HIGH PENETRATION OF PHOTOVOLTAIC SYSTEMS IN ELECTRICITY NETWORKS

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Abstract: While the global photovoltaic market is extremely growing and this technology is more and more seen as important future energy supply which will significantly contribute to the electricity generation, current electricity grids are not yet designed to integrate a steadily increasing penetration of photovoltaic generation. This manuscript discusses the main technical challenges as well as the currently ongoing international activities in this field in order to make the electricity grids smarter with a focus on inverter technology as key element in this process.

Visoka stopnja vključevanja fotonapetostnih sistemov v električno omrežje

Kjučne besede: PV sistemi, električna omrežja, pametna omrežja

Izvleček: Medtem, ko globalni trg fotovoltaike ekstremno narašča in fotovoltaika izgleda kot pomemben vir energije v prihodnosti, ki bo pomembno vplivala na proizvodnjo električne energije, električno omrežje ni načrtovano tako, da bi bilo pripravljeno na priključevanje vedno večjega števila fotonapetostnih elektrarn. Članek opisuje tehnične izzive in trenutne mednarodne aktivnosti na tem področju, kako narediti električna omrežja pametnejša. Poudarek je na tehnologiji razsmernikov kot ključnih gradnikov v procesu vključevanja.

1 Introduction

During the last 10 years, the global development of photovoltaic (PV) increased with higher growth rates than ambitious scenarios could foresee, mainly due to ambitious programs in two countries, Germany and Japan.

In the year 2008, for the first time a growth of the annual market of more than 100% was evident as in a number of additional countries support programs began to take effect. In total more than 14 GW are nowadays installed worldwide, most of them grid connected.

Main drivers are the outstanding features of this solar technology like availability of raw material (silicon as second most frequent element on the earth) the wide acceptance of application - even as architectural element in the design of buildings - as well as the clear future perspective of further increasing efficiencies and decreasing prices.

2 PV until 2020

The European Photovoltaic Industry Association as well as other institutions and national aims see market shares of up to 12% PV of the total electric power generation until 2020 achievable. /1/ /2/

The frame conditions to achieve this goal are:

- Cost competitiveness achieved mainly by larger production facilities, improved manufacturing and automatisation, and technological progress like increased efficiencies.
- Market deployment taking into account the added value of PV beyond energy like meeting the peak demand, reducing the burden of environmental cost, reduced fuel price risk, representing a green image and many more./3/
- Policy frameworks which need to be supportive by unbureaucratic feed-in tariffs or other measures until the cost competitiveness is given (grid parity).
- Interaction with other renewable generation in order to meet the whole requirements of the future electricity system mainly by renewable energy generation.
- The supply chain to bring up multi Gigawatt productions for an annual market of up to 160 GW until 2020. The availability of materials, the production capacities and the education needs to follow these strong scenarios of market development.
- Although mainly due to the daytime generation characteristics of PV, most electricity networks can absorb much more PV generation than other fluctuating production, the system integration of huge amounts of PV into the electricity networks needs specific requirements which will be discussed in more detail in the following chapters.

3 Challenges for electricity networks

While photovoltaic as distributed generation from renewable energy resources is seen as key element of future energy supply, current electricity grids are not designed to integrate a steadily increasing share of distributed genera-

tors. The hierarchical network topology was designed for unidirectional power flows and passive operation.

Photovoltaics, even though only currently contributing to less than one percent of the power generation in the overall electricity networks of countries show traditionally a very uneven appearance. This might lead to challenges which firstly appear only in some parts of the network mainly depending on the local condition of the grid.

Overvoltage:

Local distribution networks soon can be fed by solar power to an amount which pushes the local voltage level beyond its limits laid down e.g. in the EN 50160 standards. The overvoltage concern is mostly the top priority challenge in PV interconnection. Overvoltage problems are more likely to occur on rural grid, where the line impedance is higher and the load is relatively low. One solution to overcome this problem is currently used in Japan, where inverters reduce the active output power when a certain voltage threshold is exceeded. However, with this approach, the owner of the PV system is facing disadvantages with reduced income from his PV generation. /4/

The following graph shows the change of a local distribution network from typical passive networks with load only to active networks with bidirectional power flow due to distributed generation in the low (and medium) voltage level.

