White Paper

Impact of a ±380 V DC Power Grid Infrastructure on Commercial Building Energy Profiles

Authors

Ulrich Boeke, Philips Electronics Nederland B.V., Philips Research Eindhoven
Leopold Ott, Fraunhofer IISB Institute, Erlangen

Table of Contents

Acknowledgment

The work has been performed in the project *Direct Current Components +Grid* (DCC+G), co-funded by grants from the Netherlands, Germany, Sweden, Austria and the Czech Republic and the ENIAC Joint Undertaking.

April 28rd, 2014

1 Introduction

This white paper explains the impact of low voltage DC power grid systems as key infrastructure element for requested very energy efficient buildings. The 2-phase DC power grid architecture in Figure 1 is proposed to replace classical 3-phase 230 V/400 V AC grids since very energy efficient buildings will make use of solar power systems as DC power sources and many electronically controlled applications that all have today already internal DC supply voltages [1].

The European Community has defined that new buildings must become much more energy efficient [2]. To reach the requested net-zero-energy status future buildings have to combine energy saving construction designs, energy saving applications with renewable power sources. Today photovoltaic solar power systems are the most prominent renewable power source for buildings [3]. The solar cells of solar power systems generate DC current and interestingly lighting, energy efficient building heating, ventilation, air-condition and cooling as well as computers for information technology are all operating with an internal DC supply voltage already today. Thus it would be just consequent to connect DC power sources with DC loads by means of an even more energy efficient DC power grid.

The DC power grid architecture in Figure 1 has energy efficiency advantages in three areas that are explained in this white paper.

- A central AC/DC rectifier of 10 kW rated power or higher can save about 3 % power compared with rectifiers and power factor correction circuits used in e.g. lamp drivers and many other applications.
- Power cables operate with halve the power loss (about 1 % of the total transferred energy) when operating with the proposed DC voltages compared with a power cable for a 3-phase AC grid. Alternative, 56 % copper in power cables can be saved when operating a power cable with DC and the same efficiency as with a 3-phase AC.
- The transfer of solar DC power via a DC/DC MPP converter in local DC loads saves 5 % of solar power compared to a solar system connected to a 3-phase AC grid because of the avoided power loss of rectifiers in individual products.

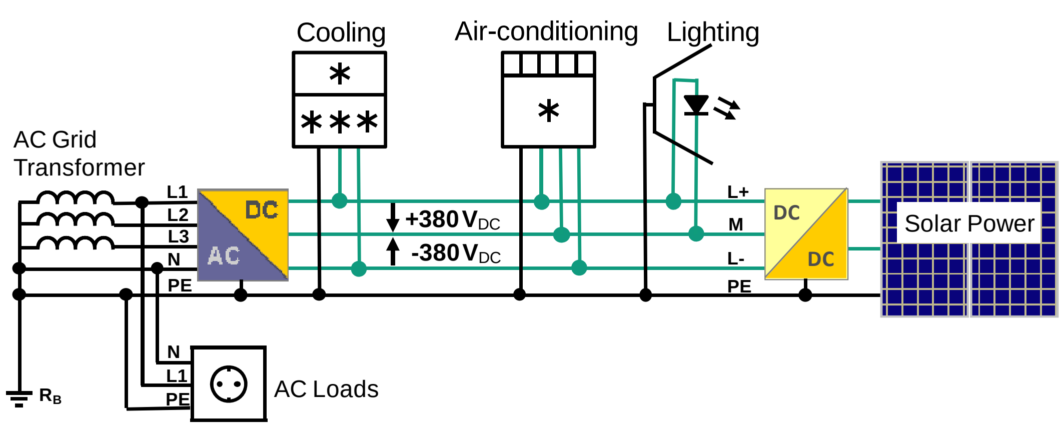

Figure 1: DC power grid architecture and applications

2 Office Buildings

2.1 Marché Restaurants Schweiz AG Office Building

The 2007 built office building of the company Marché Restaurants Schweiz AG shown in Figure 2 is a reference building for a net-zero energy building equipped with a classical AC power grid [3, 4, 5]. Electricity is the only form of energy used in this 1267 m^2 building that is equipped with a 6.1 kW_{el} heat pump for building heating. The analysis of the energy budget with the used AC grid is based on the data published in [3]. Key energy consumers are lighting, the IT system including an uninterruptable power system (UPS) and office applications like printers, coffee machines and dish washers. Building heating comes just at the 3rd position in the energy budget. The fluorescent lighting system makes use of day light sensors. Thus it is estimated that artificial lighting is required only 1500 hours in the winter halve year.

