A decentralized impedance-based adaptive droop method for power loss reduction in a converter-dominated islanded microgrid

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HIGHLIGHTS

- A new decentralized adaptive droop control method is proposed.
- Reduction of line losses is achieved in comparison to the conventional droop method.
- The droop coefficients are adjusted by the microgrid impedance sensed by each DER.
- The active and reactive power are decoupled by the adaptive droop coefficients.
- The proposed method can be applied irrespective of the microgrid topology.

ARTICLE INFO

ABSTRACT

As the integration of Distributed Energy Resources (DERs) in modern grids is increasing, the microgrid concept has been established. In the case of converter-dominated microgrids without communication links, the droop control method is mainly adopted in the primary control level. Normally, the economic operation of the microgrid is incorporated in the secondary control level, requiring communication among the DERs and a central controller. On the contrary, this paper proposes an adaptive droop control method based on local measurements, which achieves a power sharing with reduced power losses within the islanded microgrid. The droop coefficients are adjusted by calculating the microgrid impedance, sensed by each DER. Therefore, the remote DERs calculate a large impedance and inject lower active and reactive power, reducing the line losses. The location and the size of the DERs and the loads can be arbitrary. Another advantage is the absence of the virtual impedance control, as the power decoupling is implemented inherently by the adaptive droop coefficients. The effectiveness of the proposed control strategy is verified by extended simulation results in comparison with the accurate sharing method for different microgrid topologies.

1. Introduction

The development of cleaner and more reliable power grids with distributed power sources has created the microgrid concept [1]. As small-scale power sources are connected to the microgrid through DC/AC or AC/DC/AC converters, the proper control of the converters has drawn considerable attention [2]. According to IEEE 1547.4, the microgrid systems should combine the capability of a dual operation, either in grid-connected or island mode. The grid-connected mode aims to inject the available power to the grid, determined by a maximum power point tracking strategy [3]. On the other side, in island mode, the power production should fulfill the load demand, while the voltage and the frequency are maintained within the permissible limits. This operation mode may modify the injected power to a less efficient operation point.

During island operation, the DERs are in charge for balancing the voltage profile within the microgrid and ensure a proper power sharing [4]. In this primary control level, the conventional droop control method is mainly adopted [5–7] and is implemented without any communication infrastructure. In case of inductive line impedances, the frequency of the microgrid is formed by the total injected active power, while the node voltage by the respective reactive power [8]. This control law should be inversed in case of purely resistive microgrids [9,10]. In fact, in most cases the impedance is complex [10], consequently a proper power sharing is hard to be achieved by the conventional droop control method. For this reason, a virtual impedance control is used in order to modify the voltage input of the droop control and ensure an accurate

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power sharing among the DERs [9,10]. As accurate is defined the power sharing, where each DER supplies active and reactive power in proportion to its nominal apparent power. The value of the virtual impedance is calculated for a given microgrid topology, while it can be updated automatically in case of a topology change by using communication signals [11,12]. On the other hand, when the communication is not available, the proper power sharing cannot be guaranteed.

Concerning the influence of the power sharing on the line losses, it is demonstrated in [13] that the power sharing modification due to the line impedance mismatch can lead to line loss reduction. However, only resistive microgrids are considered. In [14], an on-line Optimization Strategy based on local measurements is adopted, in order to define the optimal reactive power settings of each DER, so as the power losses along the feeder are minimized. The drawback concerns the modeling approximations, since the control can be integrated to only one DER. In [15], the proposed control strategy consists of an adaptive droop controller, in respect with the local reactive power. This methodology is implemented in medium voltage microgrids, where the R/X ratio is low and the losses can be reduced without considering the active power regulation. Nevertheless, this assumption cannot be adopted for low-voltage grids. Other decentralized methodologies based on local measurements focus only on the reactive power dispatch in order to reduce losses [16–18].

