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DCC+G

DC Components and Grid

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Author	Company	E-mail
Dr. Roland Weiß	Siemens AG	Rolandweiss@siemens.com

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Editor Address data	Name: Dr. Roland Weiß Partner: Siemens AG Address: Günther-Scharowsky-Str. 1 91058 Erlangen, Deutschland Phone: +49 9131 7-31708 Fax: +49 9131 7-32469 e-mail: mailto:rolandweiss@siemens.com
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Date	Issue	E-mailer
		Al_dccg_all@natlab.research.philips.com
		Anton.Chichkov@eniac.europa.eu

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1 Vision

Europe's economic stability depends on safe, reliable and sustainable energy. 40% of Europe's current energy is consumed in buildings. To address this fact, the European Commission has set the target that after 2020 only net-zero-energy buildings shall be constructed. More than 50% of the energy consumption in commercial buildings is from heat pumps for heating, ventilation, air conditioning (HVAC) units and lighting. Net-zero-energy buildings are only possible with integrated renewable energy systems such as solar or wind, and require high attention to in-house energy distribution. The use of indoor direct current (DC) power grids in buildings will increase the energy efficiency of electricity distribution and applications by at least 5 % and it will increase the efficiency of solar power systems by at least 7 %.
Therefore, the **main goal** of the DCC+G project is:

The DCC+G project therefore focuses on ENIAC's goals in *Energy Efficiency* – where the Grand Challenge 3 "Reduction of Energy Consumption" is specifically targeted. Secondly, as the building DC grid infrastructure will be subsequently linked to an external "smart grid", this project also addresses Grand Challenge 2 "Energy Distribution and Management – Smart Grid". Finally, although this is not addressed in the annual work plan for 2011, there is also a link to Grand Challenge 1: "Sustainable and Efficient Energy Generation" through the efficient embedding of DC-generating renewable energy systems in the building environment.

Today's inefficient electricity distribution with AC power grids, which is simplified shown in figure 1, requires significant upfront investments and generates additional power losses in rectifier and inverter electronics. These drawbacks of AC power grids can be substantially reduced by changing the electricity distribution in buildings to a mixed AC & DC net as it is shown in figure 2. A 380 V DC building power grid enables the highest efficiency of building appliances (e.g., HVAC and lighting) by avoiding local rectifiers and power factor correction circuits. The DCC+G project will therefore develop further the required semiconductor power devices, demonstrate the maximum efficient use of electric power in buildings by means of direct current power grid technology, and validate the installation in commercial building environments. Until now, the European industry has not started to act in this area. Therefor,by addressing DC distribution in commercial buildings, DCC+G will bring Europe in the lead in this competitive market.
It is thus the vision of the project to take an important step to reach the European Union's "20-20-20 targets" by developing power distribution systems, subsystems and components with highest efficiency and best integration of renewable energy sources. Therefore research work will have to be conducted on components like DC-fuses, -switches, -circuit breakers, -protection devices, -lighting systems, solar and combined heat and power systems and finally a DC grid controller, a central AC/DC converter system and a utility mains interfacing module. It also includes the development of nano-electronics technologies, devices, circuit architectures and modules which can be applied in DC power grid systems. In this context, the power and high voltage electronics as well as smart miniaturized systems for power management will be specified and developed. The final demonstration of performance of all those components and modules and the proof of energy efficiency advantages through reduced power losses will validate the vision of the project.

