



POWER ELECTRONICS SOLUTIONS FOR DISTRIBUTED POWER GENERATION

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Abstract: *Distributed power generation is a new technology which becomes interesting for the increasingly deregulated power markets. Power electronics has the potential to play a very important role in this field. This paper will present an overview of distributed power generation technologies and suitable power electronics solutions together with the state of the art and trends.*

Key Words: *Modular Solutions, PEBB, Virtual Utility*

1. INTRODUCTION

At present time, there is a growing demand for clean, good quality power (with respect to availability and harmonic content) that is also reasonably priced. At the same time in many countries the economical and environmental concerns make it increasingly difficult to erect large new power plants and transmission lines. Due to these problems both production and transmission bottlenecks occur in various regions. These bottlenecks can be perhaps best solved by introducing the distributed power generation (DPG) concept, with units that are relatively small in size and can often produce not only electrical but also thermal energy.

What is common to the DPG approach is that the DPG units

- are relatively inexpensive, easy to install and produce electricity without much environmental impact,
- there is no need for increased transmission and distribution capacity because the energy is produced and consumed locally.

There is a variety of technologies applicable for DPG. What all these technologies have in common is the need for a power conditioning system (PCS) most often in the form of a power electronics converter as an interface between the generator and the grid and/or the load. Interestingly enough, due to the flexibility of power electronics solutions the DPG units can also be configured to serve various power quality functions as well. For example, they can work as uninterruptible power supplies (UPS), power factor correction circuits and can even be used as active filters. Because it is difficult to envision all the possible applications it is

perhaps a good strategy to build modular and scalable systems. Fortunately these are also the industry wide trends.

The following chapter will outline the field of DPG, then the utility level issues will be discussed while the power electronics solutions will be treated in some detail after that. Finally, the future trends and outlook in the field of DPG and power electronics will be summarized.

2. DISTRIBUTED POWER GENERATION TECHNOLOGIES

The most important technologies for distributed power generation and their typical power ranges are summarized in Table 1. Among other possibilities, marks are given for maturity and potential. From a short-term business point of view, most interesting technologies are the ones that have a mark 1 in maturity and mark A or B in potential. The characteristics of each of the above technologies is given in the following sections:

2.1. Microturbines

Microturbines are one of the most promising DPG products currently on the market. The key technical features are:

- High efficiency (as high as 85%)
- Low emission (< 15ppm NO_x and CO)
- Fuel flexibility: oil, diesel, natural gas, biogas, methanol, hydrogen, etc.
- Low maintenance cost (high speed single shaft engine and static power electronics converter)
- Remote control of power production available

Typical applications for microturbines are industrial, commercial and public buildings, large residential buildings, fun parks etc. Microturbines always require a power electronics interface to connect them to the power distribution grid. Most attractive applications for microturbines make use of the thermal energy as well. For example, Fig. 1 shows the microturbine MT100 providing electricity and heat to the ABB Corporate Research Center in Dättwil.

Table 1. Most common technologies for Distributed Power Generation.

DPG technology	Power range (kWe)	Maturity	Potential	Cost of Energy (cents/kWh)
Mikroturbines*	20 – 1000	1	A	6 – 8
Windpower	500 – 5000	1	B	3 – 4
Fuel Cells*	4 – 250	3	C	6 – 8
Solar- electric*	5 – 25	2	C	18 – 20
Small Hydro	1 – 1000	2	C	10
Gas Engines*	50 – 6000	1	B	< 6
Diesel Engines*	50 - 5000	1	B	< 4

Maturity scale: 1 selling at competitive price, 2 Selling non competitive, 3 prototypes available.

Potential: A = PE enabled solutions available, B = opportunity for PE solution, PE required but long term (data from [1, 2]). Technologies with an asterisk are combined electricity and heat generating.



Fig. 1. ABB MT100 microturbine.

2.2. Fuel Cells

Fuel cells generate electricity and heat from various fuels by an electrolytic process. Depending on the electrolyte, several fuel cell types exist and are at different stages of development. Operating temperature, fuel type and cost influence the application of each particular type of fuel cell. A good overview can be found in [3], [4]

Generally, a fuel cell delivers a low voltage, high current DC power. Due to this, a power electronics system is always an integral part of a fuel cell. For some types of the fuel cells heat is a byproduct which should be used for economical and ecological reasons.

2.3. Windpower

Windpower is one of the most promising technologies in many respects. It is predicted by several independent sources that wind turbine installations will drastically increase for the next two decades [5, 6]. Through well funded public programs this technology is advancing rapidly. The trend in wind turbine development is clearly towards higher power and wind park solutions. The main distinctive features of the wind park approach are:

- Megawatt energy level
- Connection to MV or LV grid
- Typical users are larger utilities
- Fully renewable

Due to the increased noise level in the vicinity of the windmills the tendency is to place the windparks offshore. In addition areas of constant wind speed of

sufficient magnitude are found mostly offshore, and the offshore installations do not impact the landscape.

