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Control of inverters in a low voltage microgrid with distributed battery energy storage. Part I: Primary control

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ABSTRACT

This article proposes a control architecture for a low-voltage AC microgrid with distributed battery energy storage. The droop controlled inverters interact with the microgrid through the RL combination of their virtual resistive output impedance with the series impedance of a coupling transformer. To obtain independent association of frequency with active power, and voltage with reactive power, decoupled droop control techniques are proposed and analyzed. The resulting control can be adjusted for appropriate dynamic response without modifying the droop coefficients. The application in the microgrid in diverse operating conditions is verified by a detailed simulation. The resulting primary control layer offers the capability of being easily actuated from a secondary control layer for procedures such as flexible power dispatching and frequency restoration.

1. Introduction

Remote microgrids (RMG) are microgrids [1,2] deployed in remote geographical areas either isolated from the distribution grid or with an intermittent or low-reliability connection to it. Isolated power systems are traditionally based on diesel generators (DGEN) but when combined with renewable energy sources and energy storage [3], they acquire the characteristics of a microgrid. Medium- and low-power RMGs are now considered an optimal solution for electrification where extension of the distribution grid is not feasible in the short term [4]. Solar power offers the advantages of even distribution across a country or area, good prediction accuracy of expected energy, and in most occasions is the only choice when wind or hydro generation is not applicable. Combined with battery energy storage and load control, a photovoltaic (PV) power plant or microgrid can be designed for a solar fraction (SF) close to 100% [5]. DGENs are usually included as an emergency power source and to cover below average solar power generation periods. Except for the case of very small isolated systems, RMGs are usually low-voltage AC microgrids, although they can include DC subgrids or buses in their hierarchical architecture [6,7]. The architecture studied here is sketched in Fig. 1(a). There are several physically separated sites or clusters of consumers. Each cluster of users or loads can work in isolation from each other or participate in a collaborative microgrid. Each cluster includes a battery energy storage system (BESS) with a central DC bus to which the solar panels connect through a unidirectional DC/DC converter (UDCDC), which can work in maximum power point tracking (MPPT) mode. A bidirectional DC/DC converter (BDCDC) connects the DC bus to the battery and a three-phase inverter interfaces the DC bus to the AC microgrid. The loads are distributed in non-critical (NCL), critical (CL) and dump loads (DL). NCL can be disconnected to preserve battery capacity, and DL can be connected to absorb excess solar power production. The physically distributed BESS offers the advantage of efficiency, independence, fault tolerance and modularity. The system can grow by interconnection with other clusters. For a low-voltage microgrid the distance between sites is on the order of tens of meters. This architecture is in agreement with the conceptual model proposed in [7]. Fig. 1(b) shows a diagram of an application example: a sustainable tourist resort in an environmentally protected area. This article proposes a primary control layer for inverters in this kind of microgrid that guarantees active power sharing and adequate stability of voltage and frequency. This primary layer offers the capability of being actuated from a secondary control layer for procedures such as power dispatching and frequency restoration.

