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# Influencing the bulk power system reserve by dispatching power distribution networks using local energy storage

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ABSTRACT

Multiple research works and power systems operational practices have qualitatively associated the progressive connection of stochastic renewable energy resources with the increase of power systems reserve requirements. At the same time, the price and technology of MW-class Battery Energy Storage Systems (BESSs) have considerably improved, which opens up the possibility to make electric distribution networks dispatchable. In this paper, we investigate the impact on the bulk power system of dispatchable electric distribution networks that host a large share of stochastic resources. The essential questions inspiring this research are: (1) Assuming that BESSs are deployed to achieve dispatchability of distribution grids embedding stochastic resources, what is the impact on the bulk power system reserve requirement? (2) Is this large-scale integration of BESSs economically viable compared to centralized reserve procurement from traditional power plants? To address these questions, we consider the case of the Danish transmission grid and the associated fleet of conventional power plants and compare it against locally dispatched distribution grids. We perform stochastic simulations to quantify and validate the amount of reserve necessary to operate these power systems with a desired reliability level. We establish a numerical equivalence between saved conventional reserve capacity and amount of BESS storage deployed in distribution networks. Then, we quantify the economic pay-back times of BESSs capital expenditure (CAPEX). The results show that: (1) large scale deployment of BESSs with dispatchable distribution networks is a viable technical solution to address flexibility requirements for the bulk power system and (2) this solution is economically viable with a pay-back time in the range of 11–14 years compared to providing flexibilities from conventional power plants.

## 1. Introduction

Increased reserve and steeper ramping requirements for conventional generation are among the most pressing technical concerns related to increasing the proportion of electricity production from renewable energy sources in the generation mix.

The conventional approach to counteract these issues refers to the deployment/use of fast generating units, like gas-fired and hydro power plants, see for example [1]. As an alternative to the centralized procurement of regulating power, solutions based on exploiting local flexibility have been considered in the literature, such as demand-side management and distributed storage, like battery energy storage systems (BESSs) and power-to-gas. Especially, the use of grid-connected BESSs, traditionally considered for microgrids [2,3], is gaining interest even in the context of interconnected power systems thanks to their decreasing cost, level of technical maturity, reliability [4] and fast ramping rate, an important element if considering the reduced level of spinning mass and system inertia in future grids.

Most of the applications for BESS proposed in the literature are tailored to accomplish local distribution network objectives, e.g. peak shaving [5], congestion management [6], self-consumption [7], energy arbitrage [8], and trading in the ancillary services market [9–11]. The use of storage has been also proposed to dispatch the operation of traditionally stochastic generation, e.g. wind and PV farms [12–16]. In general, this approach consists in compensating the deviations from a dispatch plan (i.e. computed before the operation by leveraging forecasts and a model of the uncertainties) by controlling the BESS's power injection. In [17], this idea was enlarged and demonstrated for a set of heterogeneous resources in a medium voltage (MV) network, including both demand and distributed renewable generation. In the following, we refer to this paradigm as *dispatched-by-design distribution systems*. The principle underlying this paradigm is that dispatching traditionally stochastic power flows inherently reduces the system reserve requirements needed to operate the grid reliably. Compared to designs based

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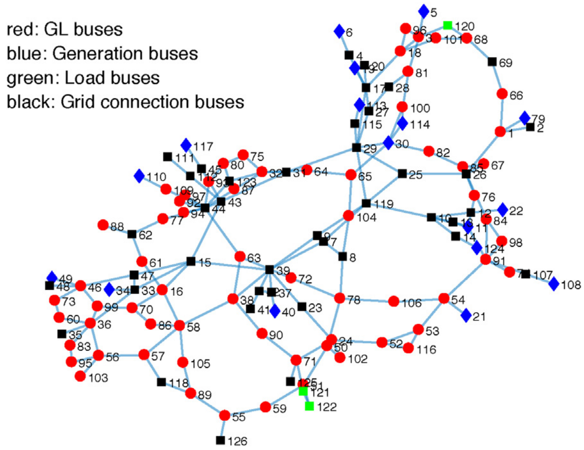


**Fig. 1.** High voltage (HV) grid topology in West Denmark.

on explicit re-dispatch of generation, which might require intensive communication procedures, it is less complex because the coordination mechanism is implicit and given by the commitment of operators to track pre-established dispatch plans, which can be communicated at a slower pace.

