Industrial DC Microgrid Analysis with Synchronous Multipoint Power Measurement Solution

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Keywords

« Microgrid », « Industrial application », « DC power supply », « Measurement »

Abstract

Paper is presenting application of synchronized power flow measurement system within 13 locations of DC microgrid installation in production plant with specific measurement equipment system developed for dynamic energy flow analysis. Insight into internal DC bus power exchange behavior and interconnected operation advantages with respect to energy efficiency improvement is provided. Future trends towards DC based manufacturing infrastructure are discussed. Presented results provide insight into electrical energy distribution behavior within DC microgrid system structure operated based of realistic industrial manufacturing tasks. Application of multipoint power measurement system provide real measurement data of various manufacturing technology tool load profiles that serve as important basis for future system modelling and dimensioning tasks.

Introduction

Presented paper is related to DC technology based electrical supply infrastructure integration effort within automotive manufacturing branch and obtained power flow measurement results with dedicated multipoint synchronized measurement equipment. High level European Union policies [1] are demanding investments towards more energy efficient production technologies. Also country specific initiatives such as Energiewende [2] in Germany present concepts toward intelligent DC power distribution in future. Such factors lead to development of highly automated manufacturing infrastructure modifications including DC microgrid as electrical energy supply concept as presented in Fig. 1. Elements of local PV generation, energy storage and consumers as well as ability to operate in islanding mode for certain periods allow to discuss presented electrical installation as microgrid. Green dots represent relevant power flow measurement locations within microgrid structure.

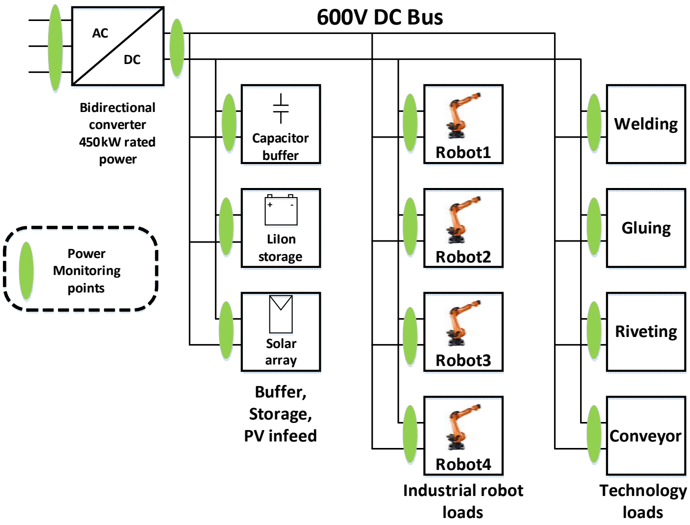

Fig. 1: Structure of examined DC microgrid for automotive manufacturing application.

Development of 600V DC electrical system for integration within existing factory infrastructure arise problems of less developed standard base and electrical component portfolios of typical suppliers with respect to state of the art AC electrical technology. However, future plans covering DC standards have been presented [3]. Insight of research activities covering both software and hardware modifications with focus on energy efficient robotic manufacturing has been presented by [4],[5]. Advantages of DC energy supply systems has recently been identified also in marine applications [6] and buildings [7]. Ideas of verified simulation model development of electrical components as well as parallel development of virtual software analogue of existing manufacturing infrastructure systems also known as digital twin concept has been considered [8]. Such concepts are demanding verified experimental data of power consumption as basis for new modelling and planning software development. Also control strategies of adaptive system operation with respect to energy prices, renewable energy production potential and energy storage options require experimental research. Realization of Fig. 1. presented DC microgrid structure has been built as operating production cell including industrial robot manipulators with related tools and technologies at Daimler AG factory in Germany as presented in Fig.2.

Fig. 2: DC microgrid realization as automotive manufacturing cell for experimental analysis.

System has central AC/DC bidirectional converter 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.

