovative tools, methods and technologies will be used to ensure energy-efficient and sustainable robotic production. Automotive industry exhibits one of the highest industrial robot density per square meter. Using DC power supply grid part of the energy consumed by production robots can be restored and reused later, making robots more efficient, as well as the production "greener", since renewable sources like PV panels can be integrated into DC power supply grid more easily. The official completion of the project AREUS took place in September 2016 at Daimler AG facilities in Germany, where the new DC power supply system was demonstrated in a real industrial robotic production cell at the Mercedes-Benz car production plant. The Latvian delegation was represented by the rector of RTU, academician Leonīds Ribickis, together with the researcher team of IEEI.

Currently, the results of the AREUS project are approbated in an ambitious undertaking by Daimler AG entitled "Factory 56" [2]. Green production technologies and CO_2 neutral electricity supply grid is implemented in real life there and currently is being continuously perfected – the new smart factory building "Factory56" in Sindelfingen uses DC power supply grid enabling braking energy recovery of production robots, as well as solar energy integration in order to minimise the CO_2 emissions [3].

The main goal of the AREUS project was to demonstrate and test the proposed DC power supply grid

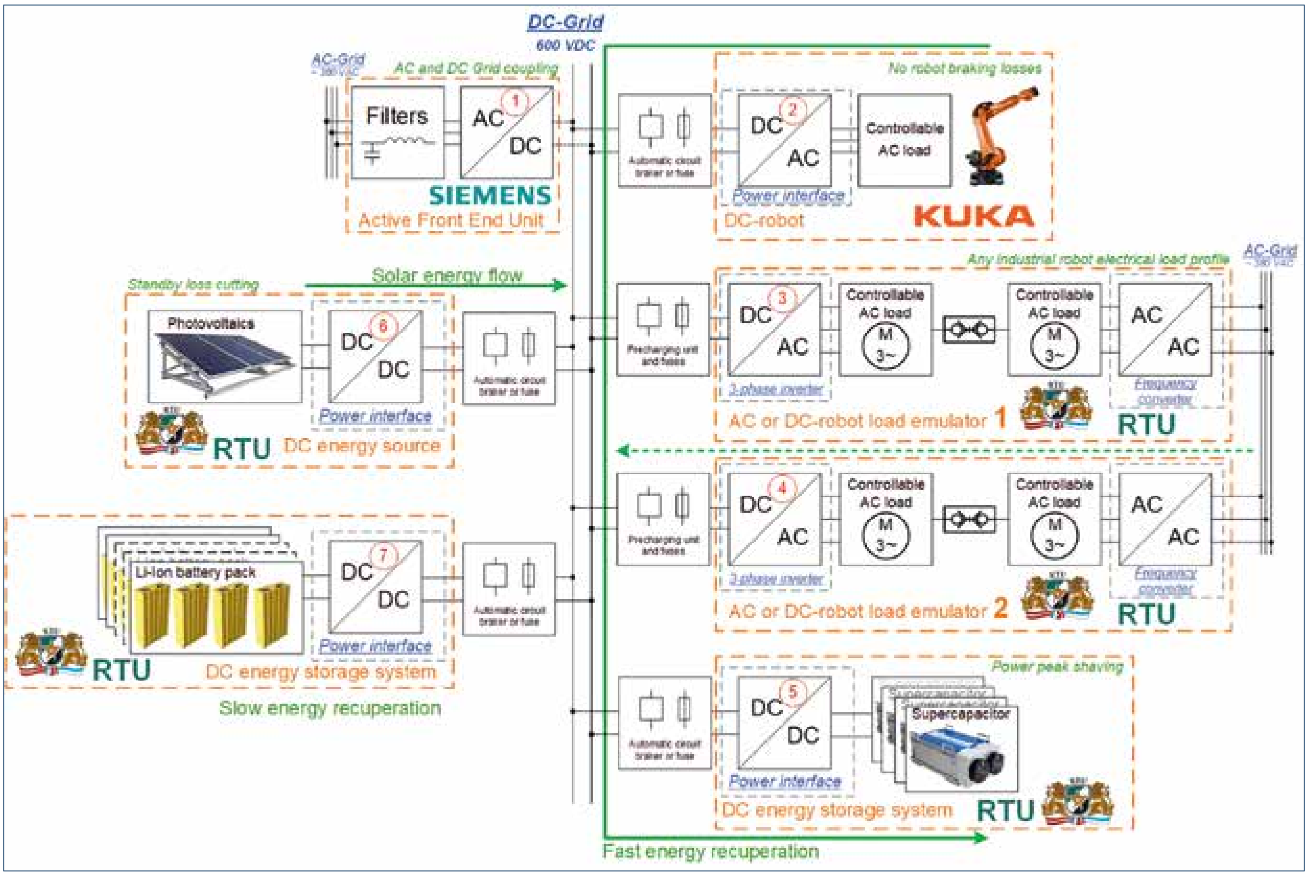

Fig. 1.
600 V DC-grid architecture of RTU demonstration laboratory

and its elements in different modes and configurations, both individually and operating in a unified DC grid. Figures 1 and 2 show the configuration of laboratory equipment developed and installed in IEEI during the AREUS project for the purpose of testing the DC grid, as well as for evaluation of industrial production cell parameters and processes.