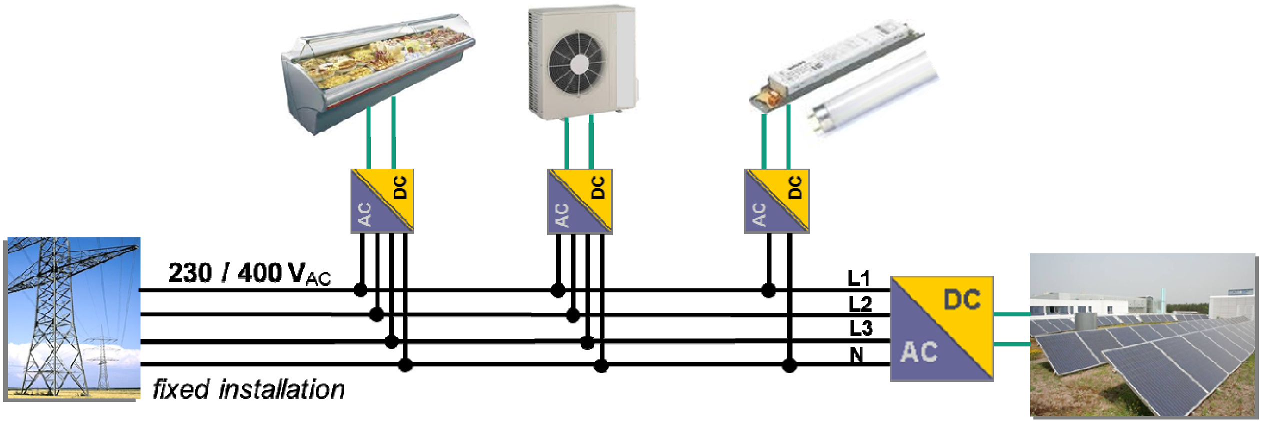

Figure 1: State of the art AC power distribution architecture

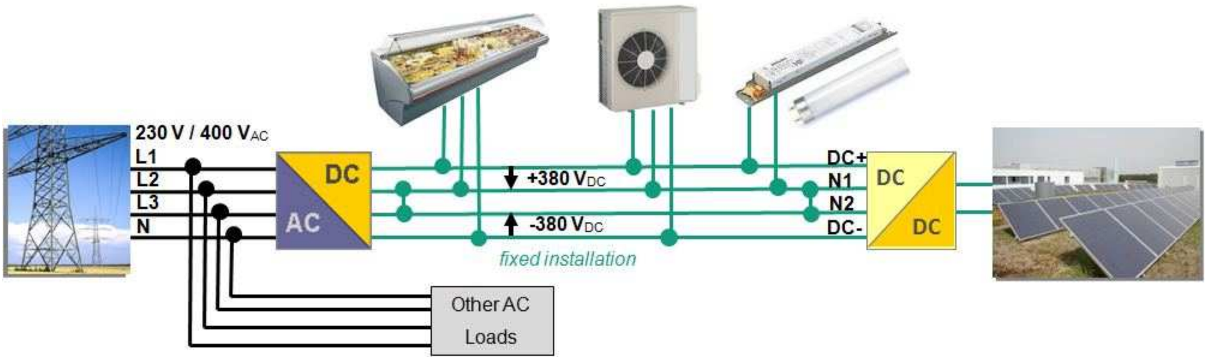

Figure 2: High efficiency DC power grid distribution architecture

2 Problem statement

Electricity in power grids and buildings is distributed as alternating current (AC) today. This fact is due to a historical decision a century ago based on features of magnetic power transformers which could change AC voltage levels for different purposes. Long distance power transport makes use of 230 kV and 400 kV AC grids. Distribution in regions and cities is done with 20kV to 100kV AC grids. The distribution in streets and buildings is realized with 230V/400V AC grids.

Currently, all of the DC-generating and -consuming appliances in buildings are connected via AC power grids (see figure 1). This historical combination of AC and DC power systems reduces energy efficiency, increases both upfront investment cost and total cost of ownership due to power losses in a very high number of locally installed DC/AC inverters and AC/DC rectifiers. The ENIAC project DCC+G aims to overcome these issues and reduce these drawbacks of today's technologies to distribute and use electricity.

These drawbacks will be significantly reduced by changing the electricity distribution network of buildings from AC to DC (see figure 2). The coupling of building DC power grids with the AC grid in streets will be performed by central AC/DC converter systems. Their higher power levels offer an efficiency advantage compared with local low-power rectifiers. Due to the reasons of higher energy efficiency and lower total-cost-of-ownership DC power grids therefore have an industry-shaping and standardization potential. In order to achieve these goals, new components (e.g. power semiconductors, DC LED lightning) sub systems (e.g. DC VSD) and systems are required.

