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Allocation of reactive power support, active loss balancing and demand interruption ancillary services in MicroGrids

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ABSTRACT

MicroGrids represent a new paradigm for the operation of distribution systems and there are several advantages as well as challenges regarding their development. One of the advantages is related with the participation of MicroGrid agents in electricity markets and in the provision of ancillary services. This paper describes two optimization models to allocate three ancillary services among MicroGrid agents – reactive power/voltage control, active loss balancing and demand interruption. These models assume that MicroGrid agents participate in the day-ahead market sending their bids to the MicroGrid Central Controller, MGCC, that acts as an interface with the Market Operator. Once the Market Operator returns the economic dispatch of the MicroGrid agents, the MGCC checks its technical feasibility (namely voltage magnitude and branch flow limits) and activates an adjustment market to change the initial schedule and to allocate these three ancillary services. One of the models has crisp nature considering that voltage and branch flow limits are rigid while the second one admits that voltage and branch flow limits are modeled in a soft way using Fuzzy Set concepts. Finally, the paper illustrates the application of these models with a Case Study using a 55 node MV/LV network.

1. Introduction

MicroGrids emerged in recent years as a very promising concept to allow wide spreading small generation sources namely in low voltage networks together with the incorporation of control devices associated both to small generation sources and low voltage loads [1–4]. This means that a MicroGrid can be seen as an association of a low voltage network with a number of components, as illustrated in Fig. 1. These components include loads, small scale generation devices (as small turbines, fuel cells, PV panels and wind turbines), storage devices (as flywheels, capacitors and batteries) and control devices. These control devices are associated with the micro-sources – MC controllers, with the controllable loads – LC controllers as well as with the MicroGrid Central Controller – MGCC, located in the beginning of the LV feeder [5]. According to this architecture, the MGCC acts as an interface both with the upstream Distribution Management System, DMS, of the Distribution Network Operator, DNO, and with the downstream Micro-source and Load Controllers – MC and LC.

As mentioned above, MicroGrids are contributing to change the still dominant paradigms associated with distribution network operation and with distributed generation. Distribution networks, namely LV networks, will no longer be passive ones but will incorporate a number of small sources getting generation closer to the demand and so contributing to turn the demand more aware of generation issues. On the other hand, the incorporation of control devices allows these small sources to provide a number of services upon request of the MGCC or of the upstream DMS system. This means that networks will have a larger amount of resources, not only in terms of providing energy but also in terms of different types of ancillary services. Regarding the demand, the incorporation of control devices can induce its participation in electricity markets, contributing to create more efficient mechanisms to profit from some demand elasticity as well as to enlarge the use of interruptible loads, provided that they receive an adequate remuneration. This means that the association of an LV network with small generation sources, loads and control devices can prove to be very powerful and effective in modernizing distribution networks and in integrating small scale distributed generation in a more natural way in power systems. Ultimately, MicroGrids can contribute to pass from the connection of large amounts of volatile DG paid in several countries according to subsidized feed-in tariffs to a more reasonable and natural way of integration while creating the conditions for their participation in markets and contributing to provide several services.

According to several authors [5,6], the development of MicroGrids brings several advantages to power systems namely the ones related with operation and investment issues, environmental

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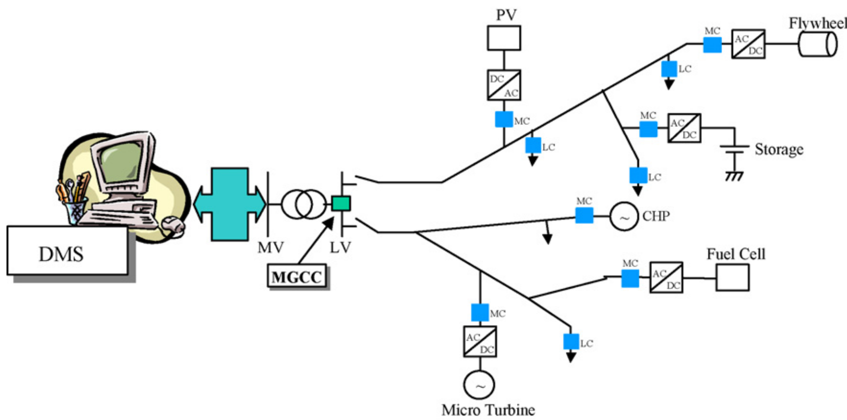

Fig. 1. Illustrative scheme of a MicroGrid.

issues, power quality improvement (namely reducing interruptions if operation in an isolated mode is considered [5,7,8]) and market issues (enabling the participation of MicroGrid agents in markets to provide electricity and services).

