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Solar energy curtailment in China: Status quo, reasons and solutions

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ABSTRACT

Recently, parts of the solar energy (especially photovoltaic power station) could not be connected to power system, leading to a serious solar energy curtailment problem. Generally speaking, in 2017, 91.4% of the rejected solar energy occurs in the northwestern China with the total electricity reaching 6670 GW h. Because China is of a large amount of the installed solar capacity, the existing large-scale solar energy curtailment problem have greatly affected the development of the solar power industry (e.g. the investors' profits) and the long-term development of the China's clean energy policy. In this review, based on the statistical data released by the authorities, the current status of the solar energy curtailment are reviewed with a detailed analysis of the reasons from the aspects of power generation and electric grid. This review focuses on the cases of the two typical provinces (Gansu province and Xinjiang Uygur Autonomous Region) with large-scale solar energy curtailment together with related analysis. Several practical solutions are also proposed to further relieve the problem in the near future. Detailed comparisons between different schemes are also given in order to help policy makers in China and also other countries for the further development of the solar power generation.

1. Introduction

China's electricity power serves an important part of the economic and social development. With the increase of the depletion of fossil and the serious environmental pollution problem, renewable energy becomes a paramount direction of China's energy development [1]. Solar energy is one of the important types of the renewable energy resources on the earth. With the technology development, the cost has been significantly reduced. Many countries identify the solar energy related industry as an important emerging one, which has shown a rapid development in the worldwide. Based on the statistics of International Renewable Energy Agency (IRENA), by the end of the year 2017, the cumulative installed capacity of solar power generation of the global had reached 390.625 GW [2, p.21], accounting for 18% of the global installed capacity of renewable energy generation [2, p.2]. The total and new installed capacity of photovoltaic (PV) power generation of global is 385.674 GW and 93 GW [2, p.24] respectively. Comparing with the data of the year 2016, the new installed capacity of PV power has increased by 32%. By the end of 2017, China's new grid connected installed capacity of PV power generation was 53.06 GW [3] and the cumulative installed capacity reached 130.25 GW [3], which is 68.7% more than the data of the year of 2016 [3]. The cumulative installed capacity of China accounts for 33.77% of the global PV installed capacity.

Specifically, China owns abundant solar energy resources due to its broad areas with rich solar radiation. Supported by the Chinese government, the photovoltaic industry system has made continuous progress with the significant improvement. China's PV power accumulative installed capacity increases from 70 MW in 2005 to 130.25 GW in 2017 [4]. By the end of the year 2017, the cost of polysilicon in China dropped to 60 thousand RMB per ton, the cost of component production dropped to 2 RMB per watt, and the cost of PV power investment dropped to about 5 RMB per watt, and the cost of the electricity was reduced to 0.5–0.7 RMB per kWh [5]. The form of photovoltaic power generation is shifting from the large-scale centralized power plants to the distributed ones, and also shifting from the northwest to the middle east. The development of solar thermal power generation are being accelerated with two demonstration projects finished in 2012 and 2013 respectively [6]. And the first batch of the solar thermal power generation demonstration projects start in 2016. The solar power generation installed capacity will reach above 110 GW including 105 GW of PV power and 5 GW of solar thermal power by the end of 2020 [6,

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Nomenclature

Roman/Greek letters

C_i	unit capacity of the ith photovoltaic module
$\widetilde{C}_i$	unit capacity of the ith benchmark photovoltaic module
C_{pv}	real-time start-up capacity of PV power station
L	time
M	number of the benchmark photovoltaic module
N	number of operating photovoltaic module
P_i	actual output of the ith benchmark photovoltaic module
Q	solar energy curtailment in a certain time
Q_i	solar energy curtailment of ith photovoltaic module
R_i	real-time output power of EMS (Energy Management Services) in photovoltaic power station
T_i	theoretical active power of ith benchmark photovoltaic power station
$\overline{\alpha}_p$	averaged output coefficient of benchmark photovoltaic module

