Development of 600V Industrial DC Microgrid for Highly Automated Manufacturing Applications: Factory and Laboratory Infrastructure Experience

Armands Senfelds, Ansis Avotins, Leonids Ribickis, Peteris Apse-Apsitis
Department of Industrial Electronics and Electrical Technologies
Riga Technical University
Riga, Latvia
armands.senfelds@rtu.lv

***Abstract*—Approach of DC based power distribution as promising alternative to existing infrastructure has become interesting topic considering simplified management of power flow and integration of energy storage and renewable source solutions. This paper is presenting DC based power supply approach investigation within real automotive manufacturing environment. More detailed evaluation of opportunities regarding operation of industrial robot manipulators coupled to DC grid has been introduced. The physical layout within industrial environment has defined needs for multipoint power measurement equipment development and verification leading to practical results. Based on obtained practical results evaluation of energy efficiency potential by conversion towards DC based infrastructure can be evaluated and future operating scenarios defined considering new energy storage and buffering applications.**

Keywords-component; formatting; style; styling; insert (key words)

I. INTRODUCTION (HEADING 1)

Modern industrial manufacturing environment has to face challenges presented by needs for improvement of productivity including efficient use of resources and materials in order to maintain competitiveness and meet diverse legal conditions. This research article is related to novel DC based power supply system application research considering highly automated automotive production facility utilizing industrial robotics solutions located in Europe. The major motivation of carmakers to reduce energy intensity during production process is imposed by European Union 2020 Directive [1] striving for 20% energy efficiency improvement target by 2020 and considering full life cycle of product. Also increasing electrical energy prices and national initiatives for new power distribution infrastructure solutions with high rate of renewable resource integration such as Energiewende energy transition policy in Germany allow to consider DC based infrastructure with modern power electronic solutions to be feasible in future in broad range of applications as presented by [2]. The opportunities presented by transition of electrical power supply and distribution infrastructure towards DC based solutions has been recognized and major drawback as lack of unified standards and normative basis with respect to existing AC infrastructure is expected to be improved in future according to standardization roadmap [3]. Diverse applications in fields such as marine transportation [4] or aviation [5] along with commercial building integration as presented by [6] support interest for further exploitation of DC voltage based power supply within robotics based industrial manufacturing application. This paper present insight into DC based power system application by replacement of existing AC based automotive manufacturing equipment with DC based. Within research activities both full production cell conversion to DC in existing factory along with small scale university located research laboratory has been utilized.

II. DC BASED INDUSTRIAL ROBOTIC APPLICATIONS.

Analysis of highly automated industrial manufacturing with significant number of industrial robot manipulator applications has presented potential for energy efficiency improvement considering electrical consumption as optimization parameter along with existing constraints for production cycle performance [7]. The effective utilization of regenerative energy can also be introduced in small scale robotic applications by introduction of local individual robot DC bus coupling as proposed by [8]. Comparison example of same trajectory extracted from automotive manufacturing application and performed with AC and DC based industrial robot is presented in following Fig.1.Potential of energy reuse is closely related to robot manipulator movement character and typical share within automotive production is expected to be about 10%.

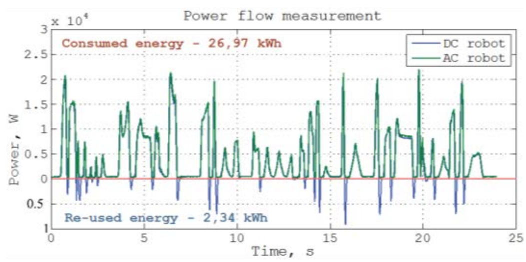

Figure 1 Power consumption of same trajectory for AC and DC based industrial robot manipulator.

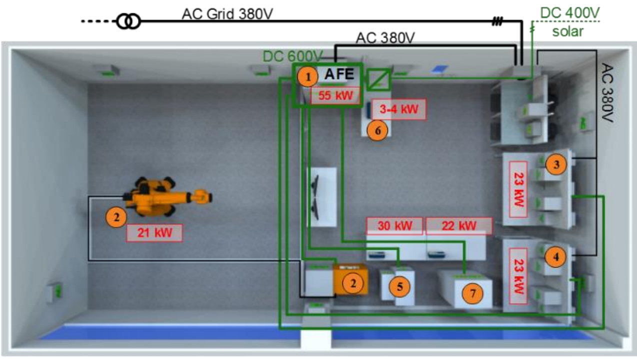

Figure 2 Overview of small scale DC supply grid laboratory layout.

III. DC Supply System Application Environment

A. Reduced scale DC supply system at university laboratory

In order to provide experimental verification of DC power supply application considering industrial robots along with electrical equipment for energy storage and future application for renewable power sources reduced scale power system has been assembled within university laboratory as presented in following Fig.2. The system is combined of central AC/DC active frontend unit (1) of 55kW nominal power rating and 600V DC bus voltage. Set of industrial robot (2) combined with two motor-generator sets (3,4) for equivalent power flow control as industrial robot. As auxiliary subsystems lithium ion based storage (7) and supercapacitor module (5) has been introduced combined with photovoltaic panel integration DC/DC converter (6). Such layout present ability to partially replicate real manufacturing process being performed in full scale DC converted production section located in factory. Also simulation model including available electrical components has been developed [9].

