Renewable and Sustainable Energy Reviews 65 (2016) 577–586

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Wind and solar energy curtailment: A review of international experience

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A R T I C L E   I N F O

Article history:
Received 11 May 2015
Received in revised form
15 March 2016
Accepted 28 June 2016

Keywords:
Wind
Solar
Curtailment
Transmission congestion

A B S T R A C T

Greater penetrations of variable renewable generation on some electric grids have resulted in increased levels of curtailment in recent years. Studies of renewable energy grid integration have found that curtailment levels may grow as the penetration of wind and solar energy generation increases. This paper reviews international experience with curtailment of wind and solar energy on bulk power systems in recent years, with a focus on eleven countries in Europe, North America, and Asia. It examines levels of curtailment, the causes of curtailment, curtailment methods and use of market-based dispatch, as well as operational, institutional, and other changes that are being made to reduce renewable energy curtailment.

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http://dx.doi.org/10.1016/j.rser.2016.06.082
1364-0321/

1. Introduction

In many regions of the world, penetrations of renewable energy generation, particularly wind and solar energy, have increased substantially as a result of policies, incentives, and declining technology costs. High levels of wind and solar power can be challenging to integrate into electric power systems because of their variability and limits in predictability. In some cases, increased wind and solar penetration levels may drive a system to encounter transmission or operational constraints, forcing the system operator to accept less wind or solar than is available. When high levels of wind and solar generation are planned, infrastructural, operational, or institutional changes to the grid may be necessary. During this transition phase, curtailment may be higher than it is after these changes are made.

There are a variety of reasons for curtailment, including lack of transmission availability and system balancing challenges [1]. System operators often distinguish between the various reasons for curtailment for the purposes of compensating generators and system accounting. We use the term *curtailment* broadly to refer to the use of less wind or solar power than is potentially available at a given time. Definitions of curtailment can vary, and the availability and tracking of curtailment is limited in some areas.

Transmission congestion, or constraints on the local network, is a common reason for renewable energy curtailment [2]. In cases of where transmission networks are constrained, grid operators may utilize generators with higher marginal-costs instead of less expensive renewable generation, which do not have fuel costs (marginal costs). Lack of transmission access can also cause curtailments. Wind power plants are generally quicker to construct than transmission; therefore, in some instances wind power plants have been built in advance of the necessary transmission infrastructure to transport the energy to load centers. If curtailments are infrequent, it may be economically efficient to curtail periodically rather than expanding the transmission network.

System balancing issues can be another reason for curtailment. Wind energy, in particular, is often more available at night, when loads are low and thermal units are pushed down against their minimum operating constraints. If thermal plants are either retrofitted or replaced so that the minimum operating constraint is reduced, this type of curtailment may be reduced over time. A related issue is the requirement for downward reserves. If legacy wind and solar plants are unable to provide downward reserves, sufficient downward capability may need to be held on thermal units, raising their operating levels. This should not be an issue with modern wind and solar plants, however.

In the distribution system, curtailment can occur to avoid high penetrations or back-feeding, in which more energy is produced at the feeder level than consumed. High penetrations of solar generation on feeders can lead to voltage control issues due to the variability of the resource [3]. Back-feeding can be problematic for the distribution system if protection devices or other infrastructure were not designed, and have not been adapted, for this type of operation.

In some cases, especially on small, isolated grids, limits may be placed on the levels of nonsynchronous generation in order to maintain frequency control and address system stability issues. Modern wind and solar generators interconnect to the grid through the use of power electronics. Conventional synchronous generators provide inertia and often provide governor response. If a contingency event occurs when there is a high penetration of nonsynchronous generation on the system, frequency response might suffer, if non-synchronous generators are not able to provide synthetic inertia and fast frequency controls.

This paper provides an overview of renewable energy curtailment experience internationally. The objective is to understand the magnitude of renewable energy curtailment in various jurisdictions in recent years and how it has been managed. Lessons from these countries may be useful to other areas where additional renewable energy generation is expected in coming years. The following section reviews curtailment levels and causes of curtailment in eleven countries in Europe, North America, and Asia. Subsequent sections provide a broader synthesis and discussion of curtailment methods and mitigation measures or operational changes that are being made to reduce renewable energy curtailment.

2. Experiences with curtailment

2.1. Canada

In 2013, approximately 17,500 GW h of electricity was generated from wind resources in Canada, which comprised approximately 3.1% of the nation's overall electricity generation. Hydro Quebec currently has 1500 MW of installed wind power capacity (5% energy penetration) and expects to have 3000 MW of installed capacity (10% energy penetration) by 2016. TransÉnergie, the transmission system operator (TSO), assumes responsibility for system security. The distributor purchases power from wind developers, estimates the cost of lost energy using wind resource data, and compensates the wind plant operator.

To date, neither voluntary nor mandatory curtailment losses have occurred. However, additional installed wind capacity is planned for the Gaspésie Peninsula and will likely result in curtailment caused by congestion. It may also result in increased voluntary curtailment to ensure system stability.

Given the current projection for 2016 wind penetration levels, Hydro Quebec does not anticipate significant curtailments in the near future. For similar reasons, Hydro Quebec has not yet considered valuing curtailed generation as a source of system operating reserve or strategized how to reduce future losses.

2.2. China

In China, installed wind capacity reached 77.16 GW in 2013 with total generation of 142 terawatt-hours (TW h), which represented 73% of all non-hydropower renewable generation and approximately 2.6% of the nation's overall electricity generation. Installed wind capacity has grown 56% annually since 2001 and now represents approximately 6.2% of China's energy generating capacity, with the vast majority of this capacity situated in