The available literature mostly focus on the definition of the algorithms for controlling storage with, however, no emphasis nor quantitative analysis on how coordinated operations of distributed storage can contribute to improving performance at the system level. Motivated by the objective of understanding the advantages of large-scale integration of storage, we consider in this work *dispatched-by-design distribution systems* as the operational paradigm implemented by distributed BESSs. From this standpoint, we investigate the effect of varying the penetration level of *dispatched-by-design distribution systems* in the bulk grid on the amount of reserve required to operate the global electrical grid with a predefined level of reliability. Also, based on an existing model for the price of regulating power, we perform an economic assessment to quantify the economic pay-back times of BESSs capital expenditure (CAPEX). The essential questions inspiring this research are: assuming that BESSs are deployed to achieve dispatch-by-design operation of distribution systems, what is the impact on total power system reserve requirements? Is this integration approach economically viable compared to the centralized procurement of reserve from traditional sources?

To address these questions, we consider as a case study the Danish transmission grid and the associated fleet of conventional power plants. We perform stochastic simulations to quantify the reserve requirements necessary to operate the power systems with the desired reliability level (measured by the Expected Load Not Supplied, ELNS, and chosen according to ENTSO-E recommendations). More specifically, we study the following two cases:

- Case I the power reserve is fully provided by conventional power plants;
- Case II the capacity of conventional power plants to provide reserve power is reduced and compensated for by implementing *dispatched-by-design distribution systems*.[1]

Once the amount of regulating power and required storage capacity are obtained for each case, we first quantify the amount of regulating power that can be saved by a given installed storage capacity. Then we perform an economical comparison of power reserve versus storage. The former evaluated by using a cost model adapted from the existing literature, while the latter is quantified by referring to recent assessments of electrochemical storage costs.

The rest of the paper is organized as follows. Section 2 presents the case study and related data set. Simulation methods are described in Section 3. Afterwards, the numerical results regarding reliability assessment as well as economic evaluation of the above mentioned cases are presented in Section 4. Section 5 discusses the strengths and uncertainties of the findings in the context of the existing knowledge. Finally, conclusions are presented in Section 6.

## 2. Case study and data set

### 2.1. West Denmark power system

The transmission network in Denmark is divided into two separate systems, Western and Eastern respectively synchronized with the European continental grid and Nordic grid. In this work, we consider the Western Danish power system as the case study because of its large wind generation (as stochastic generation source) installed capacity and availability of public power system and power market data. The Western Danish grid includes 126 buses at 400 kV and 165 kV which are connected through 147 transmission lines and 41 high voltage (HV) transformers. It is connected to Sweden, Norway and East Denmark (DC connections with total capacity of 2480 MW) and Germany (AC connections with total capacity of 1780 MW). In general, the internal electricity consumption and production in West Denmark is balanced. In this work, the case study does not consider the above mentioned interconnections for the sake of simplicity. Therefore, hereinafter we refer to the case study as Isolated West Denmark (IWD) power system. Fig. 1 shows the high voltage transmission grid configuration in the IWD power system. In particular, we consider the following 4 kinds of buses:

- generation bus: only generation units are connected to the bus;
- load bus: only aggregated downstream loads (power consumers) are connected to the bus;
- generation + load (GL) bus: both the generation units and downstream loads are connected to the bus;
- grid connection bus: neither generation units nor downstream loads are connected to the bus.

The information about the grid topology, the technical parameters of the transmission lines (i.e., type, impedances, power flow capacity, length and nominal voltage of each line), and high voltage transformer data, are from [18]. Moreover, the unavailability and failure rates of the main components like transmission lines and transformers are obtained from the European Network of Transmission System Operators for Electricity (ENTSO-E) report on Nordic grid disturbance statistics in 2014 [19].

Two hundred twenty-seven power generation units are connected to the grid through the GL and generation buses, for an overall generation capacity of 7321.3 MW. The detailed technical data of generators including nominal apparent power, minimum and maximum active power output, and location (bus number) of each generator are available in [18] and used in this study to fully replicate the system. The unavailability and the failure rates of the generators are determined as a function of the type of each unit according to the statistical data available in [20]. The total load (electric energy consumption), during 1 h, distributed among GL and load buses of the system is 2071.9 MW h (in other words, total power demand of the system is 2071.9 MW).

### 2.2. Distribution networks with dispatch-by-design capability

Whereas conventional power plants and large-scale renewable energy facilities are connected to GL and generation buses, downstream

[1] BESSs are deployed in the distribution grid to dispatch the operation of traditionally stochastic prosumption power flows. This analysis is carried out considering different penetration levels of *dispatched-by-design distribution systems*, which corresponds to as many different values of deployed storage capacity.