Energy Efficient Low-Voltage DC-Grids for Commercial Buildings

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***Abstract*—The European ENIAC R&D project consortium DC Components and Grid (DCC+G) is developing suitable, highly efficient components and sub systems for 380 VDC grid to show the benefits of DC grid concept on test site in an office environment. The newly developed DC grid components and their integration into a generic system are presented in this paper. The targeted overall efficiency saving compared to AC grid is 5% and the energy conversion from PV (photo voltaic) is calculated to be 7% more cost effective compared to traditional PV installations. This paper also shows the realized DC grid prototypesupplying an office building of the Fraunhofer Institute in Erlangen, Germany, and describes general benefits of a DC grid system. The DC grid prototypeconsists of a DC lighting system, a DC low power supply for IT infrastructure, DC electric vehicle charger, a DC µCHP unit, DC photovoltaic MPPT units, a central rectifier and grid controller unit as well as a mixed AC/DC power monitoring unit. It is shown that less conversion losses and higher distribution efficiency can be achieved with a 380 VDC grid compared to conventional AC grids.**

Keywords—Efficiency; central rectifier; demonstrator; EV charger; micro CHP; solar power

I. INTRODUCTION

The major electric energy consumers in commercial buildings (heat pumps, ventilation systems, air conditioning units, cooling units, LED lighting systems and information technology), ready for the “net-zero-energy“ goal of the European Union, are in the most energy efficient versions executed with a rectifier system as interface to the conventional AC grid [1, 2]. Furthermore, local producers of electrical energy at buildings (photovoltaic, wind energy, energy storage systems) natively provide DC.This potential can be used more efficiently using a 380 VDC grid compared to a traditional AC grid in commercial buildings due to the fact that passive components and conversion losses in electronic devices can be dimensioned smaller or be completely omitted in case of a direct supply out of a 380 VDC rail [3]. This can lead to a cheaper and simpler design of devices and to a significant reduction in electronic scrap. Beside that a significant reduction of conversion losses by avoiding repeated conversion from DC to AC and vice versa as well ashigher distribution efficiency can be achieved with a 380 VDC grid compared to conventional AC grids. By comparing the simplified sketch from Fig. 1 and Fig. 2 it can be clearly seen that for the use of solar energy for example the effort for energy conversion and for power electronics is significantly reduced.

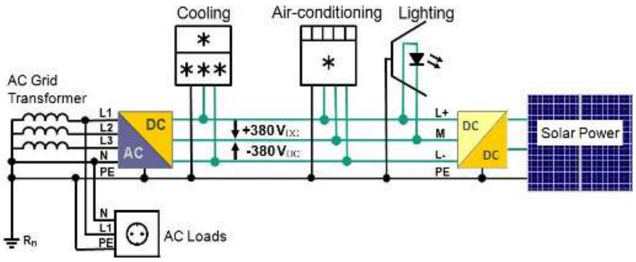

Fig. 1. Proposed 2-phase DC-grid system for high power and high efficiency applications with ±380 VDC

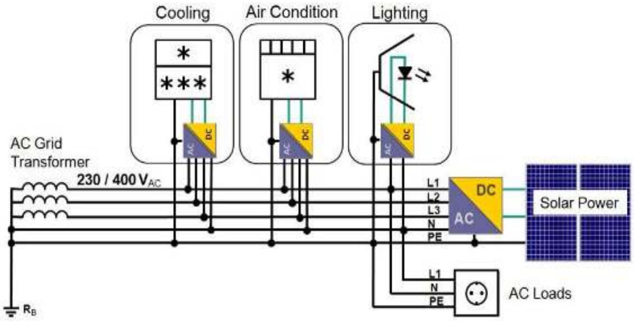

Fig. 2. Usual 3-phase AC-grid system

Thus, with the proposed DC grid approach,an efficiency and availability improvement as well as a reduction of cost and system complexity can be realized [4]. To proof this, the European ENIAC R&D project consortium “DC Components and Grid” (DCC+G) is developing suitable, highly efficient components and sub systems for 380 VDC grid to show the benefits of DC grid concept on test site in an office environment [5].The targeted overall efficiency saving compared to AC grid is 5% and the energy conversion from PV (photo voltaic) is calculated to be 7% more cost effective compared to traditional PV installations [6, 7, 8].