Power semiconductors are changing the way electricity is used and distributed today. Power semiconductors enable new functions and allow especially the control of energy usage in applications with maximum efficiency reducing total cost-of-ownership and greenhouse gas emissions. Very long distance electricity distribution is realized with High Voltage Direct Current transmission with voltage level of 400kV to 800kV already. Modern energy efficient electric appliances in buildings use internal DC supply voltages of 300V to 800V DC to process electricity with maximum performance using modern power semiconductors. Examples include highly-efficient DC-powered variable speed drives in heating, ventilation and air-conditioning (HVAC), IT equipment in data centres, and solid-state lighting systems. Furthermore, photovoltaic (solar) systems on buildings generate direct current. Batteries in uninterruptable power supplies and electric cars also operate with DC.

The development and introduction of novel DC components for energy-consuming and -generating appliances in a DC-grid building infrastructure will create an **energy-efficiency-optimized electrical installation**. The combination of energy savings in lighting and HVAC systems, together with savings in the integration of solar and wind power generation at nearly no extra cost to the customer, is substantial.

The DCC+G project is based on the development of nanoelectronics technologies, devices, circuit architectures and modules for the DC power grid system and demonstration of these components and modules in a final system to prove performance advantages as low losses and higher switching frequency. In this context the power and high voltage electronics as well as smart miniaturized systems for power management will be specified and developed.

These electronics will provide a highly-efficient, integrated DC-grid system for buildings which will link electricity consuming systems like lighting, HVAC appliances, and refrigeration with renewable power generation installations for maximum energy efficiency at very little investment cost.
The most efficient motors and machines for typical building appliances are based on (*internally-DC*) variable-speed drives (VSD), which are quite expensive due to the AC power converters. A DC supply for VSD motors with a central rectifier will significantly increase adoption of these drives, resulting in energy savings of **more than 10%** per installation.

The competitive situation around power electronics and components for DC-based systems clearly shows that Europe can take and hold a leading position. With the leading positions in renewable energy installations (solar, wind) and solid-state lighting, together with the full value chain on power electronics manufacturing in Europe, the DCC+G project can counterbalance less-efficient 48V DC-grid standardization efforts from the USA.

3 Objectives

Several technical studies indicate that 380V DC power grids are the most energy-efficient electricity distribution method in buildings. Furthermore, building-integrated solar power systems with DC grid connection are lower cost and have a faster return on investment (ROI) than classical 230V/400V AC power distribution grids. Thus DC power grids support European “20-20-20 targets” as well as several of ENIAC’s Grand Challenges on ”Reduction of Energy Consumption”, “Energy Distribution and Management – Smart Grid” as well as “Sustainable and Efficient Energy Generation”. So the main objectives of the project are:

- To develop and demonstrate DC power grid technology as a standard for future energy-efficient building installations linking solar/renewables, lighting, heating, ventilation, air conditioning and other building elements.
- To reduce power consumption of buildings by at least 5% and to increase the efficiency of solar power systems and other local energy generation by 7%.
- To focus on R&D of semiconductor technologies, DC power components, system modules and the validation of more energy efficient electricity usage in buildings.
- To reduce energy consumption in commercial and industrial buildings. For the USA alone, 4.9 million commercial buildings consumed >5000 Terawatts of primary energy in 2003 – a 69% increase over 1980 levels[1].
- To establish **commercial test beds** that demonstrate the energy saving potential of DC power grids in actual user environments and so to validate that the envisioned energy savings are achieved.
- To strengthen the market position of European companies in the highly competitive market of power electronics components for DC-based systems, renewable energy installations (solar, wind) and solid-state lighting.

Many high efficient consumers and renewable suppliers of electrical energy like PV-systems consume or produce DC power with typical voltage levels of 300V to 1000V DC. LED lighting works with DC current, too. However, the connection of both and other appliances using today’s AC-grid requires two DC/AC and AC/DC power conversion steps. At least 9% power losses of valuable solar power are generated that increases the cost of solar power. These power losses will be reduced to 2% by connecting solar panels with a DC/DC converter (solar maximum power point controller) directly to a DC power grid. Both efficiency and cost advantage of DC power grids will enable earlier cost brake-even for renewable, green energy generation (grid parity). In addition, the solar power self-consumption in DC grid connected appliances like refrigeration, cooling and lighting requires less complex system control functions resulting in lower cost, too. The block diagram in Figure 3 illustrates building blocks of the proposed DC power grids with hybrid supply from AC mains and local DC power sources.