Multipoint power metering system application

Scale of presented system and involved electrical components arise problem for power flow measurement realization. The approximate dimensions of cell are 8 by 8 meters with DC ring bus rail and electrical cabinets located along outer wall. In order to obtain power flow measurement data from 13 distributed measurement points with common sampling time reference power measurement devices combined with optical fiber data transfer system has been created and applied. Power measurement units has been built based on approach presented in [9] utilizing voltage to frequency method for voltage measurement and compensated hall effect sensor current measurement methods. Following Fig. 3 represent power measurement module designed for industrial robot cabinet connection and graph during measurement validation tests.

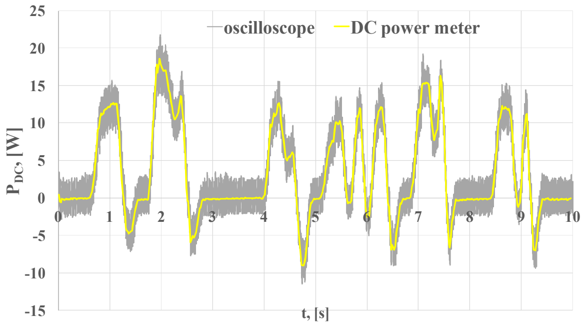

Fig. 3: Power measurement device prototype for DC industrial robot and measurement performance evaluation example against oscilloscope based power measurement.

The basic sampling frequency is 2.8 kHz and averaged values over 20 millisecond periods corresponding to 50Hz AC side power measurement are propagated via optical fiber network for central data logging as text file. The AC side power measurement device prototype is shown in Fig. 4. For installation in existing AC electrical system external current clamps have been preferred with ability to connect without dismantling the high power electrical wiring. All power metering devices have been designed for later integration within industrial automation infrastructure via Profinet communication standard for power monitoring capability. For the current scope of this paper bidirectional optical communication has been utilized enabling synchronized reading of all involved measurement modules to obtain single time base for 12 DC type and one AC type power measurement readings.

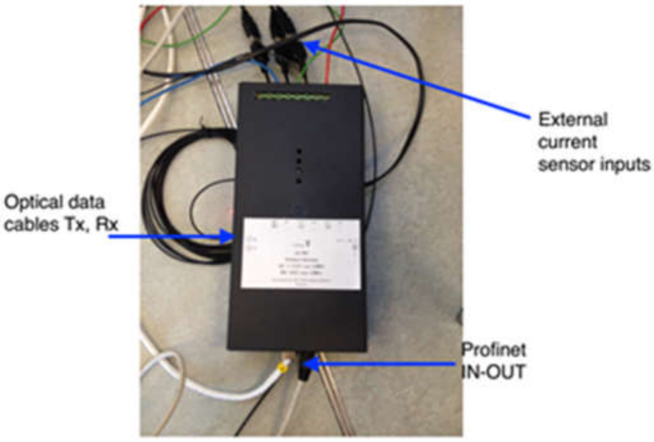

Fig. 4: AC side 3 phase power measurement prototype with external current clamps, bidirectional optical data transfer and Profinet communication module.

Synchronous Multipoint Power Measurement Data example

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.