II. OFFICE BUILDING DEMONSTRATION

A. System overview

The validation of the proposed 380 VDC grid system makes use of a DC test grid installed in an offices building at Fraunhofer IISB in Erlangen [9]. In Fig. 3 a schematic build-up of the test-grid is given. The sources and loads of the test installation interface the grid through power electronic components that were developed within the DCC+G project,e.g. the central rectifier (Emerson Network Power), LED drivers (Philips), Solar Micro Inverter (Heliox) and the Micro-CHP-unit (MTT), and through commercially available switch mode power supplies which were retrofitted for direct feed out of a 380 VDC grid, e.g. drivers for fluorescent lamps. The components are described in great detail in the following section.

More in detail (see Fig. 3) the test bed is equipped with two DC bus bars, the central 380 VDC bus and a DC bus for the photovoltaic solar panels. The difference between the two buses is that the voltage of the central DC bus is controlled to a nominal value of 380 VDC.

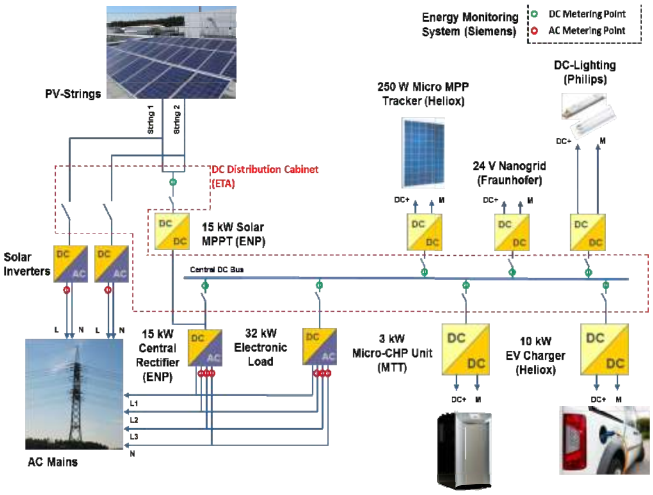

Fig. 3. Schematic overview of DCC+G office demonstrator in Fraunhofer Institute IISB in Erlangen

A droop control scheme in each power converter connected to this bus ensures keeping the voltage within ± 20 V boundaries of the nominal value. The PV bus, on the other side, has a larger voltage range up to 800 VDC which depends on solar irradiation and the temperature of the solar cells.

The voltage level of 380 VDC was chosen to benefit from the new Standard ETSI EN 300 132-3-1 for ICT equipment in telecom and data centers [10].

B. Components used for the office demonstrator

1) Central rectifier and grid controller

The main power source of the DC test grid is the interface to the AC mains, provided by a DC grid controller equipped with two isolated 15 kW rectifiers. The grid controller, regulating the voltage of the DC grid and the two devices from Emerson Network Power are located in a server rack with 24 HU. A picture of the power rack inside the DC laboratory can be found in Fig. 5.

Fig. 4. Emerson Power Rack inside the DC laboratory, containing the grid controler, two 15kW rectifiers and the integrated MPPT-unit

2) Integrated solar MPPT (maximum power point tracker) converter

Additionally to the two rectifiers, the Emerson power rack also contains a 15 kW DC/DC converter with Maximum-Power-Point Tracking (MPPT) capability, which is used to feed the solar DC power into the DC grid (see Fig. 4). It is designed to convert 260 V DC ~ 1000 V DC solar power into stable 380 V DC power. For this purpose, two strings of 21 PV modules each have been arranged on the roof of the test bed building to match the specification of the MPPT converter.