With offshore windparks, the energy has to be transported up to 60km to the mainland, which requires medium or even high voltage levels. Historically most windmills were in the 100 kW range. As we shift towards multimegawatt windmills specified for the harsh sea environment, gearless solutions are the choice and here naturally power electronics have to be used.

2.4. Gas and Diesel Engines

Almost all of today's diesel and gas-powered generators are running at constant speed with synchronous generators and make no use of thermal energy. Building on the experiences of hybrid electric vehicles programs an increased use of power electronics for this type of generator units can be expected to bring improved efficiency, flexibility, increased lifetime and reduced emissions.

2.5. Solar-electric

Photovoltaic panels usually deliver a low voltage, low to high current as input for a power conditioning interface. As in fuel cells, solar cells can not be connected to the grid without the use of a power electronic interface.

3. UTILITY LEVEL ISSUES

Clearly DPG impacts the distribution of power. All Equipment that intended to be connected to the public grid must fulfil numerous global and local regulations for safety and stability. Unfortunately there is still a long way to unified policies.

3.1. Aspects of Interconnection

The following technical and non-technical aspects have to be addressed:

- Due to technical limitations of the grid local producers are often not allowed to feed more than 100kW back to the grid.
- During maintenance of the grid reverse power flow has to be prevented (islanding protection).
- Requirements for power factor, voltage and current harmonics, etc. have to be met.
- Metering of produced energy.
- Complex authorisation procedures.

The most important technical aspects to be considered are voltage distortion limits and harmonic current limits (see Fig. 2 and 3).

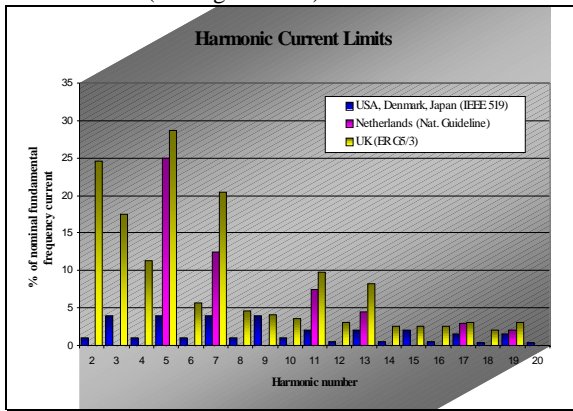


Fig. 2. Harmonic Current Limits

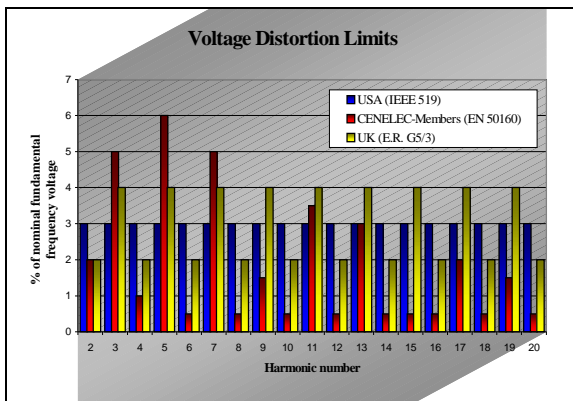


Fig. 3. Voltage Distortion Limits

3.2. Standards and working groups

The following standards are currently discussed in the different working groups:

- CENELEC EN 50160 describes the voltage characteristics of electricity supplied by public distribution systems.
- IEEE P1547 draft 05 aims at providing functional, technology neutral technical requirements.
- IEEE 929-2000 collects major technical interconnection requirements for photovoltaics.
- IEC 1000-3-3 specifies the limits of voltage fluctuation and flicker in low voltage power supply systems for equipment with rated current up to 16A.
- IEC 1000-3-5 corresponding standard for > 75A.
- IEEE 519 is also applied for DPG, defining harmonics, unbalance and sags.
- UK engineering recommendation G.59/1 requires specific studies for each project below 20kV and 5MW.
- UK engineering recommendation G.5/3 specifies voltage distortion.

A lot of regulatory and scientific focus has been on protection. Generally grid connection without reverse power flow has no impact on protection. When feeding back, protection concepts have to be adapted.

This only emphasises the importance of the very flexible solutions that can support the adaptations required from the system- and DPG unit-suppliers.

4. POWER ELECTRONICS SOLUTIONS

As outlined in the previous chapters, power electronic solutions are increasingly viewed as enabling technology for many applications in the DPG area. As the number of applications continue to increase using modularized systems might be the only way to economically cope with the multitude of new applications.