For the case that this building would be realised with a DC power grid, the following changes are considered in the right column of Tables 1 and 2. A heat pump with a speed controlled compressor motor is considered since heat pumps with typical scroll compressors operate with maximum efficiency at about half the rated power. The speed control electronic of the compressor motor converts this drive unit in a DC load [6]. Its annual electric energy consumption in Table 1 is reduced by 400 kWh/year or 4 % due to the higher energy efficiency and the avoided rectifier unit in this application. The power consumption of the office lighting installation is reduced by 40 % due to the avoided rectifier and power factor correction (PFC) units in luminaires and the transition from fluorescent lighting to more energy efficient LED lighting [7]. IT loads and ventilation will also benefit from DC grids by avoided power loss in product internal rectifier and PFC units similar like lighting. The power loss in the DC grid are estimated to be halve of the one in the AC grid case [8]. Finally the central rectifier will generate about 3 % power loss that replaces the rectifier and PFC units in individual products.

Figure 2: Marché Restaurants Schweiz AG Office Building in Kemptthal, Switzerland

The annual electricity generation of the solar system is expected not to change in case of using a DC grid. However a lot of the solar power will be consumed in local loads and hereby does not generate loss in rectifiers and PFC units of loads. This efficiency improvement is considered in Table 1 right column by the reduced energy consumptions of loads for the DC case.

The comparison of the annual energy budgets using AC and DC grids in this building example indicates that this office building equipped with a DC grid and an actual LED lighting system can save about 17 % of the total energy consumed in this building 2008.

The reference document of this building documents the absolute energy consumption used in Table 1 [3]. Additionally Table 2 offers the specific energy consumption for the comparison with other buildings e.g. the supermarket in Chapter 3.1.

Applications	Energy budget with AC Grid	Estimated energy budget with DC Grid
Heating & warm water	8 900 kWh (measured 2008)	8 500 kWh
Lighting	19 000 kWh (estimated)	11 400 kWh
Ventilation, IT , Others	20 100 kWh (estimated)	19 100 kWh
Electricity Grid	900 kWh (2% loss estimated)	400 kWh (1 % loss estimated)
Central Rectifier	*not used with an AC grid*	1 200 kWh (3 % loss estimated)
SUM Consumption	48 900 kWh (measured 2008)	40 600 kWh
PV system (44.6 kWp)	40 000 kWh (measured 2008)	40 000 kWh

Table 1: Energy budget of the Marché Restaurants Schweiz AG office building using AC and DC grids
TL Lighting (AC case): ~10 W/m^2 *1267 m^2 * 1500 h/year
LED Lighting (DC case): ~ 6 W/m^2 *1267 m^2 * 1500 h/year
IT: PC's, UPS, copier, printer
Others: Coffee machines, Dish washer, etc

Applications	Energy budget with AC Grid	Estimated energy budget with DC Grid
Heating & warm water	7.0 kWh/(m^{2}year)	6.7 kWh/(m^{2}year)
Lighting	15.0 kWh/(m^{2}year)	9.0 kWh/(m^{2}year)
Ventilation, IT , Others	15.9 kWh/(m^{2}year)	15.1 kWh/(m^{2}year)
Electricity Grid	0.7 kWh/(m^{2}year)	0.3 kWh/(m^{2}year)
Central Rectifier	*not used with an AC grid*	1.0 kWh/(m^{2}year)
SUM Consumption	38.6 kWh/(m^{2}year)	32.0 kWh/(m^{2}year)

Table 2: Specific energy budget of the 1267 m^2 Marché Restaurants Schweiz AG office building
using AC and DC grids
TL Lighting (AC case): ~10 W/m^2 *1267 m^2 * 1500 h/year
LED Lighting (DC case): ~ 6 W/m^2 *1267 m^2 * 1500 h/year
IT: PC's, UPS, copier, printer
Others: Coffee machines, Dish washer, etc

2.2 Fraunhofer IISB Office Building

The extension building A of the Fraunhofer IISB in Erlangen is an office building of the power electronics department. Besides typical electric loads in each office, like lighting and IT equipment, the building also contains several laboratories, in which power electronic circuits are developed and tested in the power range from milliwats up to 600 kilowatts. The major electric loads of the laboratories are therefore programmable electronic power sources as well as measurement equipment. In addition to that, the basement of the building contains the data center of the entire Fraunhofer IISB institute. A picture of the Fraunhofer IISB with L-shaped extension building A right in the middle can be seen in Figure 3.