Inheriting a similar architecture, a demonstration production cell was later set up at the car manufacturing company Daimler AG – at the plant in Sindelfingen, Germany, where system testing and parameter measurements were performed in a real production environment, comparing electricity consumption of a traditional AC-grid supplied system with the novel DC-grid production cell while carrying out the same production tasks. Thus the obtained results were highly credible and reliable.
As distribution system operators of electrical grids do not currently offer DC supply voltage, the DC-grid laboratory located at IEEI had of course to be tied to the AC grid by an AC to DC converter. A unit

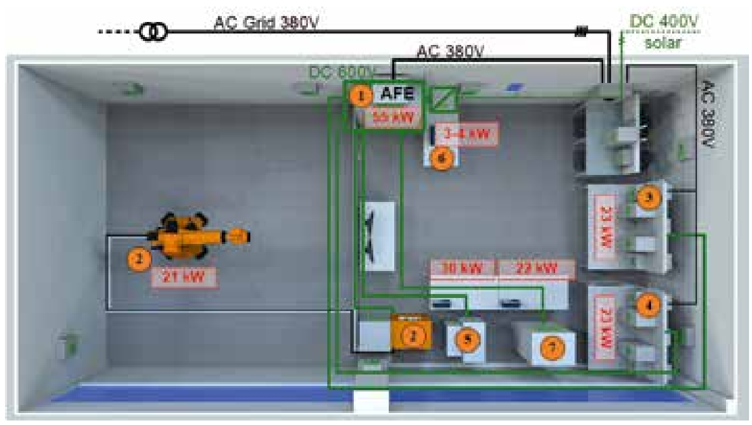

Fig. 2.
Connection scheme of DC-grid laboratory in IEEI of RTU

Fig. 3.
Power measurement device for DC industrial robot and measurement performance evaluation example against oscilloscope based power measurement

produced by SIEMENS – an active rectifier/inverter (AFE) with power of 55 kW (see Figures 1 and 2) was installed. The task of the unit was to provide 600V DC voltage in the power supply grid, and in case of surplus DC power – to return it back to the AC grid. The unit (2) shown in Figure 2 is a 600V industrial DC-Robot prototype, built by KUKA "Quantec Prime" with a 210 kg lifting capacity and electric power up to 21 kW. While most of the time a robot is a consumer of electrical energy, during the braking modes, it becomes a generator.

Two universal robot emulator stands with power of 23 kW (3) and (4) were constructed to simulate the dynamics and power consumption pattern of any of the manufacturer's robots used in car production factories. In tandem with the actual robot (2) they formed a tiny robot production cell. The stands comprised two AC motors driven by two 4-quadrant