Alternatively, an economic operation of the microgrid can be achieved by deploying a microgrid central controller (MGCC) with low-bandwidth communication infrastructure. This control level is characterized as secondary control [7] and is based on evaluating measurements collected by the power production and consumption. In order to obtain the maximum benefits from the DERs operation, the power dispatch reaches to the optimal or near optimal operation point by solving a power flow problem [19] and updating appropriately each droop characteristics [20,21]. In [22,23] a MGCC multi-stage optimization algorithm is implemented to minimize the fuel consumption of a droop-controlled islanded microgrid, without considering the operational constraints of the voltage and the frequency. In [24] the presented multi-stage optimization takes into account the system power losses and the operational constraints. In [25,26] different algorithms propose the economic dispatch of the DERs. A method for grid-connected grids with PVs is presented in [27], where the multi-objective configuration concerns only the reactive power for minimizing the power losses. In order to provide the highest possible autonomy to the DERs, decentralized methodologies based on Multi-Agent Systems (MAS) have also been developed [28–31]. However, the communication is still considered necessary.

Furthermore, various other methods have been proposed for loss minimization by means of distributed generation integration [32,33]. The most important are concentrated on capacitor placement, cooperation with Flexible AC Transmission Systems (FACTs), energy storage allocation, feeder reconfiguration and DG allocation. However, these methodologies use complex mathematical tools, while they assume a known topology for the DG placement. Furthermore, in many cases, the communication is regarded necessary.

This paper proposes a new power sharing methodology for converter-dominated islanded microgrids for achieving reduced line losses in comparison to the conventional droop method. The proposed control strategy adapts the droop coefficients, according to a microgrid impedance sensed by each DER. Therefore, the DERs closer to the loads are forced to supply them in priority, leading to power flows through smaller line impedance routes. The proposed method can be adopted in any arbitrary microgrid topology, while no communication is needed. Furthermore, the implementation of virtual impedance control is no longer necessary, as the different impedances of the power lines are taken into account indirectly in the adaptive droop coefficients. Since the proposed control strategy relies only on local measurements, the function of loss reduction is implemented in the primary control level, instead of the secondary control level. The proposed method is compared with the accurate power sharing methodology, proving its effectiveness in line loss reduction.

The accurate power sharing with virtual impedance control strategy is explained in Section 2, while Section 3 presents the proposed adaptive droop control strategy. In Section 4, both looped and radial topologies are examined. Finally, Section 5 contains the conclusions.

2. Power sharing with conventional droop control

The conventional wireless droop method functions by emulating a traditional power system with parallel synchronous generators. In this method, the microgrid frequency and voltage serve as communication parameters for all DERs. Therefore, the active and reactive power of the loads are shared among the connected DERs without using physical communications among them [5,6]. Considering inductive line impedances, the control law imposes the determination of the microgrid frequency f from the active power P, while the node voltage V_n is determined by the reactive power Q,

$$f = f_0 - m \cdot P - m_d \frac{dP}{dt} \tag{1}$$

$$V_n = V_0 - n \cdot Q - n_d \frac{dQ}{dt} \tag{2}$$

where f_0, V_0 correspond to the frequency and voltage magnitude at no-load operation, m, n are the droop control coefficients and m_d, n_d are the derivative droop coefficients.

The active and reactive power are calculated by transforming in the rotating dq frame the voltage and the current at the LC output filter of each DER:

$$P = \frac{3}{2}(V_d I_d + V_q I_q) \tag{3}$$

$$Q = \frac{3}{2}(V_d I_q - V_q I_d) \tag{4}$$

where V_d, I_d are the direct axis components of the voltage and the current and V_q, I_q are the respective quantities in the quadrature axis.

The slope parameters of the conventional droop control m and n are set proportional to the maximum power of the DER [5–13], in respect to the permissible frequency and voltage variation. The purpose is to achieve a power sharing in proportion to the nominal power of each DER.

However, the line impedance in low-voltage microgrids rarely is purely inductive. In most cases consists of both resistive and inductive part [10]. With complex impedances, an efficient power sharing cannot be achieved, due to the coupled active and reactive power characteristic of the system. As a result, reactive currents are circulating among the DERs, increasing significantly the power losses on the connection lines. In order to overcome this problem, the output voltage is adjusted according to the virtual impedance control [5–12]. The advantages of using a virtual instead of a physical impedance is attributed to the increased cost, weight and power losses.

Additionally, the virtual impedance control aims at sharing the power accurately among the connected DER. For this reason, the value of the virtual impedance is adjusted differently for each DER, taking into consideration the relative distance of each DER to the common ac bus of the microgrid. This value is usually