Renewable Energy 118 (2018) 555–564

Contents lists available at ScienceDirect

Renewable Energy

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

Dynamic subsidy model of photovoltaic distributed generation in China

Yongxiu He [a, *, 1], Yuexia Pang [a], Xinmin Li [a], Minhui Zhang [b]

[a] School of Economics and Management, North China Electric Power University, Zhu Xin Zhuang, Bei Nong Lu No.2, Changping District, Beijing, China
[b] Vaughan College, 9121, Weston Road, Woodbridge, Ontario, Canada

ARTICLE INFO

Article history:
Received 24 March 2017
Received in revised form
19 October 2017
Accepted 15 November 2017
Available online 16 November 2017

Keywords:
Photovoltaic DG
Dynamic subsidy
The learning curve of cost
China

ABSTRACT

The differences in resources between regions and the environmental benefit are not currently considered in the subsidy policy on the photovoltaic distributed generation in China. To promote a further development of distributed generation, this paper establishes dynamic subsidy models for photovoltaic distributed generation from the aspect of the emission reduction benefit, based on a dynamic generation cost simulation, which is combined with the learning curve of cost. For projects that their internal rate of return does not reach the basic rate, a certain proportion of the initial investment subsidy will be provided. The calculated results show that with the gradual progress of photovoltaic power generation technology, the emission reduction benefit subsidy will be reduced with the reduction of unit cost. Moreover, factors such as the resources level, the proportion of generation internal consumption by the project and subsidies, all have an important impact on the internal rate of return of photovoltaic distributed generation projects.

1. Introduction

As of 2015, the total installed capacity of photovoltaic power generation in China is 43.18 TW, that China is becoming the country with the largest photovoltaic power generation installed capacity in the world [1]. The installed capacity of photovoltaic power plants in China is 37.12 TW, the distributed photovoltaic power generation is 6.06 TW, and the annual generating capacity is about 392 GWh [1]. In 2015, China added 15.13 TW capacity, accounting for more than 1/4 of the global added installed capacity [1]. Furthermore, China is one of the main countries producing the components of photovoltaic cells. Therefore, it also provides effective support for the development of the photovoltaic market. In addition to relying on the development of equipment manufacturing and technological progression, the development of distributed photovoltaic power generation has to rely on policy support, such as different subsidies [2].

As to the subsidy policies for the photovoltaic distributed generation (DG), from 2013 China mainly subsidized the photovoltaic DG according to the quantity of generation [3]. The subsidy standard was 0.42 yuan/ kWh (tax included), paid through renewable energy development funds, for a period of 20 years [4,5]. The current subsidy policies for photovoltaic DG are divided into state subsidies and local subsidies. The power grid enterprises transfer the expense of subsidies to distributed photovoltaic power generation companies, while a few provinces also add the initial investment subsidy based on the state subsidy. The most representative example is “Gold Sun Demonstration Projects”, where the national government gave 50% bid price subsidy support for the construction of photovoltaic roofing systems [6]. But since photovoltaic DG is still in the preliminary stage of development in China, many mechanisms are not as perfect, that the current subsidy policies do not take into account the differences of regional resources. With the cost of photovoltaic DG reducing, the current subsidy policies also do not flexibly reflect the changing of photovoltaic technology with time.

Apart from China, the main countries which implement photovoltaic DG subsidy policies are England, Germany, Australia, Italy, Japan, and others. Germany is one of the most mature countries in the field of photovoltaic technology and construction. In the early period of photovoltaic DG development, the German power grid company purchased all the electricity that the photovoltaic power grids generated and set different fixed price according to the

* Corresponding author.
E-mail address: heyongxiu@ncepu.edu.cn (Y. He).
[1] The first author's resume: Professor of North China Electric Power University. The main interest is energy economics and management.

https://doi.org/10.1016/j.renene.2017.11.042
0960-1481/

installation location of the photovoltaic power station (roof or floor) and different installed capacity. Considering the reduction of the price of PV components and updating of the technology, the initial investment in photovoltaic power generation has gradually decreased. In comparison to fixed tariff subsidies, in 2004 Germany proposed a mechanism for reducing photovoltaic power generation subsidies, by about 5–6.5% annually [7]. One study investigated Germany's feed-in tariff reform for photovoltaic DG in 2012. The reform was mainly to reflect the falling of costs of renewable energy distributed generation and to encourage photovoltaic DG to participate in the market competition. This reform proposed a feed-in tariff reduction rate mechanism according to the installed capacity, and the subsidy was adjusted every 3 months, with the rate of adjustment depending on the amount of added installed capacity [8]. On the other hand, the subsidy policy of the United States is different from Europe, which is mainly based on a preferential tax policy, such as the one-time cash subsidy (ITC). It means that 30% of the photovoltaic equipment investment as the tax-exempt amount can be used for other business [9]. Moreover, the Australian government tried to increase its generating capacity by providing subsidies to residential tenants installing solar power, and these subsidy funds were from taxes or electricity expenses that the community inhabitants paid [10].