Abbreviations

AC	Alternating Current
AGC	Automatic Generation Control
BPM	Benchmark Photovoltaic Module
CSPG	China Southern Power Grid Company Limited
CPV	Concentrator Photovoltaics
DC	Direct Current
EMS	Energy Management Services
EPDI	Electric Power Dispatching Institution
FIP	Fit-in-Premium
FIT	Feed-in-Tariff
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
NEA	National Energy Administration
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
SGCC	State Grid Corporation of China
UHV	Ultra-high Voltage

p.11], which proposed in the “13th Five-Year solar energy development plan”. The subsidies of the PV tariff will be terminated in 2020, and the cost of solar thermal power generation is less than 0.8 RMB /kWh [6, p.12]. "China Solar development roadmap" [7, p.13] predicts PV power and solar thermal power reach to 400–600 GW, 30–60 GW in 2030, and 1000–2000 GW, 180–500 GW in 2050, respectively. For more detailed introduction of the China's solar energy industry and electric power system, readers are referred to the Appendixes A and B.

However, with the rapid growth of the solar power generation in China, a large-scale photovoltaic power is unable to connect to the grid, leading to the solar energy curtailment. The problem of solar energy curtailment appeared in 2015, especially in the northwest region. In the year of 2017, the quantity of the solar energy curtailment was 7300 GW h [3] in China and the rate of solar energy curtailment was about 6% [3]. The quantity of solar energy rejection in the northwest reaches 6670 GW h [9], accounting for 91.4% of the total quantity of solar energy curtailment [8]. Other kinds of renewable energies (e.g. wind energy) is also facing the challenges raised by the curtailment [9–15]. In recent years, many researchers have investigated the problems of the wind energy curtailment. Bird et al. [9] summarized the reasons of wind energy curtailment in eleven countries, and also proposed several possible solutions to reduce the negative effects. In our previous work, Zhang et al. [10] conducted a systematic investigations on the problem of the wind energy curtailment in China based on the data released by the authorities and government. Several paramount reasons for the wind energy curtailment have been proposed including the insufficient local adoption, unreasonable structure etc. They classified the solutions into several categories e.g. grid side, demand side and energy generation side. Furthermore, brief suggestions to the other countries was also given based on the China's experience. For recent advances of the photovoltaic technology in China, readers are referred to Lam et al. [16]. Based on the literature survey, one can find that analyze of the status quo, causes and solutions of the solar energy curtailment in China is still insufficient. As the problem has appeared

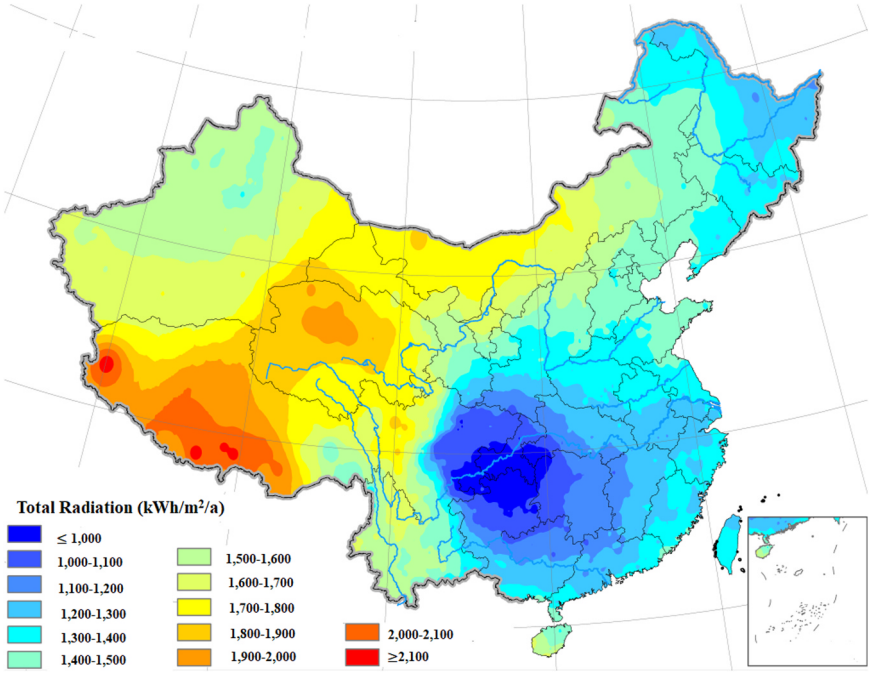

Fig. 1. Distribution of the total solar radiation on the horizontal surface in China. The figure was translated from China National Renewable Energy Centre [7].