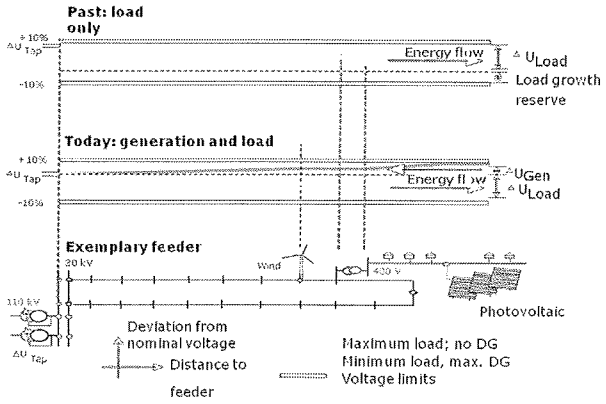

Fig. 1: Transition from passive to active distribution networks /5/

Harmonics:

While the impact of harmonics was a high concern in the beginning of PV grid interconnection, it is now extremely small with the recent advancements in power electronics and other technologies. Meanwhile, modern inverters are even capable to filter harmonics out of the grid, which are caused by various consumer applications.

Safety:

Unintentional islanding in distribution networks due to the presence of PV generation is one of the major safety concerns for the grid interconnection of generators. Although the possibility of unintended islanding operations is very small, the probability to encounter an island is not negligible. The risks involved if unintended islanding does occur are great.

Protection methods to the standard voltage and frequency monitoring are required in order to detect a loss of mains at the generator and ensure the safety of customers and maintenance personnel.

There are significant differences between national interconnection requirements in the recognition of the problem's importance which causes troubles mainly for international inverter manufacturers. /6/

Further aspects:

Beside concerns of the impact to the general voltage level, the behavior during grid faults like voltage sags /7/ and other grid interaction (reactive power, voltage unbalance,...) have to be taken into account at high levels of PV penetration in local grid situations.

Stability problems might occur if simultaneous loss of a large number of distributed PV-generation in higher level networks happens. Therefore, inverters must be able to provide a coordinated and/or local grid management, also to not disconnect at the first occurrence of a grid disturbance.

In order to avoid excessively expensive grid reinforcements, new solutions for active grid operation will be necessary.

The development of photovoltaic inverters, from simple conversion of direct current into the alternating current of the public grid with highest efficiency under sometimes frequently changing solar conditions ("maximum power point tracking", MPPT) to multifunctional inverters now able to support the local grid situation is indeed remarkable:

The new generation of high quality inverters is now capable to actively contribute to grid stability by power and frequency control, reactive power management, coordinated voltage control as well as by a sophisticated fault ride through capability. Power quality is addressed mainly by the already mentioned filtering of harmonics as well as compensation of voltage unbalance in three phase network. An additional function will be to contribute to the short circuit current.

Germany, one of the leading countries in photovoltaic has recently issued the Interconnection requirements for generators connected to the Medium Voltage Network based on the Transmission Code 2007 (TC 2007). This document might show the way of PV interconnection in the future and further encourages or rather makes high demands on the inverter manufacturers to develop innovative products.

4 Positive effects for the electricity networks

Predominantly, the supply profile of PV systems fits well to most of the load profiles in industrial countries with a load peak around noon. The currently increasing application of air conditioning systems leads to the fact that these peaks are getting even higher and higher. The energy demand for Air-conditioning corresponds quite well with the solar irradiation which is directly linked to the power generation of grid connected PV systems.