Compared with traditional power generation, distributed power generation is an emerging industry, thus both the investment risk and costs of technology research are high. Many incentive policies have been proposed to develop DG effectively, such as feed-in tariff, quota-obligation, net-metering systems and so on. The goal of the incentive mechanism is to reduce the privately incurred cost and risk in order to guarantee investors' income [11]. Among which the feed-in tariff mechanism is one of the most popular means in the world, as it can protect the income of distributed generation investors and reduce the investment risk by setting a certain feed-in tariff [12]. A net power system was used in Japan in the early stage of photovoltaic DG development. A net-metering system requires a customer's local utility to purchase energy produced by a customer-sited DG system at the same retail price charged to the customer for energy consumption. If a DG system produces less than the customer's energy consumption, this DG production offsets the amount of energy drawn from the utility system. Thus, the utility sells less energy to the customer. Otherwise, if a DG system produces more than the customer's energy consumption, the excess energy is fed back into the utility system. In this case, the customer's meter runs backward to reflect the energy being sold to the utility. Thus, the utility only charges the customer for net energy sales [13]. Some research has compared the economic benefits of the feed-in tariff mechanism and net power system. Although both of them can save electricity costs and reduce emissions, the investment payback period of the feed-in tariff mechanism is less than the net power system, so the feed-in tariff mechanism is more effective [14]. In addition, one research study calculated the cost reduction of greenhouse gas and water usage due to photovoltaic DG from 2015 to 2050 in the United States and found that photovoltaic DG plays a role in environmental protection [15,16]. There are many kinds of subsidies for photovoltaic DG around the world, but few policies consider the environmental benefits, the main reason being that they are unable to quantify the environmental benefits of photovoltaic DG accurately. Taken the wind power generation of Xinjiang province in China as an example, the environmental benefits in terms of environmental protection has been analyzed and simulated [17]. Compared with the traditional thermal power generation, the cost of DG is high. However, the extent to which the cost of environmental protection can be reduced by DG can be used as a basis for subsidy compensation which includes two main aspects of expenses. One is the ecological damage of the environment caused by the decline of environmental quality and excessive consumption of natural resources. Another is the fines for the discharge of pollutants. At present, many pieces of research analyzing the environmental benefit of distributed generation mainly reflect the optimal allocation of distributed power planning [18].

Since the current subsidy mechanism for photovoltaic DG is relatively simple in China, and it does not reflect differences in regional resources, this paper is aimed at expanding the subsidy method based on dynamic calculation of the PV generation cost by means of the cost learning curve, and researching ways of allocating subsidies from the two aspects of initial investment and emission reduction benefits. These models can provide suggestions for photovoltaic DG development in the developing countries.

2. Dynamic subsidy models of PV DG in China

2.1. Simulation model of photovoltaic DG dynamic cost

For a photovoltaic distributed generation project, the cost of power generation depends on factors such as the initial construction cost, operating cost, financial expense, installation capacity, annual utilization hours, system efficiency, project life cycle and so on. The unit generation cost of a photovoltaic DG project is a ratio of annual average cost, which is the annual average investment cost, annual operation, maintenance cost, and annual financial expense, divided by the annual electric energy production. The calculation method is shown in formula (1,2).

$$C_{per} = \frac{C_{\text{inv}} \times PVA + \left(C_{\text{ope}} + C_{\text{fin}}\right)}{Q_{gen}} \tag{1}$$

$$PVA = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{2}$$

Annual electric energy production is determined by the installed capacity, annual utilization hours, the efficiency of the PV system and photovoltaic curtailment rate. It is calculated by formula (3).

$$Q_{gen} = M \times H \times \eta \times (1-d) \tag{3}$$

The initial construction cost of the project is composed of the equipment cost and installation cost, it is calculated by formula (4).

$$C_{\text{inv}} = C_{\text{equ}} + C_{\text{ins}} = C_{\text{equ}} + C_{\text{equ}} \times K_{\text{ins}} \tag{4}$$

The annual operating cost is estimated in accordance with a certain proportion of the total fixed investment. It is calculated by formula (5).

$$C_{\text{ope}} = C_{\text{inv}} \times K_{\text{ope}} \tag{5}$$

The annual financial expense is related to loan funds and lending rate, as shown in formula (6).

$$C_{\text{fin}} = C_{\text{inv}} \times K_{\text{loan}} \times i_{\text{loan}} \tag{6}$$

Based on formulas (1)–(6), the formula for calculating the unit generation cost of the distributed photovoltaic DG project is as follows.

$$C_{per} = \frac{C_{\text{equ}} \times (1 + K_{\text{ins}}) \times \left[PVA + \left(K_{\text{ope}} + K_{\text{loan}} \times i_{\text{loan}}\right)\right]}{Q_{gen}} \tag{7}$$

From the above equations, the generation cost of a photovoltaic DG project is mainly affected by the equipment cost and installed