Flat tie-line power scheduling control of grid-connected hybrid microgrids

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HIGHLIGHTS

- Propose a concept called flat tie-line power scheduling.
- Can integrate power ramp-rate limitation and power smoothing functionalities.
- Select proper operation modes and achieve seamless transfer between them.
- Perform power curtailment functionality.
- Ensure constant power injected into the grid within a determined dispatch period.

ABSTRACT

In future active distribution networks (ADNs), microgrids (MGs) may have the possibility to control the power dispatched to the ADN by coordinating the output power of their multiple renewable generation units and energy storage units (ESUs). In this way, each MG may support the active distribution network, while promoting the penetration of renewable energy sources in a rational way. In this paper, we propose a tie-line power flow control of a hybrid MG, including photovoltaic (PV) generator, small wind turbines (WT), and ESUs.

Firstly, the structure of the hybrid PV/WT/ESU MG is presented. In this power architecture, the battery is directly connected to the PV side through a DC/DC converter, thus reducing the number of conversions. Secondly, a hierarchical control is proposed to coordinate all those elements of the MG, making the tie-line power flow constant for a period of time, e.g., 15 min. Also, a method to calculate the tie-line power flow to be exchanged between the MG and the ADN is explored, and a power ramp rate is given between different dispatch intervals. Finally, a simulation model of the hybrid MG is built and tested. Simulation results show that the proposed hierarchical control strategy can select the proper operational mode and achieve seamless transfer between different modes. It also presents power curtailment functionality when the difference between the WT/PV output power and tie-line exchanged power flow is too large.

1. Introduction

The high penetration of wind and solar distributed generation in microgrids (MGs) may cause fluctuations in the tie-line power flow and may affect considerably the electrical distribution system operation. Therefore, large-scale distributed renewable energy generation units have been integrated with energy storage units (ESUs) to form electrical MGs [1]. At the same time, with the development of concepts like Energy Internet or active distribution networks (ADN), it is expected that more distributed generation (DG) and MGs will be interconnected in the next future [2–6]. Therefore, in order to facilitate the next ADN’s operation, it is necessary to effectively schedule, dispatch, manage, and control MGs or MG aggregators [7].

A lot of work has been done in islanded MG control, aiming to balance active power (P) and reactive power (Q) between...
Furthermore, in networks with high renewable energy penetration, it is desirable to lower the power ramp-rate of the generator to avoid instability. In this sense, the use of ESUs together with power electronic inverters can be beneficial [16], and high power-rates are analyzed, which may affect the grid performance. These fast slew-rates may affect the stability of the grid, especially in weak-grid/high-impedance situations [17].

The first concept, called peak shaving, is shown in Fig. 1 (a). It is used in MGs to reduce the need for back-up generators and the large peaks of power delivered to the main grid. An illustrative example can be found in [12], in which a MG energy management system, an optimal power control combining online rolling-horizon optimization and active real-time control is proposed in [25].

The second concept, called power ramp-rate limitation, is shown in Fig. 1 (b). It consists of limiting the maximum slew-rate of the power caused by the fast variations in solar irradiance and wind speed. These fast slew-rates may affect the stability of the main grid, especially in weak-grid/high-impedance situations [18]. The effect of cloud-passing in PV systems output power is studied in [19], and high power-rates are analyzed, which may affect the grid performance. In this sense, the use of ESUs together with PV/WT is suggested to reduce the maximum power ramp-rate. Some examples about it can be found in La Ola island PV plant, in which the power ramp-rate was measured to be more than 50% of the rated capacity per minute, being desirable to lower it down to 30%. In other cases, it has been lowered down to 50% [20]. Furthermore, in networks with high renewable energy penetration like Puerto Rico, authorities have limited the ramp-rates of the PV generators to 10% output power change per minute [21].

The third concept called power smoothing, makes MGs smoothly integrated into the electrical distribution grid [22]. This concept consists of smoothing the output power of a DG or MG [23]. In the literature, several ways to implement power-smoothing can be found. One way is, for instance, to use heat pumps. In [24], a regulation method of stabilizing the power fluctuation of a MG tie-line by using the heat pump load start/stop is proposed. In another work, a coordinated control strategy of a MG by using a combination of a battery and an electric-controlled heat pump load as a virtual-ESU to limit the MG tie-line power fluctuations is proposed. In that work, by setting two different time-constants of two Butterworth filters applied to the virtual-ESU and the battery, the high-frequency and low-frequency components of the MG tie-line power fluctuations are effectively suppressed [22,23]. Alternatively, in [3], the use of composed energy storages to smooth the output power fluctuations of a hybrid PV/WT/ESU hybrid MG in different time periods is presented. Further, in [24], the characteristics and the mathematical models of a hybrid MG are analyzed, and a charge/discharge optimization control of the storage is proposed to smooth the output power fluctuation. Alternatively, in order to reduce the output power fluctuations and to compensate reactive power of a PV/WT/ESU hybrid generation system, an optimal power control combining online rolling-horizon optimization and active real-time control is proposed in [15].

However, the aforementioned previous works still present a number of problems such as low-frequency power-flow fluctuations and lack of controllability. In order to solve these problems and to facilitate the management and dispatch of the future distribution grid, this paper proposes a concept called flat tie-line power scheduling, shown in Fig. 1 (d). It consists on controlling every MG generation system, an optimal power control combining online rolling-horizon optimization and active real-time control is proposed in [25].
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