Figure 3: Photo of Fraunhofer IISB in Erlangen with extension building A

On top of the extension building, a PV plant with a peak power value of approximately 10 kW is mounted. Within the DCC+G project the second floor of the extension building is considered as test bed. Empiric conducted studies have shown that an average office workplace of 6.3 m^2 on this floor in the extension building consumes around 182 kWh of electric energy per year [12]. The site specific electric energy consumption can then be computed to 29 kWh/m^2 for the considered second floor. It has to be mentioned that only the office space is considered in this figure, whereas the space of floors, laboratories and conference rooms are missing in the calculation due to the lack of appropriate data. On building level also the district heating system has to be added to calculate the complete specific energy consumption.

The used consumption data includes IT equipment and lighting exclusively. It has been furthermore measured that the PV plant yields 7932 kWh on average yearly. The second floor houses the offices for around 30 employees, which leads to a total electrical energy demand of 5460 kWh. That means that mathematically the second floor can already be considered as a net zero energy building. Of course no simultaneity factor is considered here and the mismatch between PV feed-in and electric energy consumption is big, especially in the summer month.

In chapter 2.1, it is stated that with a DC grid the energy consumption of IT equipment can be reduced by around 5 %, whereas for lighting the consumption can be reduced by 40 % when all luminaires are replaced with high efficient DC driven LEDs. In case of the second floor of the extension building A, the energy consumption is approximately divided 50:50 between IT equipment and lighting which is in good accordance to available data of the Marché office building in chapter 2.1. A comparable energy budget can therefore also be created and looks as follows:

Applications	Energy budget with AC Grid	Estimated energy budget with DC Grid
IT Equipment	2 730 kWh (average value)	2 594 kWh
Lighting	2 730 kWh (average value)	1 638 kWh
Electricity Grid	109 kWh (2% loss estimated)	42 kWh (1% loss estimated)
Central Rectifier	*not used with an AC grid*	128 kWh (3 % loss estimated)
SUM Consumption	5 569 kWh (average value)	4 402 kWh
PV system (9.9 kWp)	7 932 kWh (average value)	7 932 kWh (average value)

Table 3: Energy budget of the second floor IISB office extension building A using AC and DC Grids (Assumption: 30 employees)
TL Lighting (AC case): ~10 W/m^2 *1267 m^2 * ~1500 h/year
LED Lighting (DC case): ~ 6 W/m^2 *1267 m^2 * ~1500 h/year
IT: Notebooks, LED Displays, IP Phones

Applications	Energy budget with AC Grid	Estimated energy budget with DC Grid
IT Equipment	14.4 kWh/m^{2}year	13.6 kWh/m^{2}year
Lighting	14.4 kWh/m^{2}year	8.6 kWh/m^{2}year
Electricity Grid	0.6 kWh/m^{2}year	0.2 kWh/m^{2}year
Central Rectifier	*not used with an AC grid*	0.7 kWh/m^{2}year
SUM Consumption	29.4 kWh/m^{2}year	23.1 kWh/m^{2}year

Table 4: Specific energy budget of the 190 m^2 second floor IISB office extension building A using AC and DC Grids (Assumption: 30 employees)
TL Lighting (AC case): ~10 W/m^2 *1267 m^2 * ~1500 h/year
LED Lighting (DC case): ~ 6 W/m^2 *1267 m^2 * ~1500 h/year
IT: Notebooks, LED Displays, IP Phones

3 Supermarket Buildings

Supermarkets are interesting commercial building types for more energy efficient applications because of their much higher specific energy consumption compared with the office buildings described above.

3.1 REWE Green Supermarket Berlin

The retail company REWE has opened its first supermarket with DGNB gold certificate also for low energy consumption in Berlin-Rudow with a sales area of 1830 m^2 in 2009 that is a supermarket reference building for the DCC+G project. The specific energy consumption per square-meter in Table 5 [9, 10] is even without commercial cooling appliances five-times higher than the office building in chapter 2.1. The right column in Table 5 considers calculated specific energy consumption data for the use of a DC grid from the partners of the DCC+G project that is explained in the following.

The compressor system for refrigeration and freezers can be realized today with more efficient permanent-magnet motors and an inverter for speed control without integrated rectifier about 5 % more energy efficient as with the technology used 2009. The motor inverter converts the compressor system in a DC load.

The REWE supermarket in Berlin has been equipped with a lighting system using mainly fluorescent lamps that results in a specific installed power of about 20 W/m^2. 2012 a newer REWE supermarket has been equipped with a Philips LED lighting system that has a specific power installation of only 10.8 W_{AC}/m^2 [11]. This specific power installation for the lighting system can be reduced to about 10 W/m^2 using a DC grid.

