An improved decentralised coordinated control scheme for microgrids with AC-coupled units

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Abstract

Microgrids (MG) are characterised by their need to cover many different control objectives and to perform according to the well-established standards (e.g. EN 50160) regardless of their connection status to the main grid. Especially in case of inclusion of Renewable Energy Sources (RES) in a MG, additional control designs must be explored in order to harvest the maximum energy that can be provided at a particular set of weather conditions. According to the nature of each Distributed Energy Resource (DER), different control schemes must be employed. Regarding RES, maximum power point (MPP) controllers are massively employed. Commonly, while connected to the grid, RES assets are operated in MPP and thus in P-Q mode. However, when the MG is islanded, in order to ensure that the MG operation will not be jeopardized by potential excess of power, in most cases RES generation/output is curtailed. On the other hand, in regards to Energy Storage Systems (ESS), various control schemes have been employed over the years based on State-of-Charge (SoC) balancing or specific charging and discharging C-rates [1].

In order to design an integrated unit control coordination scheme, it is imperative to take into account individual control aspects and their inbetween interaction . In such schemes, the most vital control objective is proper power sharing, which is often accomplished via variants of droop controllers, master-slave techniques or hybrid combinations of those [2]. Coordinating such control schemes highly depends on the MG architecture, namely whether the RES and ESS are DC- or AC-coupled, meaning coupling on a common DC bus between the unit's DC/DC converter and its respective inverter or directly on the AC bus. The majority of existing literature proposes coordinated control schemes for DC-coupled RES and ESS units [3]. Such a configuration, whilst convenient for tight regulation of the DC bus voltage, is not always applied in real site MGs. Nonetheless, AC-coupling configuration poses additional challenges in designing coordinated control for the MG units because extra care must be taken for the regulation of the voltage of each unit's DC bus which affects the overall MG stability. Especially in case of small-scale MGs, where the amount of controllable units is limited and thus, there is no guarantee that at all times and regardless of the ESS state, a unit can act as grid-forming. On the contrary, in the limited cases where coordinated control schemes for AC-coupled units have been proposed, there are still aspects that require extensive research for real-life applications, such as [3] considers that each unit's DC bus is a stiff voltage source or [4] handles only one operational mode at a time without hotswap during transition from grid-connected to islanded and vice versa.

This paper proposes a coordinated droop-based control scheme for AC-coupled units. During grid-connected mode (Fig. 1a), the PV is operated in standard P-Q control, injecting its MPP, while the ESS control is comprised by multi-segmented, adaptive reversed droop. The droop segments are defined by the operating mode (i.e. charging or discharging) and the segment inclinations is determined by the chosen C-rate and current SoC. On the other hand, during islanded mode (Fig. 1b), PV follows a reversed MPP-adaptive droop, which limits the output power in case frequency increases higher than the nominal, whereas the ESS is controlled as a grid-forming unit, according to a multi-segmented droop curve.

The proposed control scheme has been applied on a small-scale MG, equipped with AC-coupled PV and ESS. MATLAB/Simulink simulations have been realised using detailed physical form models in order to assess the actual

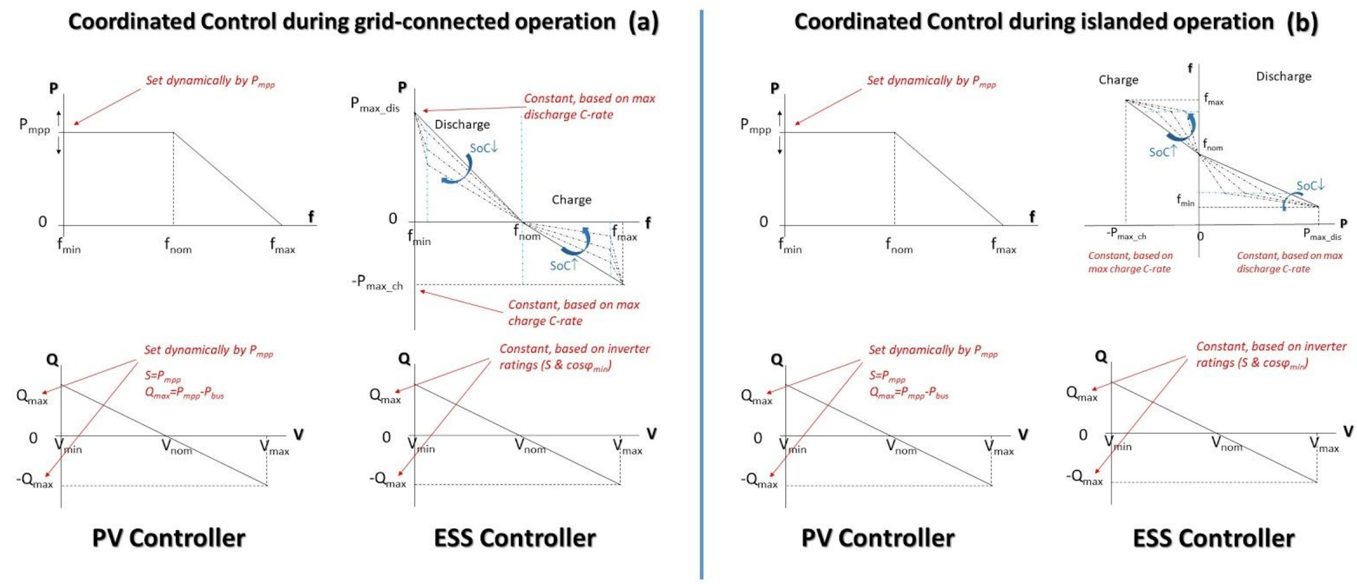

Figure 1. Overview of the proposed coordinated control for the PV and ESS during grid-connected (a) and islanded (b) operational modes.

dynamic response of the units in both grid-connected and islanding modes. The control of the PV comprises of a three cascaded loop design with different response times (current, power loops along with a lead compensator for the DC bus voltage regulation). The ESS control module contains a hot swap system that is able to switch between control schemes according to the operating mode (charging, discharging, grid-connected, islanded). It is composed of a two-branch cascaded loop system: the first branch, similar to the described controller of the PV, is assigned at the grid-connected mode while the second branch is energised during islanded operation and it's composed of the well-known cascaded loops of voltage-controlled voltage-source inverters which are lead by the proposed droop controllers. It is noted that control modes are changed automatically and without the use of a centralised controlled or any kind of bus signaling/ communication channels via a locally computed algorithm based on frequency sensing at the terminals of each unit (PV or ESS).

Preliminary simulation results demonstrate that power sharing accuracy among the units is improved compared to conventional drooped or master/slave control concepts. Additionally, the system has been tested during varying weather conditions and thus volatile power generation from the PV. During this test, the proposed controller managed to compensate the lack of power by demanding power from the batteries whilst protecting them from excessive discharge rate. Finally, the system is able to initiate black start since specified sequence is pre-programmed in the unit controllers.

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