3) Micro CHP (Combined Heat Power) unit

The second largest power source inside the DC test grid is the µ-CHP unit (typeEnerTwin) of the company Micro Turbine Technologies (MTT), based on a small turbine, quite like the once used for turbo chargers. The EnerTwin µ-CHP unit from Fig. 5 was modified for the use in a DC grid and is fueled by methane gas. It provides about 3 kW of electrical power to the DC grid and 14.4 kW of thermal power for heating.

Fig. 5. MTT µ-CHP unit installed in the offices demonstrator with gas supply

4) Micro MPPT (maximum power point tracker) converter

Another way to feed solar generated power into the DC test grid is introduced through panel-integrated DC/DC converters with MPPT capability. One of the panel-integrated PV convertersfrom Helioxfor a 380V DC grid can be seen in Fig. 6;it has a maximum output power of 250 W. Two of these converters are attached to the DC supply bus.

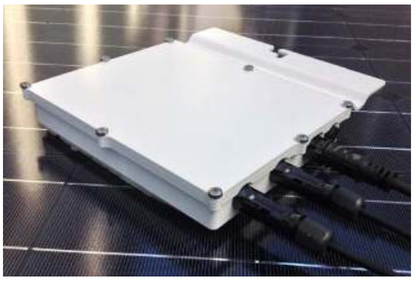

Fig. 6. Heliox 250 W solar MPPT micro converter unit for the 380V DC grid

5) DC coupled EV charger

A DC/DC, three-level, phase-shift controlled, isolated converter with reduced switch stress specially designed to operate from a nominal 380VDC bus as EV charger is part of the offices demonstrator. The converter, with a nominal power of 10kW, is capable to be operated under ZVS from zero to the maximal output voltage of 418V and from zero to maximal load current of 22A. The charger is controlled by simple CAN bus commands.

6) 24V nano grid

A 24V DC nanogrid concept to supply IT equipment was implemented in the office demonstrator to get rid of the individual power supplies of each device, thus significantly reducing clutter in office rooms. The nanogrid interfaces the 380 VDC grid through commercially available isolated DC/DC converters.

To deal with different input voltages of laptops, monitors and mobile equipment, which in most cases lies below 24 VDC, a buck converter with variable output voltage was developed. The correct output voltage for each device is encoded in the plug. Each power socket is laid out to deliver 100 W output power at maximum. A 24 VDC frame connector with three output sockets can be found in Fig. 7.

Fig. 7. Frame connector with three output sockets of the 24 VDC nano grid

7) Electronic load (32 kW)

For hardware simulation of the electric energy consumption of cooling, air conditioning, ventilation anddata center equipment, a programmable electronic load with a nominal power of 32kW was integrated into the DC grid. The programmable electronic load TopCon TC GSS from Regatron used in the offices demonstrator is shown in Fig. 8. It can be used to simulate a large variety of electricity consumers, thus increasing the flexibility of the DC grid demonstrator.

Fig. 8. Programmable electronic DC load TopCon TC GSS from Regatron for the 380V DC grid

8) Lighting system

The lighting installation is comprised of Philips LED luminaires as well as Zumtobelfluorescent luminaires of which somelamp drivers have been modified to work with 380 VDC instead of 230 VAC. In total, 26 DC supplied fluorescent luminaires are installed, each with a nominal power of 102 W_{DC}, making a total nominal power of 2652 W. One typical office room has been equipped with AC and DC supplied LEDluminaires depicted in Fig. 9. Hereby the specific installed power of luminaires could be reduced from measured 1.8 $W_{AC}/m^2/100Lux$ of AC mains supplied fluorescent luminaires to 0.90 $W_{AC}/m^2/100Lux$ and 0.87 $W_{DC}/m^2/100Lux$ of AC mains and 380 V DC supplied LED luminaires.

The office rooms in the test bed building usually contain two light bands with an equal number of luminaires. To make a comparison between AC and DC simple, one light band was left unchanged as an AC supplied load, while the other light band was modified for DC supply. The number of AC and DC light bands was selected to be equal.

