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# Integration of Photovoltaic in Distribution Systems

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## Introduction

In Germany, the role of renewable energies in overall electricity generation has gained in importance during recent years. While large wind farms with several MW of installed capacity are often connected to transmission systems, the steadily increasing amount of installed photovoltaic (PV) capacity mainly affects the operation of distribution systems. However, existing distribution system structures were not built to handle high amounts of uncontrolled decentralised PV power feed-in, which can easily lead to violations of technical constraints of the distribution systems in times of high solar irradiation. Some of these constraints are:

- The maximum tolerable voltage rise at the respective points of common coupling (PCC),
- the maximum voltage imbalance between single phases
- the maximum transformer and conductor loading.

Amongst others, all of these constraints have to be taken into account for a reliable and secure operation of distribution systems and the protection of connected loads.

But PV systems do not only negatively influence the operation of distribution systems. On the contrary! If they are actively controlled, PV systems can also be used to support the operation of distribution systems, which offers new technological and economical perspectives for distribution system and PV plant operators.
In recent years, researchers at the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) in Kassel, Germany (former Institute for Solar Energy Supply Techniques (ISET)), have been investigated and developed strategies for a technically and economically optimised integration of PV systems in distribution networks and the provision of ancillary services. Some of these ancillary services are introduced within the following sections.

## Multitalent Photovoltaic Systems

By taking a close look at single components of common PV systems, technical potential for the provision of ancillary services could be identified and investigated for PV systems in recent projects. Multitalent Photovoltaic Systems comprise

a) multifunctional modules
b) multifunctional inverters
c) multifunctional energy storages

a) Multifunctional Modules
Building integrated, multifunctional PV modules can be used to provide additional applications, such as improved building insulation, a contribution to air conditioning and many other functions. (Further information can be found at *www.pv-multielement.de*)

b) Multifunctional PV inverters
Multifunctional PV inverters are not only optimised for feeding-in maximum active power like conventional PV inverters, but are also using innovative control algorithms and techniques to provide ancillary services for distribution system operators and additional functionalities for PV plant operators. Multifunctional PV inverters can actively control their reactive and active power output in different time domains.

c) Multifunctional energy storages
Concerning a proper distribution system operation the majority of technical problems arise from the fact that PV energy production and feed-in directly depends on meteorological conditions. Even in combination with multifunctional inverters, conventional PV systems can only offer active power control if sufficient energy is generated at the moment of request. The availability of PV energy can be significantly increased if storage devices are added, because the PV energy can be locally stored and fed-in when needed.

Figure 1 gives an overview over the most promising control capabilities of multifunctional PV systems combining multifunctional inverters and energy storages.