DC power grids are targeted first for commercial and industrial buildings. The REWE Green building supermarket in Berlin, Germany is an example that energy efficiency is for several reasons an important topic for innovative retail companies. Figure 4 depicts

[1] US Department of Energy, Office of Energy Efficiency and Renewable Energy (2009) *2009 Building Energy Data Book.*

a sketch of that building extended by optional roof mounted wind power units. Over 90% of the electricity in retail buildings is used in applications with internal DC supply voltages. Key applications are drives in heating-ventilation-and-cooling (HVAC) appliances, lighting and solar power generation. Hence, the energy efficiency of an already “Green” retail building can further be improved (of around 5% -7%) at little cost by changing to a 380V DC power grid.
In addition many other commercial buildings are also investigating the generation of “Green Power” by using photovoltaic or wind power systems; however, **integrated systems are not optimized for maximum energy efficiency and are therefore not cost-optimized.**

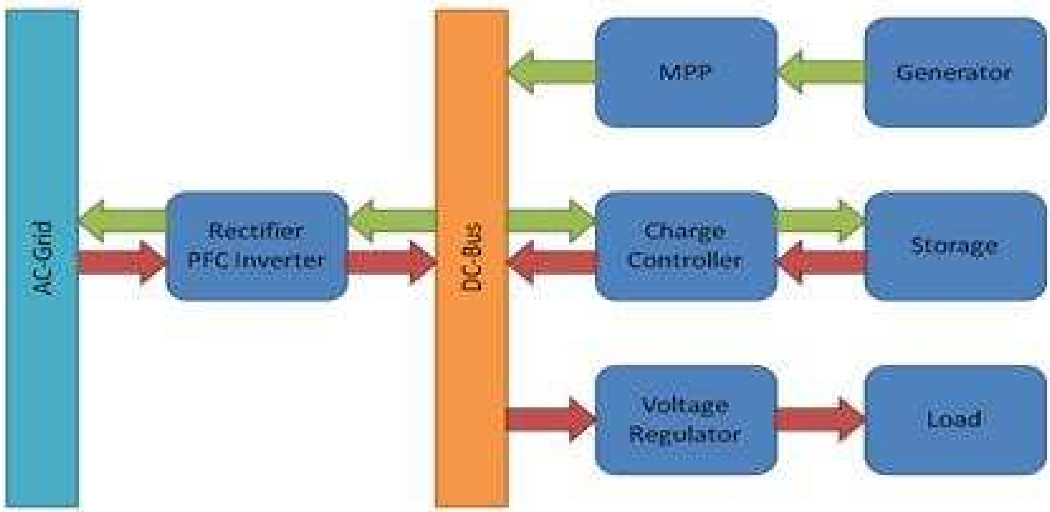

Figure 3 Optimized energy flow DC bus

Figure 4 Proposed building integrated power system

4 Expected results

The main goal of the DCC+G project is to research on semiconductor technologies, design components, system modules and validate more energy efficient electricity usage in buildings. A DC power grid will be especially valuable for connecting photovoltaic devices or generators of micro combined heat and power (CHP) systems with DC LED lighting systems or DC variable speed drives for cooling and ventilation systems. The today's AC-grid requires an additional DC/AC and AC/DC power conversion step to connect those applications wasting precious electrical energy
By making optimal use of all these aspects of electricity generation, distribution and usage we aim to reduce power consumption of buildings by at least 5% and to reduce the cost of solar electricity by 7%. Through the use of variable speed drives for climate control (motor) applications, these figures can rise to 13% energy savings – at low investment levels. Hence, the total AC mains power saving of commercial buildings is estimated to be 5% - 13% range by combining the advantage of DC power grids with new innovations summarized in following table.