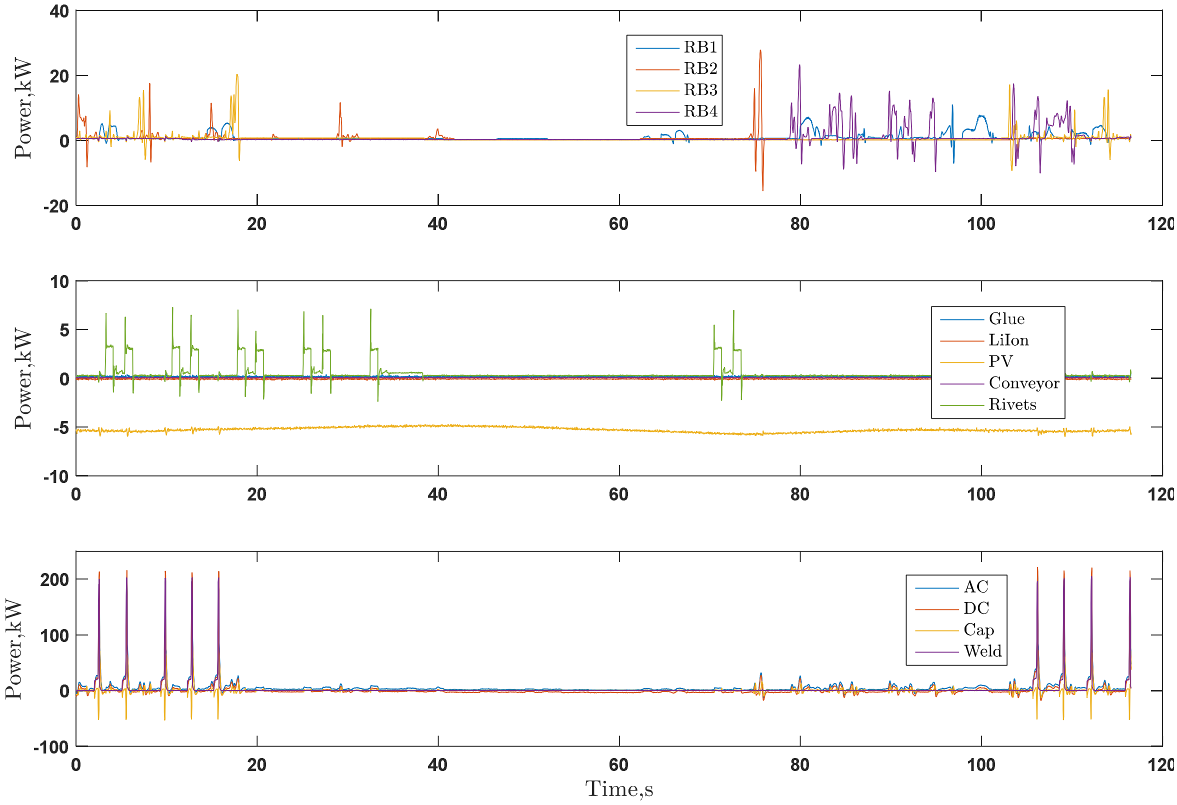

Fig. 5: Obtained synchronous power flow measurement data at 13 microgrid locations: 4 industrial robots (top), tool technologies, PV infeed and LiIon storage (middle), AC, DC, Capacitor buffer and welding (bottom).

Power flow direction is considered positive as consumption from DC bus or AC grid respectively. Alternative way to classify involved microgrid components regarding functional tasks can be addressed as already introduced in Fig. 1.

Industrial DC Microgrid Power Flow Analysis

By observing behavior of consumers it is possible to derive group of elements operating with bidirectional power flow in DC bus. In order to obtain insight about intermediate power flow behavior within DC network following calculation has been performed according to equations (1) and (2) calculating average positive P_{Pos} and negative P_{Neg} power flow within given 116 second operation period T and results have been summarized in Table 1.

$$P_{Pos} = \frac{\int_0^T P(t)}{T}; P(t) \in [0, \infty) \tag{1}$$

$$P_{Neg} = \frac{\int_0^T P(t)}{T}; P(t) \in [-\infty, 0) \tag{2}$$

Table I: The title of the Table I

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

Observing analytical results one of advantages of integrating industrial robots within common DC system is verified presenting reused braking energy utilization in range between 1.2% and 10.6% depending on programmed robot motions and tasks. All technology loads have been analyzed as group and also 1% of negative energy flow has been detected that can be explained by significant internal capacitance of welding technology converter. Main electrolytic capacitor bank buffer power flow yield to 66% ratio of supplied average power flow with respect to stored power flow and can be explained by internal losses of assembled unit. Analysis of combination of 4 technology load units, 4 industrial robots and capacitor buffer as common DC load group ratio of reused power flow with respect to fundamental consumptions power flow is 13.2%.

