"Grid forming" is a generic term for many functionalities and ancillary services that can be provided by the PE based systems and equipment, e.g., black start capability, synthetic inertia, VSM, contribution to short circuit current, ...etc.

- *Does the industry need to develop a standard definition of grid forming functionalities including details of controls, response time, ramping rate?*
- *Which challenges are foreseen with large integration of PE-based ancillary services? What industry contributions are needed to enable large integration of PE-based ancillary services?*
- *The number of VSC grid forming converters (GFM) is still very limited to pilot projects around the world and very conceptual EMT simulations. What is the experience of these VSC GFM projects?*

In order to achieve an industrial deployment of the Grid Forming (GFM) solution, a common understanding of its definition among stakeholders is certainly needed.

In the WP3 of the OSMOSE H2020 project, we first proposed to clearly differentiate the features related to technical capabilities, more relevant for Original Equipment Manufacturers (OEM), from the ones that falls into the service category addressed to the providers. **Grid forming capability** is then defined as a set of technical requirements suitable for specifications or grid code implementation such that: *a grid forming unit shall, within its rated power and current, be capable of self-synchronise, stand-alone and provide specific* ***synchronisation services*** *which includes synchronising power, system strength, fault current and inertial response.* Therefore, a GFM unit, by definition, does not rely on grid conditions to synchronise (it can operate at a wide range of short-circuit ratios and inertia levels) and will help others to maintain synchronism under stressful conditions, while still complying with the general requirements applying to the specific technology.

Second, existing ancillary services, which include balancing services[1], but also non-frequency ancillary services[2] (shown in yellow in Fig. 1 proposed by the OSMOSE WP3 project), can be provided by any source, independently of its synchronisation mechanism in normal operation: this includes synchronous machines and Power Electronic Interfaced (PEI) resources such as Power Park Modules (PPM) or HVDC systems. In particular, regarding black start capability, it can be today provided by assets that normally operate in Grid following mode (Gfol) but that can be switched to Vf mode to perform network recovery. With respect to GFM capability, we can quote GC0137: Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability which states that "a Plant with a Black Start Capability would be required to have a Grid Forming Capability", however the contrary is not necessarily true. Not all GFM units shall be requested to provide black start capability. More generally, no capacity reservation or overload capability should be associated to the GFM capability, neither the provision of traditional ancillary services such as primary voltage and frequency regulation or new stability services like the enhanced frequency response entailing firm energy requirements. Only the new synchronisation services (shown in blue in Fig. 1 and added to the existing "inertia for local gird stability") are expected to be provided by a unit linked to its GFM capability.

[1] Frequency Containment Reserve (FCR), Frequency Restoration Reserve (aFRR) and Replacement Reserve (RR)

[2] Steady state voltage control, fast reactive current injections, inertia for local grid stability, short-circuit current, black start capability and island operation capability according to Directive (eu) 2019/944.

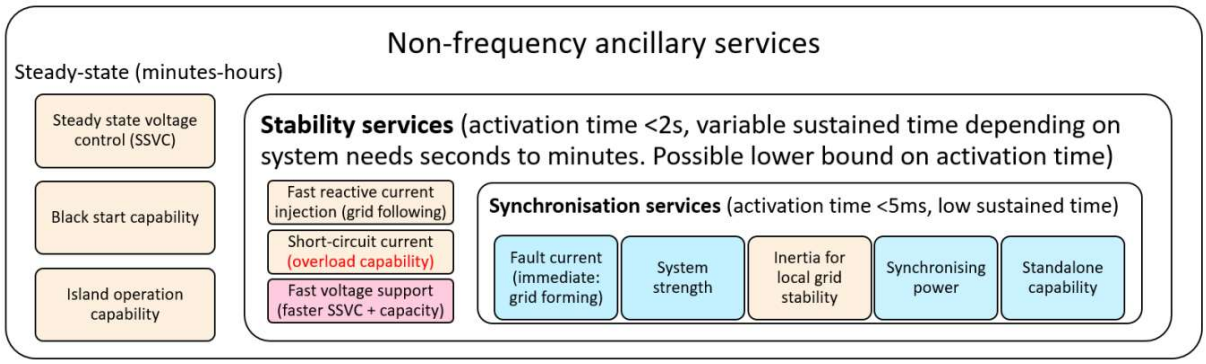

Figure 1. Defining synchronisation services as new non-frequency ancillary services

