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Microgrid clustering architectures

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HIGHLIGHTS

- The microgrid cluster architectures are identified.
- A comparison between the different architectures is performed.
- The cost, scalability, protection, reliability, stability and business models are analysed.
- The best architectures are identified.

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ABSTRACT

Microgrids are considered one of the most promising solutions to integrate renewable distributed generation into the electric power system. During the last decade, the microgrid concept has been studied and developed and nowadays it is becoming a reality. Hence, in the coming years a transformation of the current electric power system to a multi-microgrid power system can be expected. In this direction, the study of multi-microgrids is currently being explored. Accordingly, this paper examines the possible multi-microgrid architectures to form a grid of microgrids. For this purpose, the microgrid as a single entity and its possible interactions with external grids is first defined. Then, the possible multi-microgrid architectures are defined in terms of layout, line technology and interface technology. Finally, a comparison between the different architectures is performed in terms of cost, scalability, protection, reliability, stability, communications and business models. This analysis is expected to be of great utility for grid planners and policy makers, who can select the most adequate architecture in function of their necessities.

1. Introduction

The energy demand, which is commonly supplied by fossil fuels, is expected to grow in the coming years. This will lead to an increase of the CO_2 emissions among other adverse environmental effects. Due to the rising awareness about sustainable growth (e.g. the 20/20/20 EU Objectives [1]) and due to the variability of electricity price and the reduction of fossil fuel reserves, different countries and organizations are considering renewable energy generation as a solution to satisfy the future energy demand [2]. Particularly, in the electricity sector, wind and photovoltaic (PV) power are experiencing the highest growth in Europe [3]. Owing to their intermittent nature and the distributed location of these resources, the integration of large amount of renewable energy in the conventional power system is a challenging process. Currently, some power systems are evolving from conventional grids to smart grids. This could also improve their reliability, resiliency or stability. At the distribution level, grids have been traditionally operated as passive systems. But the integration of distributed resources is transforming these networks into active systems with distributed control and bidirectional power flows. So, new concepts are required for the expansion of active distribution networks, where one of the most promising network structures is based on microgrids [4].

The integration of distributed energy resources (DER) such as distributed generation (DG) as wind and PV, combined heat and power (CHP) together with energy storage can potentially reduce the carbon emissions, improve the power quality, reliability and the energy efficiency. In addition, the integration of DER may mitigate the system expansion needs [5]. But, due to the huge number of DERs, the new challenges focus on grid operation and control. These challenges can be addressed by microgrids [5,6]. A microgrid is a group of interconnected loads and DERs that, operated in a coordinated way, behaves as a single producer or consumer from both the grid and the market perspective.

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Microgrids are basically low voltage (LV, < 1 kV) or medium voltage (MV, 1–69 kV) grids that can operate in grid connected mode (interconnected to an external grid) or in an isolated or islanded mode (without the support of external grids).

The microgrid concept is currently being investigated. While in 2001 the number of publications including this topic could be counted by tens, currently more than 1500 papers per year are being published and the trend is to increase. In [7–24] the microgrid development status is summarized. The authors from [7] review the DG technology, the grid benefits from microgrids, the power electronics applications, the operation and control in microgrids, the protection, the communication systems and different economic aspects of microgrids. The concept of microgrid clusters is also included, showing they can benefit from lower costs and lower emissions. In addition, [7] highlights the need for further research studies in this field. In [8,9], a review of the microgrid technology including distributed generators, storage and power electronics is performed. In [9], the potential benefits of microgrids, protection, control, economics and communication are also described. The works presented in [10–14] are focused on the operation and control techniques of microgrids. These papers analyse the centralised, decentralised and hierarchical control of microgrids and issues related to the stability, power quality and the corresponding solutions. The work is mainly performed for radial[1] microgrids as meshed[2] topologies requires further development. The studies presented in [15,16] review the particular case of hybrid alternating current/direct current (AC/DC) migrogrids and are focused on the classification of the topologies and control strategies. A general overview of the microgrid status can be found in [17], which also includes real cases of microgrids (as in [18]) and standardization. In [19], a review of the microgrid DG resources and the operation of the microgrid is performed. It also includes different developments in recent projects around the world. On the other hand, the architecture of microgrids is reviewed in [20–24].