Another aspect of verification of experimental results has been presented in Fig. 6. Assuming that sum of all 11 DC bus end user elements (4 robots, 4 loads, 3 storages, buffer and PV) power flow should be a close match of one infeed power flow value DC respective difference has been calculated as value SumDC. Deviation of average value of SumDC over period is 180W. Higher deviation can be observed during rapid power flow change at welding process. It has to be noted that SumDC represent both internal DC bus conductor rail losses and measurement errors. Obtained value support confidence of experimental measurement dataset of 13 power flow locations. More in-depth analysis of measurement system dynamic response, particularly current sensor behavior at high current rate of rise is foreseen as future activity.

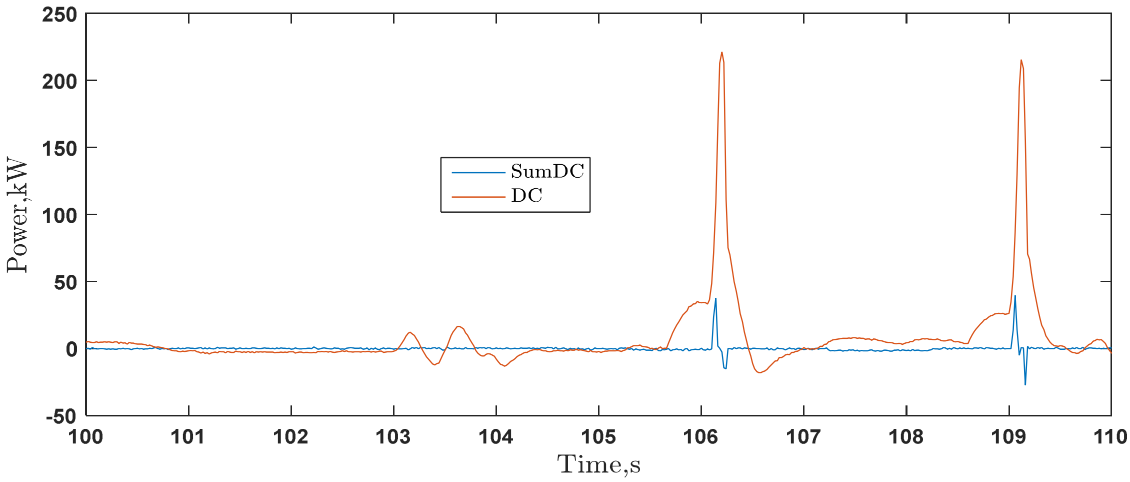

Fig. 6: Comparison of analytical calculation of DC bus component power balance: *SumDC* and measurement of main supply converter DC side power flow: *DC*.

Obtained results allow further analysis of such concepts like power peak shaving since welding process impose dynamic consumption on AC grid side. Also dimensioning of internal storage capacity considering accumulation of renewable energy during weekends or bridging of possible grid outages can be done based on experimental data.

Conclusion

Power flow measurement results covering industrial scale DC microgrid has been obtained in synchronized manner and based on real production equipment operation use case. Such data serve as important basis for validation of simulation models of both component and system levels. Application of experimentally verified electrical component models regarding dynamic power consumption is considered as one of key advantages for design of energy efficient manufacturing installations. Presented results support expected energy efficiency advantages of interconnecting electrical loads with regenerative energy potential within common DC grid. Further activities are foreseen towards analytical dimensioning of central AC/DC power supply converter regarding planned load group within DC microgrid supply area. Since demand for individual welding tool peak power and production cycle average power present large difference new approaches of intermediate energy storage with dynamic response are scope of further research. Also optimal distribution of capacitance within system is interesting topic and will be analyzed in order to reduce unnecessary energy exchange between loads during operation. All aforementioned topics has been considered during initial design phase of DC infrastructure but more detailed analysis covering all DC microgrid can be pursued with assistance of power flow measurement system introduced in this paper.

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