B. Industrial scale DC supplied robotic manufacturing testing facility.

Real environment prototype has been developed according to Fig. 3. DC microgrid structure is realized as basis for industrial robotics manufacturing cell with related tools and technological processes. Fully functional DC manufacturing cell has been developed by Daimler AG factory in Germany

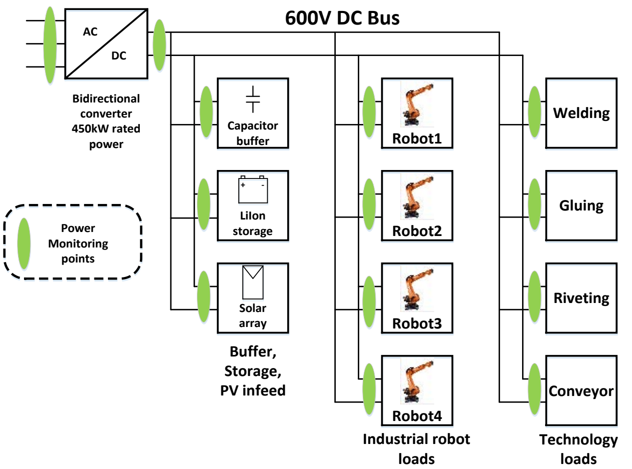

Figure 3 Structure of examined DC microgrid for automotive manufacturing application.

Figure 4 DC microgrid realization as automotive manufacturing cell for experimental analysis.

during European research project AREUS [10]. System has single AC/DC of rated power 450 kW based on industrially available components. Industrial robots serve as basis for load group of 4 units supported by production tools for glue dispensing, rivet joining, spot welding and rotating tabble for part positioning. Electrolytic capacitor bank is directly connected to DC bus and LiIon storage, photovoltaic panel array are additional energy storage and generation equipment with respective DC/DC power converters.

IV. Multipoint Power Metering Application Development.

Physical realization of DC manufacturing cell protoype present challenge for synchronized electrical power flow measurements with cell area of 10 by 10 meter dimensions and electrical cabinets located around the cell under ring type DC rail. Synchronous acquisition of 13 power flow measurement locations with common sampling time has led to development of custom made measurement system as described in [11] utilizing voltage to frequency method for voltage measurement and compensated hall effect sensor current measurement methods. Data collection within single unit and respective text file has been realized by optical fiber communication with measurement sampling frequency of 2.8 kHz and averaged values on 20 milliseconds corresponding 50 Hz AC mains system measurements.
Based on application of aforementioned measurement setup power flow data has been obtained based on industrial manufacturing application operation of 110 second duration completely supplied via local DC microgrid. Following Fig. 5 represent 13 datasets with common time axis grouped according to similar magnitudes of power flow. Table 1 represent analytical results supporting idea of regenerative energy reuse potential in industrial robot application presenting braking energy in range between 1.2% and 10.6% at various motion tasks. Manufacturing technology loads adapted for DC type supply has been evaluated as well representing 1% average reverse power flow. Important influence has been observed for main electrolytic capacitor bank operation with 66% average reverse power flow. Such application of capacitor can be optimized since large component of energy is related to internal losses of functional capacitor unit. Combined analysis of 4 technology load units, industrial robots and capacitor buffer as common DC supplied equipment group demonstrate reused power flow of 13.2% related to cycle average power consumption.