Fig. 9. Philips SmartBalance LED luminaire prototypes with 380 V DC supply

C. System efficiency evaluation

For a comparison ofan AC and a DC distribution system in terms of the system efficiency,efficiency data and AC power factors for the different components for the AC and the DC casewere measured. Always an averaged efficiency and power factor was used to take the different load conditions into account. The used data for device efficiencies and power factors can be seen in table I. With a simple model taking the different wire resistances of the wires used in the demonstrators and the power factor as well as a symmetric 3-phase system for AC into account, efficiency values were calculated from the measurement data. For the efficiency comparison between the 400/230VAC and the 380VDC system the same data for the local source power (PV, µCHP) and the load power as well as the same electrical wiring system were used, to ensure a direct comparison between a 400/230VAC and a 380VDC distribution system. So, only the amount of AC power from the utility grid will vary due to the different system efficiencies. In consequence, only the different voltage level, the different efficiency of the components, the power factor and the slightly different topology (central rectifier) will lead to different system efficiencies and not different technologies for the sources, loads or power electronic used in the system.

TABLE I.

DC grid component	Efficiency DC [%]	Efficiency AC [%]	Power factor
Central rectifier and grid controller	96,9	1	0,99
Integrated solar MPPT converter	96,7	95,4	0,98
Micro CHP (combined heat power) unit	94,2	89,97	0,99
Micro MPPT converter	97,6	96,0	0,98
DC coupled EV charger	97,2	94,2	0,98
24V nanogrid	95,0	91,7	0,98
Electronic load (sim. data center)	95,0	91,7	0,98
LED driver	94,9	91,7	0,98
Fluorescent lamp driver	96,3	92,7	0,97

For the gathering of energy consumption data during the DCC+G test period a combined AC and DC energy monitoring system was developed; the metering spots can be seen in Fig. 4. The evaluation of the obtained energy data is done with the Siemens PowerManager software, to which the data are transferred. Inside the software a graphical user interface has been set up to monitor current power values as well as to analyze measurement curves and export data into Microsoft Excel.

In Fig. 11 the AC power consumption for a usual operation day of the offices demonstrator during the start of the test phase is shown. The AC power is necessary to fill the gap between the locally produced and consumed energy of the DC grid demonstrator and is provided by the central rectifier. From Fig. 10 it can be seen that the measured and the calculated ACpower are quite similar, so the quality of the calculated efficiency figures should also be quite precise.

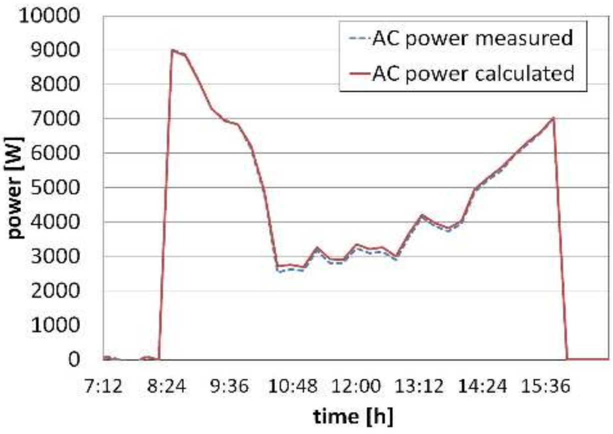

Fig. 10. Comparison between the measured and the calculated AC power taken from the AC utility grid to balance the system

In Fig. 11 the obtained power data (right axis) and the calculated efficiency for 400/230VAC and a 380VDC distribution system (left axis) are shown in detail. It can be seen that for low power consumption and low local power production the difference of the instantaneous AC (92.7%) and DC (93.1%) efficiency is quite small. But with an increase of the power consumption and the local power generation at noon (12:00 p. m.) the difference of the instantaneous AC (86.2%) and DC (90.0%) efficiency increases to about 3.8%. The overall energy efficiency (whole day cycle) for the 400/230VAC distribution system was 87.3% and for the 380VDC distribution system it was 90.0%. Thus the energy efficiency advantage of the DC system was about 2.7%. Here it is important to note that for obtaining these values for both systems the same technology for the loads, the local sources and the power electronics (e.g. the use of wide band gap materials) was used.

