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Review of energy system flexibility measures to enable high levels of variable renewable electricity

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ABSTRACT

The paper reviews different approaches, technologies, and strategies to manage large-scale schemes of variable renewable electricity such as solar and wind power. We consider both supply and demand side measures. In addition to presenting energy system flexibility measures, their importance to renewable electricity is discussed. The flexibility measures available range from traditional ones such as grid extension or pumped hydro storage to more advanced strategies such as demand side management and demand side linked approaches, e.g. the use of electric vehicles for storing excess electricity, but also providing grid support services. Advanced batteries may offer new solutions in the future, though the high costs associated with batteries may restrict their use to smaller scale applications. Different "P2Y"-type of strategies, where P stands for surplus renewable power and Y for the energy form or energy service to which this excess in converted to, e.g. thermal energy, hydrogen, gas or mobility are receiving much attention as potential flexibility solutions, making use of the energy system as a whole. To "functionalize" or to assess the value of the various energy system flexibility measures, these need often be put into an electricity/energy market or utility service context. Summarizing, the outlook for managing large amounts of RE power in terms of options available seems to be promising.

Contents

Abbreviations: AC, alternating current; APC, active power curtailment; AUP, average unit price; CAES, compressed air energy storage; CCGT, combined-cycle gas turbine; CHP, combined heat and power; CPP, critical peak pricing; DHW, domestic hot water; DLC, direct load control; DOD, depth of discharge; DSM, demand side management; E2T, electricity-to-thermal; EV, electric vehicle; EWH, electric water heater; HVAC, heating, ventilating, and air conditioning; HVDC, high-voltage direct current; ICT, information and communications technology; MPC, model predictive control; P2G, power-to-gas; P2H, power-to-hydrogen; PEV, plug-in electric vehicle; PHES, pumped hydro energy storage; pp, percentage point; PV, photovoltaic; RE, renewable energy, renewable electricity; RTP, real-time pricing; SG, smart grid; SMES, superconducting magnetic energy storage; TOU, time-of-use pricing; TSO, transmission system operator; V2G, vehicle-to-grid; VRE, variable renewable energy

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1. Introduction

Energy systems need flexibility to match with the energy demand which varies over time. This requirement is pronounced in electric energy systems in which demand and supply need to match at each time point. In a traditional power system, this requirement is handled through a portfolio of different kind of power plants, which together are able to provide the necessary flexibility in an aggregated way. Once variable renewable electricity is introduced in large amounts to the power system, new kind of flexibility measures are needed to balance the supply/demand mismatches, but issues may also arise in different parts of the energy system such as in the distribution and transmission networks [1,2].

Large-scale schemes of renewable electricity, noticeably wind and solar power, are under way in several countries. Denmark plans to cover 100% of country's energy demand with renewable energy (RE) [3], Germany has as a goal to meet 80% of the power demand through renewables by 2050 [4], and in several other countries increasing the RE share is under discussion or debate [5–7]. At the same time, the renewable electricity markets are growing fast, e.g. in the EU, wind and solar stood for more than half of all new power investments in 2013 [8]. On a longer term, by 2050, RE sources could stand for a major share of all global electricity production according to several studies and scenarios [9–12]. Compared to today's use of RE in power production, the variable RE power utilization (VRE) could increase an order of magnitude or even more by the middle of this century. The experiences from countries with a notable VRE share, such as Denmark, Ireland and Germany, clearly indicate challenges with the technical integration of VRE into the existing power system, but also problems with the market mechanisms associated. Therefore, improving the flexibility of the energy system in parallel with increasing the RE power share would be highly important.

There is a range of different approaches for increasing energy system flexibility, ranging from supply to demand side measures. Sometimes more flexibility could be accomplished through simply strengthening the power grid, enabling e.g. better spatial smoothing [13]. Recently, energy storage technologies have received much attention, in particular distributed and end-use side storage [14–16]. Storage would be useful with RE power [17], but it is often perceived somewhat optimistically as a generic solution to increasing flexibility, underestimating the scale in energy [18]. Different types of systemic innovations, e.g. considering the energy system as a whole and integrating power and thermal (heating/cooling) energy systems together, could considerably improve the integration of large-scale