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Integrated micro-generation, load and energy storage control functionality under the multi micro-grid concept

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ABSTRACT

Large scale integration of micro-generation, together with active loads and energy storage devices, under micro-grid and multi micro-grid concepts, requires the adoption of advanced control strategies at different distribution network levels. This paper presents advanced control functionality to be housed at high voltage (HV)/medium voltage (MV) substations and to be used to manage micro-generation, active loads and energy storage, subject to different constraints. Some of these constraints involve inter-temporal relations, such as the ones related with energy storage levels in consecutive time moments. This functionality is specially oriented to deal with stressed MV network operation involving overload and excessive voltage drops situations.

1. Introduction

The technology advances together with environmental concerns have paved the way for future increased penetration of micro-generation (μG) together with active demand side integration. Since renewable power resources are geographically distributed and are characterised by some variability, it is necessary to develop flexible solutions to manage the electric distribution network when integrating namely large amounts of small and μG units that exploit different sources, like renewables [1].

This scenario presents to the distribution system operators (DSOs) several technical and economic challenges requiring the identification of a set of control actions, in which several agents connected to the distribution network can participate. These control measures will facilitate full integration of controllable μG (fuel-consuming units) and non-controllable (renewable) generation units. Micro-grid (MG) and multi micro-grid (MMG) concepts [1] provide a way to manage the complexity that results from this new scenario.

A medium voltage (MV) network with several micro-grids can be managed and controlled using a hierarchical multi-level decentralised management structure as described in Fig. 1. In this architecture, an intermediate control level – the central autonomous management controller (CAMC) – depending from a central distribution management system (DMS), is responsible for the management of the MV network and owned by the DSO [2]. The low voltage (LV) control level – level 3 – is assured through a micro grid central controller (MGCC), an independent grid operator that is in charge of a single MG.

With this architecture, one can develop specific functionality, to be housed at the CAMC level, to deal with stressed MV grid operating conditions, exploiting the existing flexibility of local generation and load. These stressed operating conditions may result from the violation of the following technical restrictions:

- Thermal branch limits
- Voltage drops

as a result of natural load growth or grid reconfigurations.

Local trading mechanisms, such as internal retail market [3], performed at MGCC level, aim towards minimisation of the MG operating cost, considering the controllable μG units' bids together with controllable load/controllable load reduction bids inside the MG and the wholesale market prices. Such trading mechanism grants the controllable μG units with the possibility of selling at higher (than wholesale market) prices while the MG consumers obtain better electricity price due to avoided grid charges for the μG produced and consumed locally [4]. The economic, technical and environmental impacts of such trading mechanism may then be evaluated at LV and MV network level, referring to a set of costs and benefits, if one adheres to the MMG concept [5,6]. At this stage, it is relevant to mention that the MGCC, acting as an aggregator or retailer, aims to supply consumers of a specific geographical area,

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without exporting power to the upstream distribution grid [3]. Nevertheless, in case the MG is encouraged to sell back the excessive energy to the upstream network, the consumers of neighbouring MGs would have the chance of choosing different retailers (MGCCs).

Increased portion of μG may pose challenges to the distribution network operators, namely in what regards increasing network capacities in order to accommodate growing generation capacity levels. Such a cost burden could act as a barrier for integration of additional amount of local generation capacity. Therefore, a development of new control functionalities at CAMC level is required, capable to deal with the greater complexity that increased presence of μG will bring to the system [1]. Some of these functionalities may use price signals due to potential upstream network constraint violation so as to boost the controllable μG to produce and controllable loads to be shed even in periods of low wholesale electricity prices [4].

In this context, large scale integration of μG, controllable loads and energy storage, if properly managed and controlled under the MG and MMG concepts, may reduce the power flows in the distribution network lines. Consequently, the DSO may suffer from reduced use of system charge due to local trading mechanisms for the part of the energy consumed within each MG [4,7]. Nevertheless, dealing with upstream network constraint violations, such as overloads and excessive voltage drops, may be seen as an opportunity for the DSO to set off potential reduction of system charges for the part of the energy produced and consumed at a single MG level [7]. In that sense, technical (ancillary) service market acknowledgement at MV network level may help the DSO to recognise and value the benefits due to large scale integration of μG together with active loads and therefore, opt for MG and MMG solutions adoption [4,7].