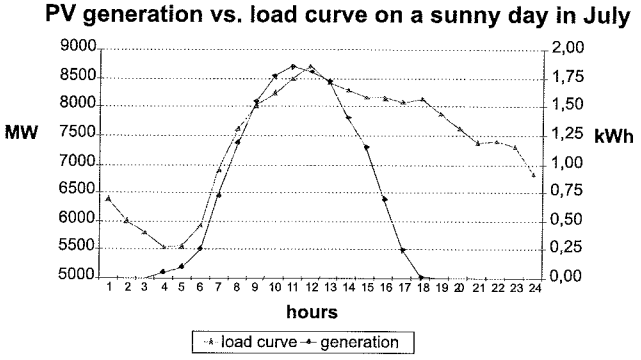

Fig. 2: PV generation versus typical load /2/

Besides matching some peak load situations quite well, there could be some other positive effects for the electricity networks:

- Reduction of network losses due to more local generation and therefore decreased power transmission
- More transmission capacity opens space for other transmission services
- Active network services from multifunctional photovoltaic inverters can support the local network management

However, most of these functionalities will only be effective in high penetration scenarios. /8/

5 Key requirements for electricity networks in order to cope with high penetration of PV

Beside multifunctional inverters as the main link to the electricity network, there are several further requirements for the networks in order to be well prepared for a high penetration photovoltaic scenario:

- The European Technology Platform Smart Grids estimates that until 2030 investments in European electricity networks of approximately 500 Billion Euro will be necessary. In this context, the replacement of old infrastructure needs to be innovative to maximize capacity and functionality for high penetration of photovoltaics and other distributed generation.

Especially the distribution networks will require major communication infrastructure improvements to better make use of the fluctuating generation from photovoltaics by allowing active demand participation.

This "empowering of the customers" comprises the choice of managing the cost and the peak demand by e.g. different tariffs (Time of use, peak pricing,...) communicating programs (e.g. intelligent heating systems), as well as various energy information systems that eases energy saving. Smart metering might play an important role in this context.

- Forecasting programs will allow better PV generation prediction and help to optimize the total power management.
- The use of storage capacities might further help to integrate large amount of PV into the electricity system. The intensive E-mobility discussion we are currently facing with the probability of the future appearance of huge battery capacities need to be more closely linked to the requirements of PV generation.

6 Currently ongoing activities

The International Energy Agency (IEA) has recently started an initiative dealing with "High penetration of photovoltaic systems in electricity networks" within the "Photovoltaic Power System Program" (IEA-PVPS). The new task is currently under development and will bring together experienced researchers, industry and network operators from all countries which show a good development in the penetration of grid connected photovoltaic.

The main topics which are dealt within this new activity are

- PV generation in correlation to energy demand focusing on the consumer behavior to be better linked to the generation profile
- The effects on PV generation to the local grid as well as to the general electricity system
- Smart inverter technology dealing with requirements for inverters at high PV penetration as well as
- Economics and needs in Standardization and Regulation

Modeling and simulation are tackled in this global research initiative as well.

Other activities like the IEA ENARD Implementing agreement (Electricity Networks, Analysis, Research and Development) are dealing with renewable energy integration in distribution networks more generally (ENARD Annex II – DG System Integration into Distribution Networks) or European research projects like: META PV or PV UPSCALE.

In the United States, the Solar Energy Technology Program (SETP), within the Department of Energy Office, conducts research, development, demonstration and deployment activities to accelerate widespread commercializa-

tion of clean solar energy technologies (PV and concentrating solar power /CSP/) across America. Systems integration has placed high importance on working with utilities, industry, and other stakeholders to develop the technologies and methods enabling the widespread deployment of distributed PV technologies, including storage systems, advanced power electronics, and controls, into the U.S. electricity grid.

6 Conclusion

PV in high penetration as significant source of electricity production might appear most probably in the next decade.

However some challenges in interacting with the electricity network needs still to be addressed.

New inverter technology offers a wide range of services dedicated to an unproblematic interoperation of photovoltaic systems with the electricity network.

Generally, the technical solutions seems not to be the main barriers for high penetration of PV, but standardization, regulation as well as new market models needs to be developed. The necessary refurbishment of the European electricity network in the upcoming years should take into account the needs and requirements due to decentralized generation, predominantly by the integration of communication technologies.

International collaboration is already established in order to ease the way and derive benefit from first experiences already made in other countries and regions.

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