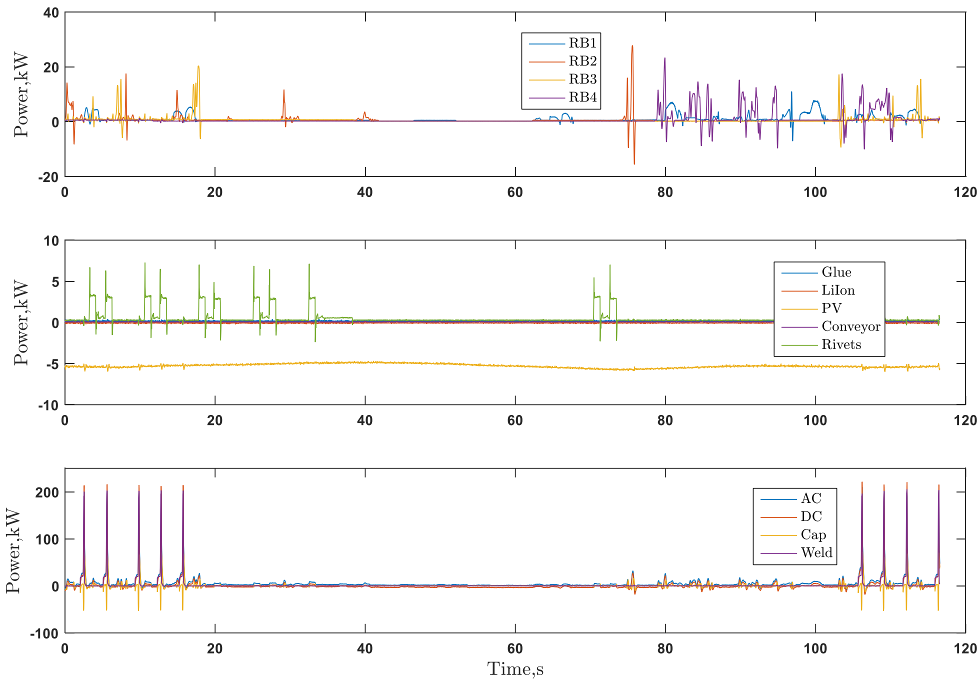

Figure 5. Obtained synchronous power flow measurement data at 13 microgrid locations: 4 industrial robots (top), tool technologies, PV infeed and LiIon storage (middle), AC, DC, Capacitor buffer and welding (bottom).

TABLE I. MANUFACTURING CYCLE AVERAGED POWER FLOW RESULTS

	P_{pos}, kW	P_{neg}, kW	P_{neg}/P_{pos}, %
DC load group (4 robots, tools, capacitor buffer)	8.01	1.06	13.23
Robot 1	0.99	0.012	1.21
Robot 2	0.94	0.1	10.64
Robot 3	0.68	0.04	5.9
Robot 4	0.64	0.04	6.25
Technology tools (4 units)	3.51	0.04	1
Capacitor buffer	1.25	0.82	66

CONCLUSIONS AND FUTURE WORK

With ability of DC grid based small scale university laboratory and factory located industrial DC production cell along with novel power metering equipment it has become possible to obtain experimental data considering new functionalities of industrial robotics with respect to energy efficiency improvement. The analysis of DC based infrastructure indicate energy efficiency improvement potential related to regenerative energy utilization of industrial robots. Typical application with related robot motions lead to as high as 10% reusable energy margin for individual robot unit. Further system level advantages are related to energy storage and utilization for pulsed load operations as welding example or backup power for stable manufacturing process shutdown in case of power grid outage. Optimal design and dimensioning of internal energy buffering capacities and single infeed unit from existing AC infrastructure present future challenges for DC supply infrastructure adoption within established industrial environments such as highly automated factory floors.

REFERENCES

[1] "Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency." [Online]. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN. [Accessed: 18-Dec-2016].

[2] R. W. De Doncker, "Power electronic technologies for flexible DC distribution grids," in 2014 International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA), 2014, pp. 736–743.

[3] "German Standartization Roadmap, Low Voltage DC Version 1." [Online]. Available: https://www.dke.de/resource/blob/778168/23cb82850b1c37070f3ebc5526770646/german-standardization-roadmap-low-voltage-dc-version-1-data.pdf. [Accessed: 29-Mar-2018].

[4] J. F. Hansen and F. Wendt, "History and State of the Art in Commercial Electric Ship Propulsion, Integrated Power Systems, and Future Trends," Proc. IEEE, vol. 103, no. 12, pp. 2229–2242, Dec. 2015.

[5] J. Brombach, T. Schroter, A. Lucken, and D. Schulz, "Optimized cabin power supply with a +/− 270 V DC grid on a modern aircraft," in 2011 7th International Conference-Workshop Compatibility and Power Electronics (CPE), 2011, pp. 425–428.

[6] P. Meckler, F. Gerdinand, R. Weiss, U. Boeke, and A. Mauder, "Hybrid switches in protective devices for low-voltage DC grids at commercial used buildings," in ICEC 2014; The 27th International Conference on Electrical Contacts; Proceedings of, 2014, pp. 1–6.

[7] D. Meike, M. Pellicciari, and G. Berselli, "Energy Efficient Use of Multirobot Production Lines in the Automotive Industry : Detailed System Modeling and Optimization," IEEE Trans. Autom. Sci. Eng., vol. 11, no. 3, pp. 798–809, 2014.

[8] D. Meike, A. Senfelds, and L. Ribickis, "Power converter for DC bus sharing to increase the energy efficiency in drive systems," in IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society, 2013, pp. 7199–7204.

[9] A. Senfelds, M. Vorobjovs, D. Meike, and O. Bormanis, "Power smoothing approach within industrial DC microgrid with supercapacitor storage for robotic manufacturing application," in 2015 IEEE International Conference on Automation Science and Engineering (CASE), 2015, pp. 1333–1338.

[10] M. Pellicciari, A. Avotins, K. Bengtsson, G. Berselli, N. Bey, B. Lennartson, and D. Meike, "AREUS - Innovative hardware and software for sustainable industrial robotics," in 2015 IEEE International Conference on Automation Science and Engineering (CASE), 2015, pp. 1325–1332.

[11] P. Apse-Apsitis, A. Avotins, and L. Ribickis, "A different approach to electrical energy consumption monitoring," in 2014 16th European Conference on Power Electronics and Applications, 2014.