4.1. A modular PEBB approach for DPG

A concept of modular Power Electronic Building Blocks (PEBB) [9, 10] has been studied and is being introduced to cope with present as well as still unknown future applications of power electronics for generation and distribution. A set of PEBBs usually consists of one or more scalable power conversion blocks and one or more scalable control systems. Once the PEBB approach is mature, it is expected, that also auxiliaries such as circuit breakers, application dependent passive elements (e.g. filter) and secondary cooling equipment will become a part of the block-set.

Unlike digital technology, where people usually abstract to uni-dimensional "layer models", power electronics exists in at least three dimensions: *power, control and cooling* (see Fig. 4). Control resembles most the digital world, while issues of power scaling and power flow (interconnects, insulation, scalability) will have their analogies in transmission and distribution.

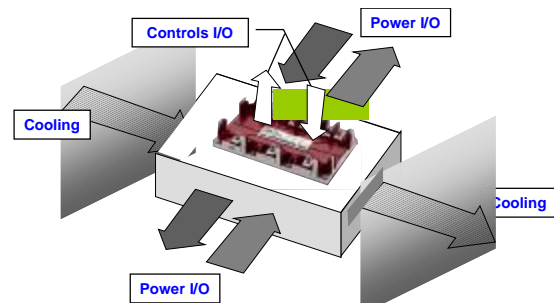


Fig. 4. The three dimensions in which a PEBB have to be defined: power, cooling and control.

4.2. PEBB Dimension I: Power

The biggest challenge in defining a family of PEBBs is probably the power scaling capability. Today's available technology is clearly limiting the possibilities. While modern power devices like IGBT can be paralleled, series connection is usually not so straightforward. This means that most power devices technologies have their designed area of application and for that reason one family of PEBBs can not be extend over more than one voltage range, limiting somewhat the scaling options.

This restriction leads to at least two families of PEBBs for DPG: one for low voltage and one for medium voltage. A low voltage PEBB makes use of 1200V or 1700V IGBT technology. For medium voltage level a good example is ABBs "Megawatt-PEBB" based on the IGCT devices, Fig. 5.

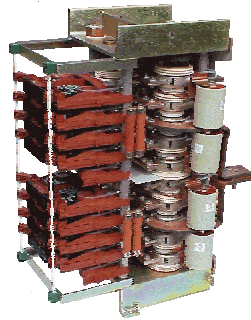


Fig. 5. ABB's Megawatt-PEBB: 4500V, 1200A valve with standardized interfaces.

It has been decided to base the family of DPG PEBBs on LoPak4 and LoPak5 IGBT modules. This gives two basic PEBBs, from which to derive any application-specific main-circuit. In addition, a main-circuit PEBB always includes its portion of the DC-link, current sensors as well as a temperature sensor for low-level protection. Fig. 6 shows few examples and the achievable rated powers, along with a power density estimate (including DC capacitors). Each LoPak is either used as a three-phase converter, or as a phase-leg.

Clearly, the level of modularization is also different for MV and LV. In low voltage, PEBBs are usually phase-legs or three-phase power conversion units. In medium voltage, it is rather a single valve, which does not exclude that these blocks are grouped to again form modular sub-units. To explain the concept, we focus on LV PEBBs from ABB.

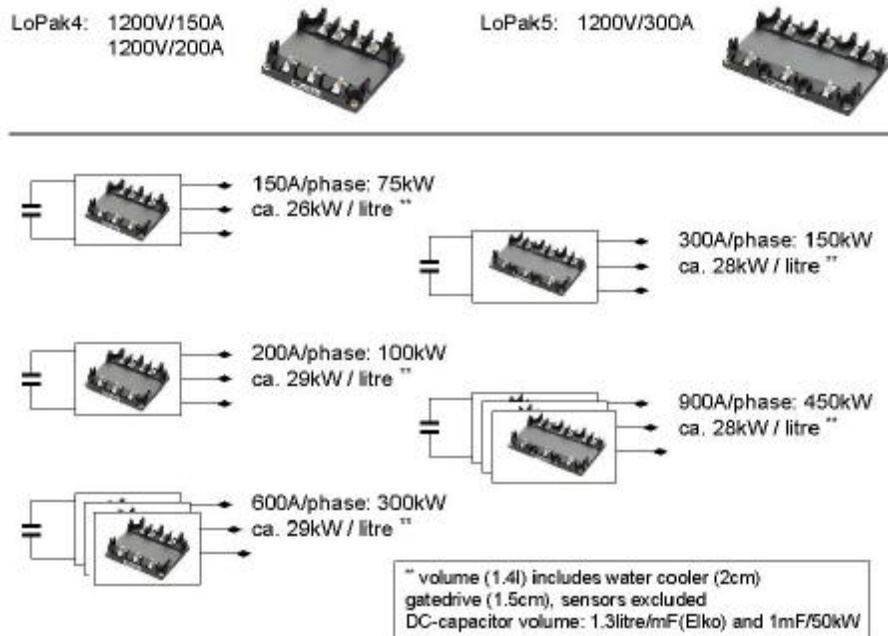


Fig. 6. Rated power and approx. power density for PEBBs based on LoPak4 and LoPak5.