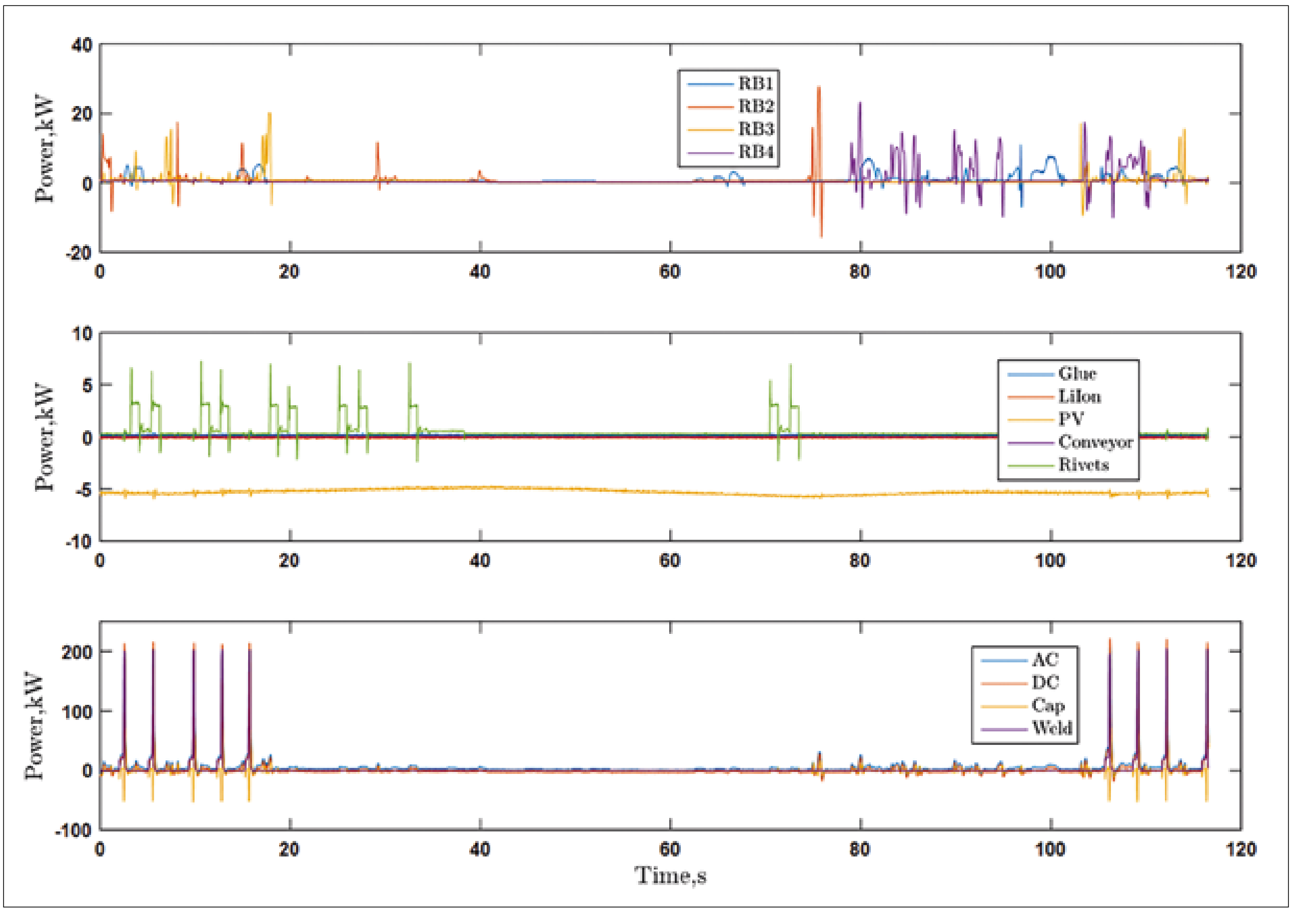

Fig. 4.
Acquired synchronous power flow measurement data at 13 microgrid locations: 4 industrial robots (top), tool technologies, PV infeed and Li-ion storage (middle), AC, DC, Capacitor buffer and welding (bottom).

frequency converters. Thanks to the control algorithms developed by researchers of IEEI, the emulator stands were capable of reproducing the dynamics of electrical energy consumption or generation of various industrial robots with very high accuracy. For rapid storage and release of energy in the DC-grid, a supercapacitor storage system (5) with power of 30 kW was developed and built. Its main task was to cut off power peaks, thus equalising power consumption over time.

Since the DC power supply grid architecture simplifies the integration of renewable energy sources, a 4 kW DC/DC converter with maximum power point control algorithm (6) was developed and installed for a series of 3.3 kW PV panels set up on the roof of the laboratory building. The energy from PV panels was supplied to the DC grid, where it could be consumed by robots or stored in a Lithium-ion battery storage system (7) with a capacity of 18 kWh.

During the experimental tests, simultaneous power measurements of multiple highly dynamic devices with bidirectional energy flow proved to be a challenging task. Devices like welding guns or capacitor banks create very sharp power spikes, which the standard energy consumption measurement equipment designed for AC systems is too slow to capture. To solve that problem, the researchers of IEEI created a novel electrical energy measurement system enabling the required high-speed multi-channel measurements. The multi-channel measurement system utilised common sampling time and optical fibre data transfer system. Power measurement units were designed basing on voltage to frequency method for the voltage measurements and using compensated hall effect sensor for current measurements [4]. The Figure 3 shows the power measurement module designed for industrial robot cabinet connection and a graph from measurement validation tests.

This multi-channel measurement system was also used in the demonstration production cell set up at Daimler AG, bringing it to INDUSTRY 4.0 level.

Power flow data of 110 second time duration acquired from real industrial manufacturing process in the DC-grid production cell at Daimler is shown here as an example. Figure 4 shows 13 datasets with common time axis grouped for similar magnitudes of power flow.

The main advantage, however, of integrating industrial robots in a common DC supply system is the possibility to recuperate the braking energy, which leads to considerable energy savings. The level of savings depends on the robot count within a production cell, as well as on the robot motion patterns and tasks. Measurements acquired in the demonstration production cell of Daimler, showed that while carrying out real-life production tasks the novel DC-grid production cell could save up to 13.2% [5] compared to the traditional AC-grid supplied system. These impressive results surely played a significant role in encouraging Daimler AG to initiate the expensive and ambitious project entitled "Factory 56".

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