Provision of frequency related services from PV systems

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Executive Summary

Solar PV in combination with Windenergy and dispatchable Renewable Energy Sources (such as Hydro and Biomass) are becoming globally the most important energy sources for the future electricity supply and the share of fossil fuelled bulk power plants with rotating generators will decrease strongly. Thus, solar PV systems as well as other inverter coupled generators (e.g. Windturbines) and storage units must take over additional grid supporting tasks of conventional power plants in order to allow for secure and stable operation of electrical power systems at all times.

This report aims to present the status and the potential of distributed solar PV and PV hybrid systems with respect to provision of frequency related services. Very large PV systems, which must be connected directly to bulk power systems (e.g. to EHV level) and its specific requirements are not considered in this report.

Due to a wide range of technical and economic advantages, Alternating Current (AC) technology has become established worldwide for public electrical power supply over the past 150 years. In order to keep the grid frequency in such AC power systems stable, it is mandatory to assure an electrical active power balance in the entire supply area, i.e. to adjust at any time the active power generation to its demand. PV systems with its capability to adapt its active power generation can thereto contribute very well to frequency stabilisation, although they have certain limitations such as dependency on solar irradiation, response speed or fast frequency measurement.

Depending on the legal background of the electricity supply and especially the power system market design in the various countries, the frequency control / balancing energy products specifications and designations are different, but the physical principles in the background are equivalent. In the European Union five different power balancing / frequency control services/products have been defined and traded on the power balancing markets:

a. Operating or Spinning Reserve
b. Frequency Containment Reserve (FCR) or primary control reserve
c. Automatic Frequency Restoration Reserve (aFFR) or secondary control reserve
d. Manual Frequency Restoration Reserve (mFFR) or tertiary control reserve
e. Replacement Reserve (RR)

With increasing share of PV power its importance for securing a stable power system frequency has become obvious and the development and implementation of frequency related grid code requirements for PV systems in various countries took place during the last 10 to 15 years.

The automatic reduction of active power feed-in of PV systems in case of overfrequency situations, so-called Limited Frequency Sensitive Mode – Overfrequency (LFSM-O) was introduced in some countries since more than 15 years and is nowadays a mandatory requirement for all PV systems in nearly all European countries and beyond.

Simultaneously with the strong increase of grid connected stand-alone Battery Energy Storage Systems (BESS) or combined PV-BESS systems requirements for the automatic increase of active power feed-in during underfrequency events – Limited Sensitive Mode-Underfrequency (LFSM-U) were developed and implemented in the latest network codes of different countries.

PV Systems already today have the technical capabilities to provide various frequency related grid services: Reduction of active power generation in case of overfrequency and – in combination with BESS – automatic increase of their output in case of underfrequency.

Furthermore, Frequency Containment Reserve (FCR) is an important frequency support service. Although this feature is procured on balancing markets, its specification has been introduced in some network codes, for instance like in the German HV network code for connection of generators.

The transition from grid-following to grid-forming operation – already foreseen in upcoming revisions of selected grid-codes – will enable PV systems to provide the full set of frequency services, analogue to services today provided by rotating generators.

Power system stability studies from Transmission System Operators have clearly shown, that during the next years and decades the probability for the provision of pre-defined inertia constant is decreasing and the time periods with less than this inertia value are strongly increasing. Thereto, it is especially in low inertia and inverter dominated power systems absolutely necessary, that any active power imbalance would be reduced as soon as possible by means of activating very fast active power reserves, such as Synthetic Inertia (SI) or Fast Frequency Response (FFR). They are currently not mandatory requested in Grid codes, but in the current draft of the lately revised European grid code Requirements for Generators (RfG) from 2023 both requirements are foreseen for inverter coupled power stations with rated capacities exceeding certain limits.

The case studies presented in this report successfully demonstrate the capabilities of Solar PV to provide a wide range of frequency related services in real-world power systems environments.

The five selected projects/case studies have clearly demonstrated that PV Systems solely or esp. in combination with BESS are able to provide different types of frequency related grid services.

PV systems equipped with grid following PV inverters must contribute to certain services such as the reduction of active power generation in case of over frequency situations (LFSM-O). In combination with Battery Electric Storage Systems (BESS) they are also often requested to increase their active power output if an underfrequency event occurs (LFSM-U).

Furthermore, it can be stated that the LFSM-O/U response times of PV inverters and BESS systems are remarkable shorter compared to rotating generating units such as steam plants or CHP units. This short response times allows PV and BESS systems in principle to contribute to Fast Frequency Response (FFR).

The emulation of intrinsic inertia of synchronous generating units and rotating loads using the grid coupled power inverters of RES power stations is often called Synthetic Inertia (SI). This is one of the most important capabilities of Grid Forming Inverters (GFI) and provides nearly instantaneously active power proportional to a frequency gradient (ROCOF) value.

The provision of fast frequency services and synthetic inertia by PV systems (with or without batteries) will become very important in near future, especially in supply areas which are dominated by inverter coupled generators.

Clearly and precisely stipulated requirements as well as standardized testing procedures are a key for compliance assessment of different PV systems and for comparison of its contributions to frequency related services.

Fast frequency services by PV systems using grid following inverters are currently either a mandatory requirement for large PV Plants connected to HV or EHV networks or on the other hand could optional be offered on power balancing markets (depending on power market design).

A similar approach (grid code requirement and participation on the power balancing market) would be also suitable for the introduction and implementation of the very fast frequency services of grid forming inverters (GFI) such as Synthetic Inertia (SI) provision.

Concluding it can be said that the results of the described case studies are promising, but further research and demonstration projects are necessary esp. for implementation of these frequency related services, which come along with Grid Forming Inverters (GFI).