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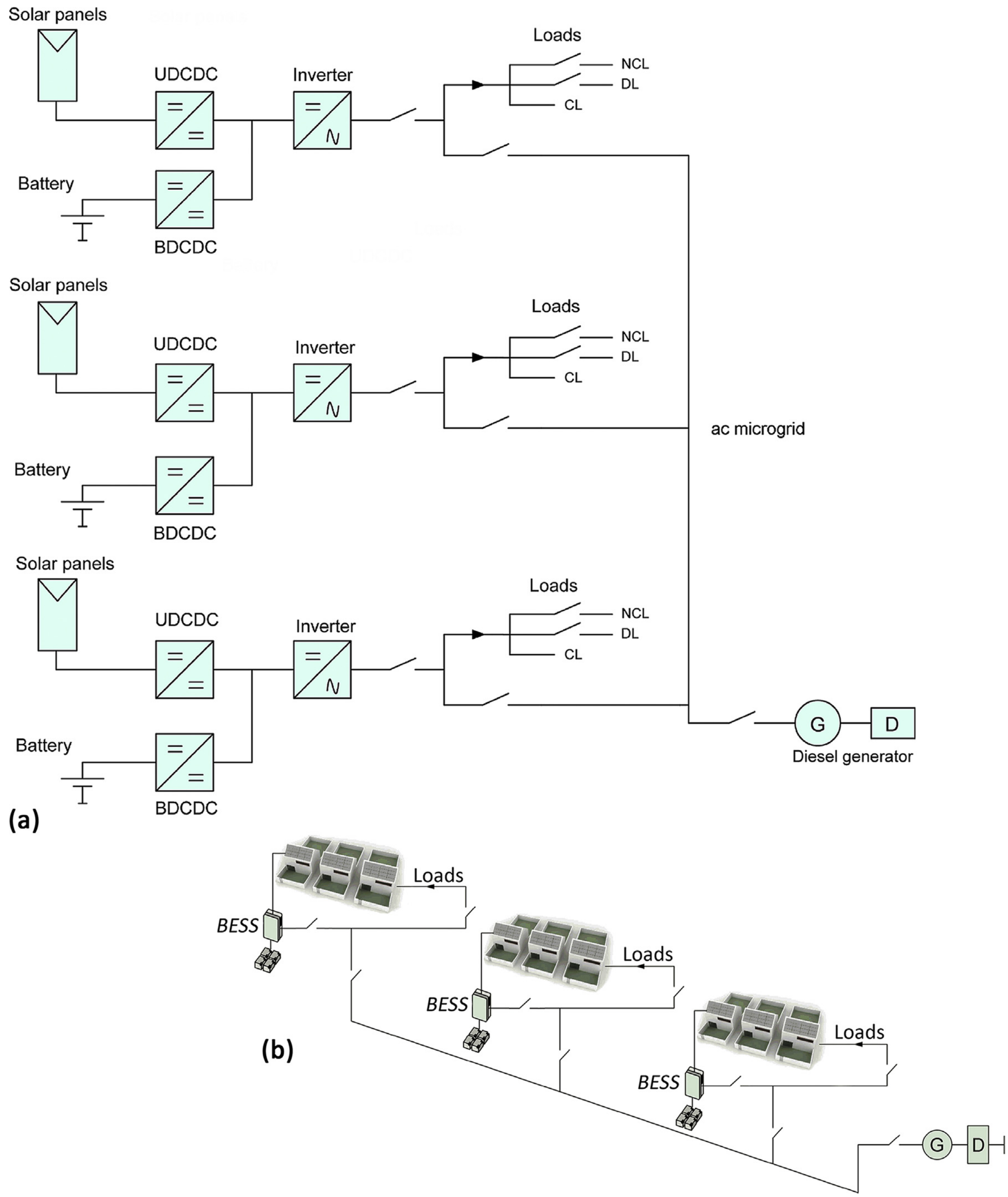

Fig. 1. Mixed DC–AC microgrid with distributed energy storage: (a) architecture and (b) example of application in a sustainable tourist resort.

It can be complemented with an NCL shedding or DL connection strategy when some of the BESS reach the end of either the discharged or fully charged states, respectively. The secondary control layer, to be presented in a future paper, will rely on a communications network that interconnects the distributed control nodes. It should be possible to operate the microgrid with adequate voltage and frequency stability [8] and to have it respond to emergencies (DGEN activation and connection to the microgrid) even in the event of a failure or disconnection of the communications network; that is, the secondary control layer should be non-critical. The fundamental aspects of the overall control layer structure and strategy adhere to recently proposed control hierarchies for microgrids [9–11].

2. Droop control of the inverters

When the MG operates in islanded mode, a critical control task is to maintain voltage and frequency in the AC microgrid, with several inverters working in parallel and sharing load [10,11]. From among the various techniques applicable to parallel inverter control in isolated microgrids [12,13], voltage and frequency droop based methods [9–22] are appropriate to fulfilling the requirement of not relying on critical communications or dedicated control lines. The classic droop control technique, typically applied to electromechanical synchronous generators, can be applied to inverters coupled with the microgrid through mainly inductive impedance. In an inverter the output impedance can be synthesized