4.3. PEBB Dimension II: Control

Control is divided into four layers in order to get modularity and scalability Fig. 7. The lowest layer, the so-called hardware manager comprises the gate drive with fast low-level protection, current sensors and signal conditioning electronics. The hardware-manager is sometimes also referred to as switch-controller and is usually a purely analog hardware. Power scaling takes place on this level.

The next level is defined as the topology manager. It plays the role of an abstraction layer, which hides all topology dependent details such as nominal currents, hard- or soft-switching, etc. It carries also the analog to digital conversion of measurement signals. Its second function is to synchronize different control boards in order to get scalable computational power on the next higher levels.

The application manager on the next level is representing the classical "inner control loops". It may for example make the block look like a controlled voltage source or like a controlled current source. Any modulator would also be part of this layer and less time critical protection like over-temperature and over-current are also dealt with here.

Finally, the system-control will only see a set of almost ideal power conversion blocks and provide the DPG relevant functionality. It will also interact with the outside world and e.g. ensure economic operation or ensure electrical system compatibility with other units on the same grid.

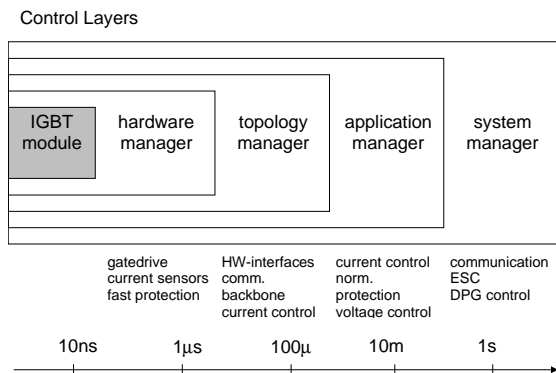


Fig. 7. Layers of control and their typical time constants.

In a practical application, not all the managers have to be individual pieces of hardware. Looking at the typical complexity, it is natural to combine the application and the system manager on one physical board and not to specify the interface between them. However the other interfaces should be defined and physically accessible. The interface from application to topology manager is typically a digital parallel interface. The interface from topology to hardware manager combines analog signals (e.g. current measurements) with digital signals (e.g. gatesignals, faults).

4.4. PEBB Dimension III: Cooling

For technical reasons, cooling is maybe the most difficult to be standardized. On the other hand, non-standard cooling interfaces do not add too much to engineering cost.

5. OUTLOOK

It is now realized that standardization could open up new and exciting markets to power electronics. On the other hand power electronics could provide efficient and almost total control of electric power to many users. The main reason for such an optimism lays in the combination of market factors such as increased demand for power electronics solutions on one side and the informal agreement on integration and modularization in industry on the other hand.

Good examples of this development are the common module standard LoPak of ABB and SkiM of Semikron, the design of a PEBB by ABB and the power PowerCage™ developed by Rockwell Automation, the IPEM of Mitsubishi.

It is certain that information technology will enable smarter and more versatile power modules. Recent progress in packaging, sensors and communication will only speed up this process. All this is supported by the almost limitless capabilities of digital control, and the fact that system engineering can be done on a software level.

Finally, a few words about the exciting new markets that demand this new breed of smart, powerful and flexible as well as reliable and easy to use power electronics solutions. Among them a special place

belongs to the concept of what is called virtual utility [1], in which clusters of distributed power generators – often making use of alternative energy sources – are connected together in an intelligent and optimised network controlled by web-enabled systems. As they are small, distributed generation systems can be built up incrementally, avoiding high initial investments and allowing fast payback. Developing countries, in particular, but also numerous niche markets, are set to benefit from the 'virtual utility', Fig. 9.

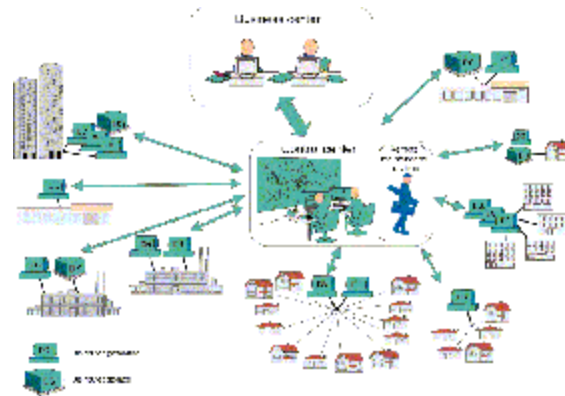


Fig. 9. The virtual utility concept.

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