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Distributed Control Strategy for Isolated Electrical Hybrid Power Systems

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Abstract. This paper presents a distributed control for isolated electrical hybrid power systems to manage the energy generated by the elements of the microgrid. Unlike other control strategies seen in the literature, this distributed control strategy takes into account the dynamic behavior of the synchronous generators and the spinning reserve requirements. The distributed control offers a simpler implementation than other proposals, a better integration of renewable generation, a greater reliability against communication failures and it reduces the energy costs. The main objectives of the controllers are minimizing fuel consumption and maximizing renewable generation. Simulation results are obtained using MATLAB/Simulink to verify the effectiveness of the proposed control strategy.

Key words. Energy storage, isolated microgrids, diesel generator, spinning reserve, hybrid system.

1. Introduction

The market for off-grid solar systems has grown exponentially over the past decade, with estimated sales reaching 23.5 million units in 2018, up from only 0.9 million in 2010. Around 7.6 million off-grid solar products were sold globally in 2018, comparable to the sales volume of the previous year; however, sales in 2018 resulted in a 45% increase in the total installed capacity of off-grid solar products, to around 58.8 megawatts (MW) (up from 40.7 MW in 2017) [1]. This growth is due to factors such as:

1) The rapid decreases in photovoltaic (PV) module costs. Since 2009, for instance, the costs have fallen by more than 80% while, globally, the cost of solar PV power declined by 73% from 2010 to 2017 [2].
2) The increase in the cost of fossil fuels for conventional generation and the reduction of dependence on fossil fuel imports [1].
3) The emergence of new energy storage technologies such as electrochemical batteries [1].
4) The urgent action to increase mitigation of climate change [1].

Although the growth of renewable energies in isolated microgrids reduces the reliability due to the intermittency of renewable resources, it also increases the power electronics and reduces the synchronous generation. Therefore, isolated microgrids have low inertia and need robust control systems to ensure proper operation [3]. In addition, the integration of Battery Energy Storage Systems (BESS) can reduce losses and increase reliability [4].

There are three levels of control in a microgrid: primary, secondary and tertiary [4], [5] and [6]. The primary control is responsible for the microgrid stability, i.e. the voltage control as well as the power sharing and balancing. It is based on droop control [7]. The secondary control restore voltage and frequency deviations to their reference values [4]. It also has the functionality of an Energy Management System (EMS). Although in [8] and [9] the EMS is integrated within the tertiary control. The tertiary control manages the power flow between the microgrid and the external electrical distribution system, in case it is grid-connected [10].

There are many different solutions to develop an EMS. In [11], [12], [13] and [14] it can be formalized using a state machine approach. In [15], [16], [17] and [18] the optimal operation of the microgrid is obtained by a mixed-integer linear programming (MILP) and by a mixed-integer nonlinear programming (MINLP) in [19]. In [6], [20] and [21] the control action for the next time step is obtained by solving an online finite horizon open-loop optimal control problem, using the current state of the plant as the initial state, known as Model Predictive Control (MPC). In [22], [23], [24], [25] and [26] the EMS is carried out from a dynamic control model of the elements in the microgrid, which calculates the optimal operation taking into account stability and frequency constraints.

BESS) to maintain stability and no need a centralized controller.

The results show the fulfillment of the initially established objectives, i.e. minimize the fuel consumption of diesel generators, while the PV power is maximized. The BESS is charged with surpluses from the renewable generation, and it is discharged to reduce the use of diesel generators.

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