This paper stresses out the new role of the DSO, where μG units, controllable loads and energy storage devices are actively managed in order to deal with periods of overloads/excessive voltage drops. Such a management requires development of integrated micro-generation, load and storage (IMLS) control functionality to deal with stressed operating conditions that may take place at the MV network level. Some of the constraints to which this functionality is subjected relate to variables that are associated to different time intervals, such as energy storage levels in consecutive time moments. In addition, the total load at particular time interval should admit the controllable load disconnected at the previous time interval, assuring no network constraints violation associated with the load reconnection. Such requirements may be defined within curtailment contracts between the consumers and the DSO, so that the controllable load shed should be reconnected within a predefined period (e.g. 2–3 time intervals from the moment of disconnection). As a consequence, the IMLS control functionality cannot be performed for independent time intervals of 1 h, for instance. Instead, a greater time horizon must be considered, i.e. several hours ahead during a day.

2. Multi-microgrid control and management

2.1. Market approach

Fig. 1 presents a potential MMG control architecture, where the cash flow interactions among different agents are presented for both internal retail and local service market.

Controllable μG units (C-μG) together with controllable loads (C-Loads) send bids to the MGCC (Control level 3, Fig. 1) for active power dispatch and controllable load shift/curtailment. Each MGCC optimises the respective MG operation according to the bids of both controllable μG units and loads and wholesale market prices for the electricity obtained from the upstream network, using for instance a local retail market [3].

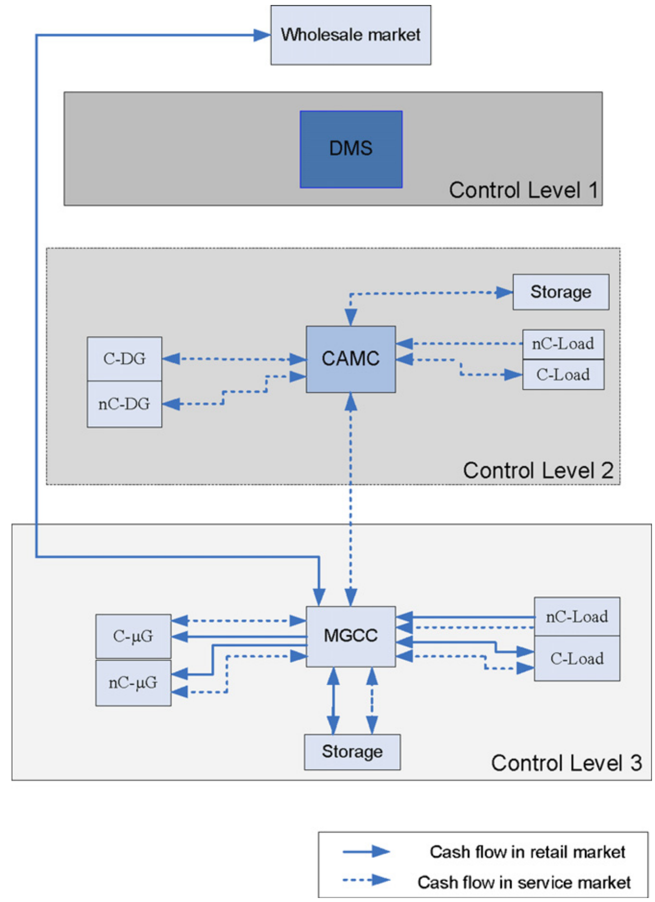

Fig. 1. Multi micro-grid operation in retail and service market.

Non-controllable μG units (nC-μG) are considered as non-competitive units always dispatched once their primary source is available. They correspond in general to μG units using renewable power sources under a feed-in tariff remuneration scheme.

Moreover, under grid-connected MG mode, the MGCC market functionality besides being a local balancer (in the retail market), may also participate in the wholesale market by selling back the energy production excess of the controllable μG units, if any (Fig. 1) [3].

Controllable μG units, whose bids are not accepted in the local retail market under MGCC, may also bid in upper level service market, under CAMC at potentially higher prices. Likewise, the consumers of each MG whose load reduction bids are not accepted in the retail market under MGCC, may obtain additional revenue by bidding in an upstream service market, for instance, for load curtailment due to technical constraints violation.

Finally, local service market performed at control level 3 and 2 (Fig. 1) may contribute towards resolution of potential LV and MV network technical constraints violation and lead to a set of technical and economic benefits assigned to the DSO [6,8,9]. Among these benefits one should highlight network investment deferral [10,11], especially when dealing with situations of more expensive and sometimes infeasible network upgrades.

2.2. Integrated micro-generation, load and storage functionality

The methodology presented in this paper involves a specific optimisation procedure – an advanced functionality to be installed at the CAMC level. This functionality aims to minimise the operation cost associated with the control variables of the optimisation problem, i.e.: (1) controllable μG dispatch, (2)