The amount of distributed generation that can be integrated in a single microgrid is limited, but the connection of multiple microgrids within the same network can mitigate this issue [25]. In addition, multi-microgrid systems can bring environmental benefits, as analysed in [26]. The study, considers a typical distribution grid with 64 connected microgrids. The results show that the distribution grid losses and the pollutant emissions are reduced with the multi-microgrid system. The loss reduction in multi-microgrids is also studied in [27], where it is determined that coordinated multi-microgrids can improve the system efficiency. Furthermore, as stated in [28], microgrid interconnections can allow to combine the advantages of AC and DC microgrids. If they are properly planned, they also improve the reliability of the multi-microgrid system [28,29]. The authors from [30] also identify benefits in microgrids clusters showing they can lead to mutual support among the interconnected microgrids during contingencies. Taking into account all these potential benefits, the research on microgrid clusters (or multi-microgrids) is one of the main drivers for the integration of microgrids into the power system.

Literature around this concept has been only focused on the system operation, control and management [25]. For the different analysis existing in the literature, either the type of interconnection between the microgrids is not addressed [31] or a particular microgrid cluster architecture is selected [25,32–41,31]. Ref. [31] reviews the control of DC multi-microgrid systems and their potential benefits without considering the possible architectures. This review is performed for the islanded mode (e.g. when the cluster operates without an external grid support). Among the benefits, the maximum utilization of energy sources and the improved reliability are identified. It is also introduced that the stress and ageing of the components can be diminished, reducing the maintenance costs. Additionally, the system stability can be improved in the case of clusters with large inertia, but degraded in the case of clusters with low inertia. On the other hand, examples of studies focusing on a specific microgrid clustering architecture are presented in [25,32–41]. In [32–37], microgrids are interconnected through an external AC network using power transformers. In [38] the same architecture is studied, and also focusing on the case where microgrids are interconnected between them through point to point connections. The point to point interconnections between microgrids is also studied in [39,40], where DC technology and power converters are used. On the other hand, mixed configurations can be found in [25,41], where interconnections to the external grid are combined with point to point interconnections between microgrids. In this case, AC and DC technologies are used. A specific design for the hybrid AC/DC connection of multiple microgrids is proposed in [42] based on linking microgrids between each other through DC lines and on keeping the AC connection to the main grid.

All the before mentioned literature studies how the operation, control and/or management affects the performance of multi-microgrid systems, but none of these studies presents a comprehensive approach of microgrid clustering architectures. To the best of our knowledge, there is an important knowledge gap in the analysis of microgrid cluster architectures and their operational and economical characterization. The existing literature adopts particular architectures as use cases for their analysis, but does not study the wellness of these architectures against others. The contribution of this paper is the identification, classification and analysis of the microgrid cluster architectures. Three main concepts that can potentially affect the microgrid cluster performance are identified and classified into (i) the layout, (ii) the line technology and (iii) the interconnection technology. Then, the possible architectures within these concepts are identified and defined. Finally, these architectures are compared evaluating the main parameters that defines the system behaviour, i.e. cost, scalability, protection, reliability, stability, communications and business models. As a result, a set of tables are created to show the value of each architecture, their strong points and their weaknesses. Finally, the results of this analysis can provide some guidance to grid planners and policy makers to take decision on how their future grids should be designed. In addition, a guidance of future research lines is provided in the conclusions.

The paper is organized as follows: Section 2 describes the microgrid viewpoint used in this work. Then, Section 3 defines the different possible architectures, which are later compared in Section 4. An example of application is shown in Section 5. Finally, from the analysis performed, some conclusions are drawn.

2. The microgrid as a whole

A microgrid is *a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode* [43].

A general scheme of a microgrid is shown in Fig. 1 where, according to the definition, distributed resources (storage and generation), loads and controllable loads can be observed. It clearly defines electrical boundaries which are identified as the points of common coupling (PCC 1 to PCC n). These points are the interconnections with other grids. The voltage nature of the microgrid and the external grids can be different. In this case, an interface element which is part of the microgrid must be installed to permit the interconnection. The control, which can be centralized or decentralized [14], permits the operation as a single controllable entity. In addition, meters and a communication infrastructure must be installed. Finally, the microgrid must have a switch per PCC to permit the operation in island-mode. The microgrid can be operated in AC, DC or mixed AC/DC technology. Depending on these technologies, power electronics or transformers should be used to interconnect distributed resources and loads with the microgrid.

[1] grid where only exists one electrical path between two different points.

[2] grid where more than one electrical path between two different points exist.