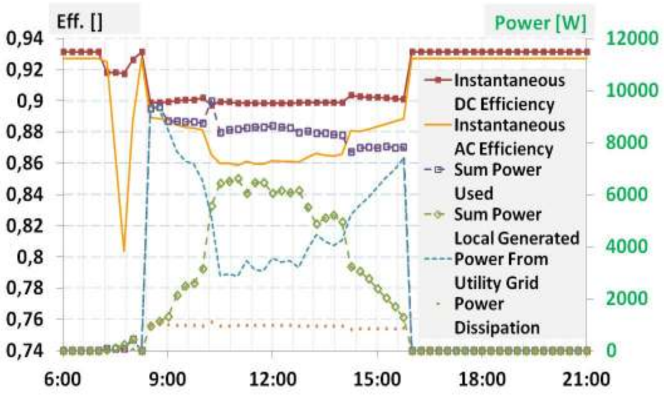

Fig. 11. Comparison of the calculated instantaneous efficiency for 400/230VAC and a 380VDC distribution system (left axis). The different generated und used power values are shown on the left axis.

In Fig. 12 another example for the operation of a commercial building is provided. During thisfictiveoperation cycle a quite huge amount of the consumed electrical power is provided by local power sources, so that only a relatively small amount of the electrical power is taken from the mains power supply (utility grid). For such a day of operation the overall energy efficiency (whole day cycle) for the 400/230VAC distribution system is about 86.3%, and for the 380VDC distribution system it is about 91.7%. Thus the energy efficiency advantage of the DC system was about 5.5%.

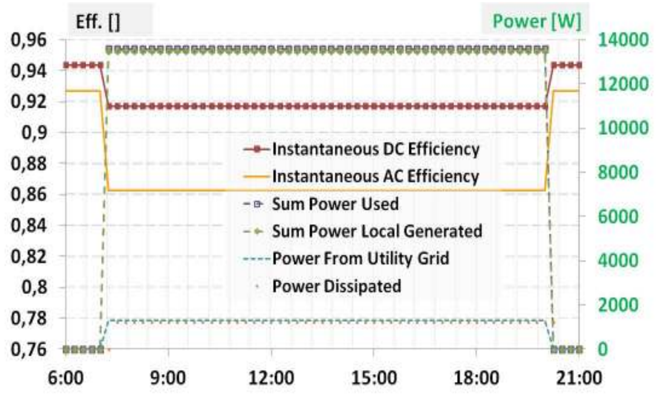

Fig. 12. Comparison of the calculated instantaneous efficiency for 400/230VAC and a 380VDC distribution system (left axis). The different generated und used power values are shown on the left axis.

III. CONCLUSION

This paper shows the realized DC grid prototypesupplying an office building of the Fraunhofer Institute in Erlangen, Germany, and describes general benefits of a DC grid system. The prototype DC grid consist of a DC lighting system, a DC low power supply for IT infrastructure, DC electric vehicle charger, a DC µCHP unit, DC photovoltaic MPPT units, a rectifier and grid controller unit and a mixed AC/DC power monitoring unit. With the proposed DC grid approach both an efficiency and availability improvement as well as a reduction of cost and system complexity can be realized. The efficiency difference between the AC and the DC distribution system varies according to the electrical power provided by the local sources; for a usual day of operation an efficiency advantage of about 2.7% was found. For an operation cycle with a huge amount of electrical energy provided by local, system integrated sources like PV facilities and CHP units the efficiency advantage is about 5.5%. The efficiency advantage could even be increased if a 2-phase ± 380 VDC grid would be used for high power loads like air conditioner and cooler, too.

ACKNOWLEDGMENT

We thank the German BundesministeriumfürBildung und Forschung and the European Community for funding the project DCC+G (BMBF FKZ 13N12113; ENIAC Nr. 296108 “DC Components and Grid”).

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