Building heating, cooling and ventilation with a DC grid is considered to be realised by means of speed controlled motors. In the DC case these motors will consume 5 % less energy because of the transferred rectifier and power correction modules into the central rectifier. Power losses in cables and the grid installation are considered to be halved in the DC grid case [8].

Applications	Specific building energy budget calculated with AC Grid	Specific building energy budget calculated with DC Grid
Food cooling	280 kWh/(m^2year)	265 kWh/(m^2year)
Lighting	100 kWh/(m^2year)	50 kWh/(m^2year)
Building Heating	30 kWh/(m^2year)	28 kWh/(m^2year)
Building Cooling	30 kWh/(m^2year)	28 kWh/(m^2year)
Ventilation	30 kWh/(m^2year)	29 kWh/(m^2year)
Electricity Grid	10 kWh/(m^2year) (2 % loss estimated)	4 kWh/(m^2year) (1 % loss estimated)
Central Rectifier	*not used with an AC grid*	13 kWh/(m^2year) (3 % loss estimated)
Warm Water	20 kWh/(m^2year)	20 kWh/(m^2year)
SUM	500 kWh/(m^2year)	437 kWh/(m^2year)

Table 5: Specific building energy budget of the REWE supermarket building in Berlin-Rudow using AC and DC grids
AC Lighting System 2009: ~20 W/m^2 * 5000 h/year
DC Lighting LED System 2014: ~10 W/m^2 * 5000 h/year

The result of this comparison is a calculated energy saving of 12 % by using a DC instead of an AC grid, LED lighting instead of fluorescent lighting and an advanced compressor system for the commercial food cooling systems.

4 Appendix

4.1 Abbreviations

AC	Alternating current
CHP	Combined Heat and Power unit
DC	Direct Current
DCC+G	Direct Current Components +Grid
ENIAC	European Nanoelectronics Initiative Advisory Council
IP	Internet Protocol
IT	Information Technology
kW	Kilo Watt (1000 W)
kWh	kilo Watt hour
L+	Line plus conductor of a DC power cable
L-	Line minus conductor of a DC power cable
LED	Light Emitting Diode
M	Mid point of a 2-phase DC grid
MPP	Maximum power point (of a solar cell or solar module)
PE	Protected Earth
PFC	Power Factor Correction (electronic circuit generating a sinusoidal AC mains current from an AC grid)
PV	Photovoltaic
N	Neutral conductor of a 3-phase AC grid
V	Volt
W	Watt
kW	Kilo Watt (1000 W)

4.2 REFERENCES

[1] Direct Current Components +Grid, European ENIAC project, www.dcc-g.eu

[2] European Commission: Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings, 2010, http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm

[3] Voss, Musall: Net zero energy buildings, 2nd Edition, 2012, ISBN 978-3-920034-80-5, http://shop.detail.de/de/net-zero-energy-buildings.html

[4] Marché Restaurants Schweiz AG: www.immofield.ch/immobilien/data/buerobauxmarche.pdf

[5] Beat Kaempfen, www.kaempfen.com/en/projects/newbuild/marche-international

[6] L. Gasser et al: Leistungsgeregelte Wärmepumpen – Erfahrungen und Potenzial, 19. Tagung des BFE-Forschungsprogramms «Wärmepumpen und Kälte» 26. Juni 2013, HTI Burgdorf, in German, www.hslu.ch/t-tevt-gasser2013_wp-tagung_leistungsgeregelte_waermepumpen-erfahrungen_und_potenzial.pdf

[7] Philips Lighting: Case Study: UK National Union of Students, www.lighting.philips.co.uk/projects/NUS.wpd

[8] U. Boeke et al: Efficiency Advantages of ±380 V DC Grids in Comparison with 230 V/400 V AC Grids, White paper of the DCC+G project, 2014, (to be published)

[9] REWE Green Building, http://www.rewe-group.com/nachhaltigkeit/saeulen/energie-klima-und-umwelt/energieeffizienz/green-building/

[10] Harald Fischer: REWE Green Building – Konzept mit Zukunft, Presentation at the EuroShop 2011, in German, Duesseldorf, Germany, www.dgnb-international.com/fileadmin/euroshop/Kurz-Euroshop-2011-Ecoforum-DGNB-Harald-Fischer-REWE.pdf

[11] Philips: Projektbericht LEDs für den Kaufpark Iserlohn, Deutschland, in German, http://www.lighting.philips.de/pwc_li/main/shared/assets/images/project/kaufpark/WM_3955_CaseStudy_Iserlohn_kaufpark_final_0712.pdf

[12] E. Schlierf: Simulation of coupled DC grids, Diploma thesis, University of Erlangen-Nuremberg, 2012