Although these advantages were identified in early publications on MicroGrids, their development and widespread still face a number of challenges related with the cost of generation technologies, with the development of control devices and new applications and models to allow the efficient and integrated operation of the MicroGrid and the upper stream networks, the absence of standards and, finally, the absence or still under developed legal and/or regulatory provisions to frame their installation and operation.

Given the advantages of MicroGrids and the new paradigm associated with their development, INESC Porto participated in two EU financed projects (MICROGRIDS and MORE MICROGRIDS projects) aiming at making new advances in several aspects associated with MicroGrid modeling. This paper describes part of the research developed in INESC Porto to allow increasing the participation of MicroGrid agents, namely small generation sources and loads, in the provision of some ancillary services. In this paper we will focus on the allocation of reactive power, on the allocation of active power generation to contribute to balance active losses and on the allocation of load interruption capability. Apart from this introductory section, this paper is structured as follows. Section 2 describes some approaches available to allow the participation of MicroGrid agents in markets and Section 3 describes the two developed mathematical, one of them corresponding to a crisp formulation and the second one using Fuzzy Set concepts to model soft constraints. Section 4 describes the solution algorithm implemented to solve these optimization problems and Section 5 illustrates the application of these models with a Case Study based on a 55 node MicroGrid. Finally, Section 6 draws the most relevant conclusions.

2. Overview of approaches to allocate ancillary services in MicroGrids

Among other advantages of MicroGrids, the creation of conditions to increase the participation of small generation sources and loads in electricity markets and the provision of some ancillary services are considered as most desirable in early publications on this subject, as [4,5], although several problems turn this integration difficult. Apart from other considerations, increasing the participation of small generation sources in MicroGrids will allow treating these generation facilities in a more natural way, substituting feed-in tariffs that, in several countries, represent increasing percentages of the final end user tariffs.

On the other hand, demand should be also more integrated in electricity markets [4,5] because it typically shows a very passive and inelastic behaviour so that current market implementations are, in practice, very asymmetrical. Introducing control devices namely in the MicroGrid loads and innovating in terms of remunerating the demand if it admits interruptions can correspond to a breakthrough to change its behaviour and to turn electricity markets more symmetric. This fact, together with the larger number of generation agents, will contribute to reduce the market power that today large generation companies still have.

In line with these concerns, reference [9] proposes an overall procedure to allow the participation of MicroGrid agents in electricity markets. This procedure corresponds to a symmetric assignment problem and once this auction ends all MicroGrid agents adjusted their positions in order to maximize their profits. The main grid is also considered a buying or selling agent so that it is possible to buy power from it to supply the MicroGrid demand, as well as selling power to the upward voltage network.

Afterwards, reference [10] describes an Energy Management System, EMS, based on the use of neural networks to implement a number of functions to autonomously adopt decisions regarding the dispatch of the generators in the MicroGrid aiming at minimizing the global energy cost. References [11,12] describe agent-based approaches to model MicroGrids. As an example, the agent-based platform detailed in [11] includes agents to model the MicroGrid Central Controller, the Micro-source Controllers and the Load Controllers. This agent platform was implemented on a laboratory micro grid using different storage schemes. Finally, [13] addresses the provision of some ancillary services. This reference focuses on the provision of primary reserve, although the authors indicate that the developed models and techniques can be extended to the secondary and tertiary reserves.

3. Allocation of reactive power, loss balancing and interruption services

3.1. General architecture and market cycle

In this paper we adopted a MicroGrid architecture similar to the one described in [5]. In this approach, the MicroGrid generation and load agents send selling and buying bids to the MicroGrid Central Controller, MGCC, that aggregates and communicates them to the Market Operator. In this sense, and apart from other functions, the MGCC acts as an interface between the MicroGrid agents and the Market Operator. The Market Operator runs an auction for the entire power system and determines the next day hourly economic schedule. Similarly to what occurs in transmission networks, the entity in charge of the MicroGrid operation checks the technical feasibility of these economic schedules, namely voltage magnitude and branch flow limits. In the MicroGrid, these functions