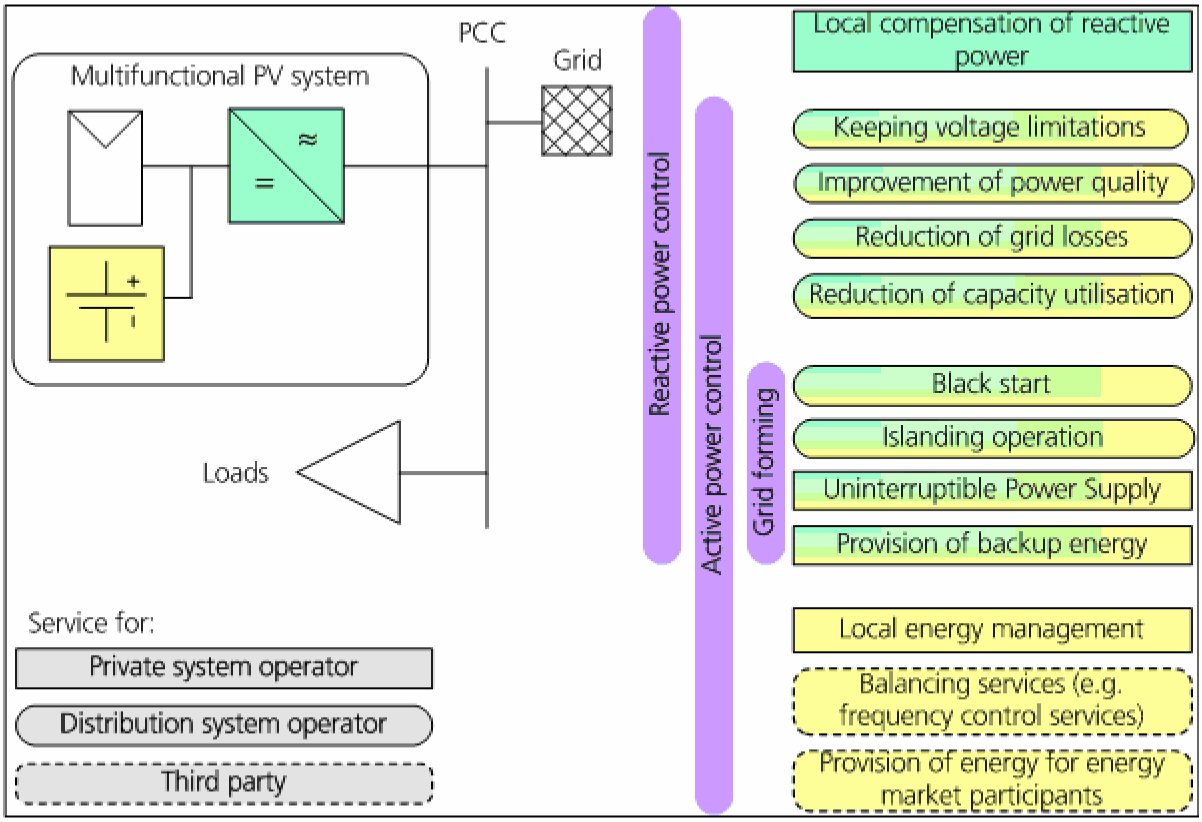


Figure 1: Multifunctional Photovoltaic system and its control capabilities. © Fraunhofer IWES

In combination with multifunctional inverters and energy storages, PV systems offer additional services for

a) private system operators,
b) distribution system operators and
c) third parties (e.g. energy market participants).

a) Additional services for private system operators

- Local compensation of reactive power: By providing reactive power at its point of common coupling (PCC), the reactive power demand of commercial/ industrial loads can be compensated and penalty payments can be avoided [Braun, Geibel 2009].
- Uninterruptible power supply: Important loads can be secured against short-term electrical power outages by innovative inverter control techniques [Braun, Stetz 2008], [Landau et al. 2009].
- Provision of backup energy: In case of long-term electrical power outages, multifunctional energy storages in combination with multifunctional inverters can provide energy and grid forming capabilities for backing up important loads [Landau et al. 2009].
- Local energy management: Multifunctional energy storage systems can shift PV energy in order to optimise the self-consumption of PV energy [Braun et al. 2009a] or to reduce peak loads [Braun, Stetz 2008].

b) Additional services for distribution system operators

- Keeping voltage limitations: Active and reactive power control can contribute to keep voltage limitations within boundaries [Braun et al. 2009b], [Braun et al. 2009c], [Braun, Büdenbender 2009].
- Improvement of power quality: Active and reactive power control can reduce voltage imbalances, voltage flicker and harmonics within the local distribution system [Geibel 2009], [Jahn 2007].
- Reduction of grid losses: Local active and reactive power provision can reduce vertical power flow from upstream systems to consumers and vice versa and hence reduce active power losses within conductors and transformers [Braun et al. 2009b], [Braun, Büdenbender 2009].
- Reduction of capacity utilisation: Local active and reactive power provision can reduce the load on network equipment and hence increase the available capacity of the distribution system.

c) Additional services for third parties

- Contribution to balancing services: Energy for balancing services (e.g. frequency control) can be provided to a transmission system operator by PV systems including energy storages [Braun, Stetz 2008], [Braun 2009].
- Provision of energy for energy market participants: PV systems including energy storages can provide energy services to third parties such as energy suppliers, energy traders or virtual power plant operators who are active on power exchange markets (e.g. the European Energy Exchange EEX) [Braun, Stetz 2008], [Braun 2009].

From a technical perspective, multifunctional PV systems with multifunctional inverters and multifunctional storages can provide local energy and ancillary services to distribution system operators, to private system operators and to third parties in the energy supply sector. However, the economic efficiency of these additional functionalities must not be neglected, neither for the owners of the PV plants nor for the distribution system operators. One example for such an integrated investigation is introduced in the next section.

## Consideration of economical aspects

## Optimal reactive power supply by photovoltaic

As a reaction to the steadily increasing amount of installed generation capacity in low voltage networks, German distribution system operators are currently working on a renewed issue of the guideline for the connection and parallel operation of generators in low voltage networks. One of the expected changes for generators (e.g. PV systems) is to provide reactive power in order to keep the local voltage within limitations.
In [Braun et al. 2009b] different possible reactive power supply methods, derived from the German guideline for the connection and parallel operation of generators in medium voltage networks were investigated especially for PV systems to show their

respective technical effectiveness to reduce voltage rises as well as their economical efficiency. The investigated reactive power supply methods are

- a fixed power factor,
- a function where the provided power factor depends on the current active power output of the inverter (cosφ(P)-function),
- a fixed amount of reactive power, and
- a function where the provided amount of reactive power depends on the terminal voltage at the respective point of common coupling (Q(U)-function).

It could be shown that an additional reactive power demand by PV systems is basically capable to reduce the maximum voltage over one year, so that an expansion of the exemplary distribution system can be avoided. From an economical point of view, it turned out that operators of PV systems have to bear the highest share on the total additional costs by reactive power. Amongst others, the sizing of future PV inverters, with the capability to provide reactive power, could be identified as one of the major influencing factors for the height of the total additional costs. Its optimisation is now an element of current project activities.

## Conclusions

Power generation based on renewable energies is an important element of a sustainable energy supply, but their continuously increasing share on the total energy generation presents new challenges, especially for a secure and reliable grid operation. The controllability and flexibility of multifunctional PV system offers a wide variety of ancillary services and hence can be actively used to support the grid operation in future networks.

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