Level	Innovation Topic	Efficiency increase	Innovation
1.1	Power semiconductors technologies and components for power conversion modules	Increase by at least 1 %	New semiconductor for more efficient processing of energy by lower conduction and lower switching loss
1.2	Highly precision current sensors	Increase by at least 2 %	Intelligent grid management systems
2.1	Central AC/DC converter systems and DC bus controllers	Increase by at least 2 %	New power converter architectures, controls and components
2.2	Solar power converter for DC power grids	Increase by at least 2 %	New power converter architectures, controls and components
2.3	DC electricity grids	Increase by at least 1 %	New communication principles to control DC power grids such as DC powerline communication
3.1	DC powered heat pumps	Increase by at least 2 %	New drives systems and its control for the supply from DC
3.2	DC powered air-conditional	Increase by at least 2 %	New drives systems and its control for the supply from DC
3.3	DC powered lighting	Increase by at least 4 %	New LED driver power converter architecture and its control for the supply from DC
3.4	DC powered freezers	Increase by at least 4 %	New drives systems and its control for the supply from DC
4	DC power monitoring system	Increase by at least 2 %	New DC-current and DC-voltage sensors with low looses, new supply and demand control and Integrated safety features

Next to these technical goals, the system should be designed in such a way that it will be affordable, easy-to-install, easy-to-use, easy-to-maintain, scalable and extendable.

We will guarantee a broad acceptance of this new system through the proper evaluation of use-case scenarios at the beginning of the project, as well as validation at both research institute and retail customer testing sites, installed by building facility specialists. The intention is to provide a route to a European high-efficiency building standard for DC grid usage.

Testbed demonstrators will be realized

- In an office building of a Fraunhofer research institute for proof-of-concept trials.
- In a retail outlet customer site (to be confirmed) for embedding into an actual building for direct comparison of AC vs. DC power usage.

5 Impact

Modern societies consume a steadily increasing amount of electricity. Improving the efficiency of electricity generation, distribution and usage is therefore of critical global importance, both for reducing greenhouse gas emissions linked to electricity usage as well as consumer electricity bills. It is relevant for the first point that since the energy efficiency of conventional (non-renewable) power plants including the provision of fuel is just 26% in Germany, every saved kWh of conventional electricity saves nearly 4kWh of primary energy. For the second point, the drive to reduce electricity bills is important since end-user electricity prices in e.g. Germany have doubled the inflation rates during last decade. This fact will drive the adoption of energy-efficient technologies, such as those described in this project.
The most significant electricity consumption in buildings is lighting and heating, ventilation and air-conditioning (HVAC). For commercial buildings in the USA, these consumed more than 50% of commercial sector primary energy in 2006[2]. In the future, heating with heat-pump systems will improve building energy efficiency substantially as opposed to heating with gas and oil. For the other energy-consuming elements, energy efficiency is being improved by adding electronic supply and control to motors and light sources. Electronic control systems for energy efficient applications operate with direct current (DC). Local electricity generation in buildings by means of photovoltaic solar systems also generate DC. In addition, highly-efficient variable speed drives (VSD) motors as used in best-in-class cooling and ventilation systems are also DC-driven.

The decision, made 120 years ago, to link electricity generation and electrical consumption with AC power grids has resulted in the 21st century into the dis-advantegeous requirement for a very high number of local AC/DC rectifiers as well as DC/AC inverters in buildings . Central rectifiers and DC power grids in buildings or building clusters are expected to reduce the building electricity consumption by 5% - 7% in comparison with top-efficient single-phase AC grid appliances. These energy efficiency improvements could be done on a insignificant small investment to the consumer, and could become a standard for building renovation and new building construction.
The impact of the DCC+G project is therefore linked closely to the “free” energy efficiency savings of DC power grids, combining DC-driven and -generating appliances in commercial buildings. As power distribution systems and appliances are demonstrated and validated vis-à-vis performance, efficiency and total cost of ownership, the drive to standardization will occur based on a leading European position in DC power technologies and components, variable-speed motors in DC HVAC systems, solid-state lighting and more.
The highly competitive market of power electronics and components for DC-based systems clearly shows that, if aggressively enough addressed, Europe can take and hold a leading position. With the leading positions in renewable energy installations (solar, wind) and solid-state lighting, together with the full value chain on power electronics manufactured in Europe, the DCC+G project can counterbalance less-efficient 48V DC-grid standardization efforts from the USA. So new jobs for high qualified people are created and general costs of living are reduced by improved usage of our energy recourses.

[2] US Department of Energy, Office of Energy Efficiency and Renewable Energy (2009) *2009 Building Energy Data Book.* ., http://buildingsdatabook.eren.doe.gov/DataBooks.aspx