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Review of hierarchical control in DC microgrids

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ABSTRACT

DC microgrids (DC MGs) are characterized by attractive features such as high system efficiency, high power quality, reduced cost, and less complex control. The hierarchical control is extensively proposed by researchers for DC MGs. This paper reviews and classifies different primary and secondary control techniques applied to DC MGs. The load sharing mechanisms employed in *primary control* are distinguished in passive methods and active methods. The different methods for *secondary control* are also categorized. Their key points and their limitations together with solutions that have been proposed by the research community are presented and critically assessed.

Contents

1. Introduction

Microgrids (MG) are a novel form of distribution systems, which belong to the wider concept of Smartgrids. The Microgrid can be considered as a small-scale electricity grid, which operates in low or medium voltage networks. It consists of distributed generation (DG) units, such as renewable energy generators and combined heat and power units, along with storage devices and controllable loads (e.g. air conditioners) [1]. Their unique characteristic is that they can be islanded, especially in case of faults, increasing the supply reliability. Currently, the most common application of DC MGs is the electric power supply of isolated systems like vehicles, space crafts, data centers, telecom systems, while they have been proposed for rural areas and islands [2–4].

The DGs are interconnected via an AC link forming an AC MG, or via a DC link forming a DC MG. While a lot of work has been done in the operation and control of AC MGs, DC MGs have started attracting attention recently, due to their potential advantages over AC MGs, such as:

(1) The incorporated DGs can be easier coordinated, as their control is based on DC voltage without the need for synchronization.
(2) The corresponding primary control is notably less complex as the reactive power flow control is absent. Yet, the DC link can suffer from harmonic content.
(3) As the DC electronic domestic loads dominate today, unnecessary AC/DC power conversions are avoided as most DGs

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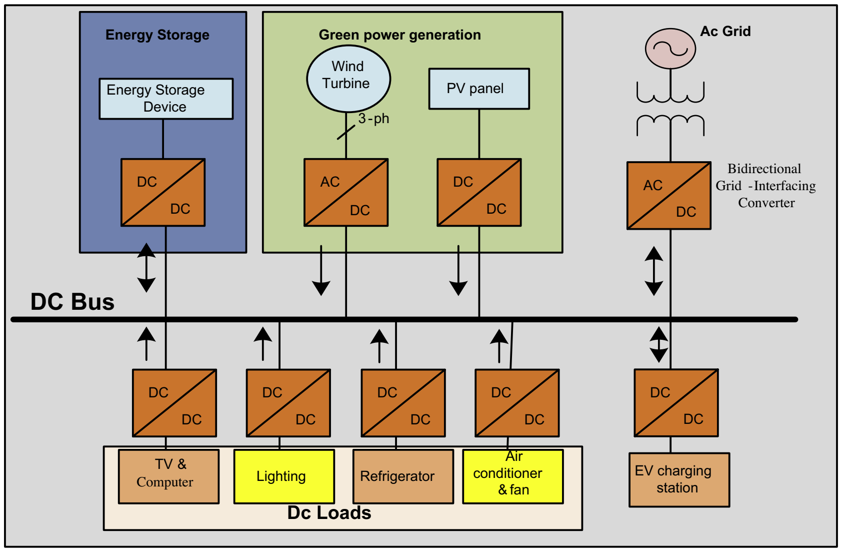

Fig. 1. The single line diagram of a typical microgrid structure.

generate DC outputs. This has a direct effect on system cost and losses. Also, the converters used for the DC microsources interface, are mostly transformer-less reducing further the size and cost of the system.

(4) DC protection in general is difficult due to no zero crossing to interrupt on. But the DC system does not experience high fault currents as the contribution to faults by the converters of the power electronic interfaced load or DGs is limited [2,5,6].

Fig. 1 shows a typical DC microgrid configuration with a common DC bus. Note that the DC MG topology may differ from radial single feeder configuration to two-pole or ring configuration. In these topologies either unipolar or bipolar configurations can be implemented. Bipolar configurations can provide more voltage level options in comparison with unipolar connections. With respect to the voltage levels, they can differ in accordance with the operating requirements of each system. For example, 380 V is a typical voltage level for data centers, while 20,230,325 V are typical voltage levels for house installations. Other levels could be 1500 V, ±750 V, ±230 V, ±170 V etc.

The interface terminals within a MG, as shown in Fig. 1, can be mainly categorized into four types: generation (deterministic or non deterministic), load, energy storage system (ESS), and upstream grid connection using voltage-source converters (VSCs). These terminals have to be parallelized with the appropriate interfaces in order to form the MG. Paralleling the DC sources presents a number of challenges: The first challenge concerns the stability of the system that needs a proper converters design. Effective control of the DC bus voltage by the DGs is important, as electronic loads are sensitive to voltage deviations. Another important issue concerns effective load sharing among DGs, as the load should be shared "equally" or depending on DGs' ratings or costs. In paralleling DGs, the role of the source output impedance is very important. This impedance has a considerable impact on the interaction between the source and the load [7]. This interaction and the way it affects load sharing among DGs will be analyzed later (Fig. 1).

The control that is applied in DC microgrids, should ideally respond to all the aforementioned challenges. An important characteristic is that DGs should be capable to support the peer to peer scenario (local control) of operation by exercising autonomous control, especially at primary level. This feature provides modularity and improved reliability of the system. In practice, a compromise has to be made among load sharing, modularity and autonomous control.

In [8], a review of DC microgrid control is presented, focusing however mostly on storage devices for MGs. Four typical control architectures are considered: droop control, hierarchical control, fuzzy control and multi-agent based control. This categorization seems rather untargeted, as the hierarchical control may include droop control, while it does not exclude intelligent control, such as fuzzy control. The droop control is a load sharing mechanism that can be used extensively in many different control architectures. Multi Agent System (MAS) control is mostly intelligent and can incorporate fuzzy logic.

This paper provides a review and a classification of the different control methods applied to DC MGs, especially for primary and upper level of the hierarchical control. In general, the control can be divided in centralized, decentralized and hybrid. The main drawback of the control – centralized or not – that is based on communication channels is the poor reliability in case of links failure, whereas the communication free control – decentralized control – suffers from poor voltage control. The hybrid control tries to combine the advantages of the aforementioned controls. Their limitations and ways to overcome them are also discussed.

The rest of the paper is structured as follows: Section 2 presents the general hierarchical control of a DC microgrid and the categorization of the power management strategies. Section 3 focuses on the primary level and the different load sharing mechanisms, while it addresses appropriate solutions to overcome their limitations. Section 4 reviews the different power management strategies and Section 5 concludes the paper.

2. Hierarchical control

The hierarchical control, as in AC MGs, applies for DC MGs too and can be divided in three levels [9,10] (also in accordance to ISA-95) (Fig. 2).

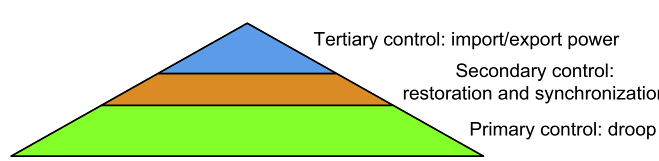

Fig. 2. Hierarchical control of microgrids [9].