Finally, depending on the subset of synchronisation services that a given unit can provide, we propose to classify them in 4 types as illustrated in Fig. 2, such that a synchronous machine is, by construction, a type 4 GFM unit while Energy Storage Systems (ESS) would fall in the type 3 category. Wind Power Plants (WPP) could provide type 2 or 3 GFM capability depending on the operating point and the specific sustained time required for the inertial response provision while PV PP, HVDC systems (at both side simultaneously) or STATCOMS could be designed to provide type 1 GFM capability.

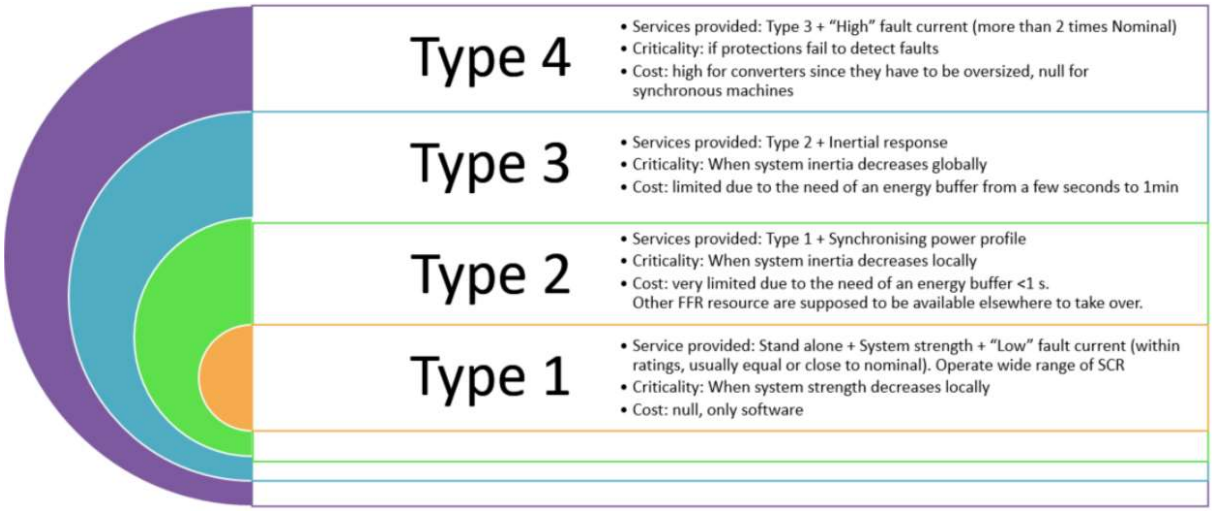

Figure 2. Types of GFM as a function of the synchronisation services they are able to provide

Pilot projects have demonstrated the technical feasibility of providing type 3 GFM capability with a battery ESS (Dalrymple ESCRI-SA Battery Project in Australia) and even a WPP (Dersalloch project by Siemens Gamesa Renewables Energy and ScottishPower Renewables). OSMOSE WP3 proposed a compliance testing procedure based on Transient Fault Recorders (TFR) used on a Power-Hardware-in-the-Loop (PHIL) platform as well as Key Performance Indicators (KPI) to access the beneficial impact of the inertial response provided by PEI ESS on the system frequency stiffness based on PMU measures with respect to a Gfol system.

In the following, new control solutions to provide Type 1 GFM capability with VSC stations with really low energy storage (PV, HVDC, STATCOM or even PEI loads) are expected to be proposed by OEM. Transmission System Operators (TSO) are working on standardising technical requirements applying to this technology and defining system needs (which resources shall provide such capability). Finally, capacity allocation and remuneration mechanisms for certain synchronisations services (such as the inertial response) could be investigated to incentivise the upgrade of certain facilities (for instance PV plants) to a "higher" type of GFM unit (become type 3 by adding storage) if considered necessarily in a given systems.