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Comprehensive review of renewable energy curtailment and avoidance: A specific example in China

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ABSTRACT

Concerns over climate change (global warming) are driving innovation for stabilizing and reducing greenhouse gas (GHG) emissions. Technologies like carbon capture and storage (CCS) as well as renewable energy sources including wind and solar have been increasingly used and integrated into existing energy systems. The global installed renewable energy capacity booms, but many problems regarding grid integration appears due to the variability and uncertainty in the output of renewable energy generation. Therefore, large amount of curtailed electric energy (CEE) exists, which means some of the renewable energy generation must be wasted to keep real-time balance between load and generation in power system. In this paper, the definition of CEE is introduced, and the main causes for CEE are discussed. Then, the worldwide CEE is estimated, especially in China. Moreover, to evaluate the utilization priority of various generation resources, the potential of reducing fossil fuel consumption, GHG emissions and air pollutants as well as the potential of capturing CO_2 with CEE are analyzed. Possible CEE reduction strategies are also presented.

Contents

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1. Introduction

Renewable energy sources, such as hydropower, geothermal, solar, wind and marine energies, can serve as environmentally responsible alternatives to reduce dependence on fossil fuels due to their zero or near-zero emissions of both air pollutants and GHGs [1,2]. Renewable energy sources are steadily becoming a greater part of the global energy mix, in particular in the power sector. According to the "World Energy Outlook 2013" (International Energy Agency, IEA), the share of global renewable energy in electricity supply was 20% in 2011 and it was expected to increase to 31% by 2035 [3]. In China, according to the 12th Five-Year Plan (2011–2015), non-fossil fuel energy is supposed to account for 11.4% and 15% of the total primary energy consumption by 2015 and 2020, respectively [4].

Renewable energy generation is uncertain because its output is determined by the underlying meteorological factors. The abundant renewable energy may have to be curtailed because real-time balance between load and generation must be maintained, and electric generation cannot be economically stored on a large scale. In addition, renewable energy generation cannot be utilized in case of equipment maintenance, upgrade works or failure. Renewable energy curtailment in these cases is called curtailed electric energy (CEE). The massive CEE has caught more attention with a higher penetration of renewable energy worldwide, especially in China. In 2011, the curtailed wind power generation in "three-N region" (North China, Northeast, and Northwest) was up to 12.3 billion kW h, eventually causing a loss of 6.6 billion CNY for wind farm investors, and 16.23% of wind power generation in the "three-N region" is lost [5]. In addition, compared with 20 billion kilowatt-hours to curtailment in 2012, China's wind power sector lost as much as 16.2 billion kW h wind energy in 2013 [6]. In Spain, the curtailed wind energy totaled 0.315 billion kW h in 2010 and it was approximately 45–50% in Texas, USA from January to August 2008 [7].

The amount of CEE is important for power grid planning, construction, operation management, dispatching, and CO_2 emissions reduction. Hence, it is crucial to estimate CEE and find possible strategies to reduce or utilize it.

Overall, the main causes for CEE are analyzed in detail as follows:

(1) For renewable energy power itself, CEE is caused by equipment maintenance or failure [8], or other technical problems such as lack of fault ride through capability for certain generators [5], low generation flexibility [9], incorrect protection parameters setting, defective control strategy, and improper grounding measures in power plants and generators.
(2) For grid integration of large-scale renewable energy sources, CEE is caused by mismatched electrical demand. For real-time power balance, if renewable energy generation is abundant (like high wind power output due to strong wind speed), the load should be increased or the output of conventional power generators should be reduced. Due to transmission constraints, uncoordinated scheduling among dispatch centers, or the lack of any coordination mechanisms, large amounts of CEE occurs. In Fig. 1, the curtailed wind energy in large-capacity wind farms is illustrated.
(3) For grid integration of distributed small-capacity renewable energy sources, CEE occurs because distributed small-capacity renewable energy sources are not considered in generation scheduling for their small-capacity and low wind power forecasting accuracy. Once an imbalance happens, the outputs of renewable energy sources would be restricted.
(4) In addition, the common causes include shortage in adjustable load and adjustable power sources, and complicated electromagnetic interaction restrictions in proportion of renewable generation to the total generation of a power system.

Particularly, it is common for wind farms to experience generation curtailment due to turbine failures, or lack of network transmission capability or peak load regulation ability [8]. Curtailment of variable renewable generation, particularly wind and solar energy is discussed by many researchers. National Renewable Energy Laboratory (NREL) defined curtailment as a reduction in the output of a generator from what it could otherwise produce given available resources like wind or sunlight [10]. EirGrid and System Operator for Northern Ireland (SONI) pointed out that dispatch-down of wind caused curtailment and they also classified the dispatch-down [11]. Dispatch-down of wind for system-wide reasons (such as system stability requirements, operating reserve requirements, voltage control requirements, and system non-synchronous penetration limit) is called curtailment; dispatch-down of wind generation for more localized network reasons (more wind generation than the capacity of the network, maintenance, upgrade works or faults) is called constraint. In this paper, CEE contains both of the curtailment and constraint. A comprehensive analysis of constraints on the effective utilization of wind power in China has been conducted on the basis of infrastructural factors and operational factors [12]. The infrastructural factors include weak grid structure, concentrated wind sources far away from load centers, large proportion of coal-fired power plants and the absence of sufficient market mechanisms. The operational factors include unfavorable feed-in tariffs, unreasonable dispatch priorities, lack of grid codes for wind power integration and low wind power forecasting accuracy.

The objective of this paper is to give a comprehensive review of global and China's CEE. A method for CEE estimation is proposed. Based on the estimated CEE, the potential of reducing fossil fuel consumption and greenhouse gas emissions as well as the