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China's photovoltaic power development under policy incentives: A system dynamics analysis

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ABSTRACT

Recently China has brought out several incentive policies to break high-cost limitation and stimulate investment in photovoltaic industry. Under this favorable policy environment, PV power is undoubtedly facing enormous development opportunities. Firstly, after analyzing current policy environment and interactions between involved variables, a simulation model of China's PV power development was built using system dynamics methodology considering both economic and technical factors. Secondly, sensitivity analyses are made to analyze the sensitivities of key variables and the effectiveness of relevant policies. The simulated results of generation, investment and capacity during 2012–2032 indicate the future developing trend, and evaluate the rationality and effect of incentive policies. The model allows an understanding of PV power's long-term development pattern under China's latest incentive policies, thus helping to provide reference for policy-making institutions.

1. Introduction

Driven by climate change and fossil fuel depletion, renewable energy will undoubtedly become the developing trend worldwide especially in those countries which depend heavily on foreign fossil fuels [1,2]. Of various renewable energy sources, photovoltaic (PV) generation is a perfect match in time to the industry electrical load. It is a clean and renewable operation mode of electrical system, which can meet the industrial power demand and cover the pick load. Further, distributed PV generation avoids the electric energy loss during the transporting process of electric power. Therefore, PV power as an important inexhaustible resource will be the fastest-growing renewable energy for a long time [3].

However, the diffusion of PV power has been limited due to high costs [4,5]. National incentive policy seems to be the only way to promote PV power development [6,7]. Thus the Chinese government has taken the development of PV power as an important policy measure to reduce emission. Further, these policy measures are accompanied by policy incentives, including price subsidies, technology supporting and cost reduction.

Under this favorable policy environment, China's PV industry enjoyed fast cost declines and fulminic investment over the past decade [8]. These changes have resulted in dramatic increase of installed PV capacity [9,10]. Although the PV capacity is growing rapidly, it only accounts for less than 1% of China's total installed capacity [11]. Nonetheless incentive policy will continue to bring new developing opportunities to China's PV power industry. So it is of great significance to investigate PV power's long-term developing pattern under policy driving.

Many scholars have forecasted energy development and proved the necessity of renewable energy [12–16]. Other scholars have simulated the expansion planning [17–19] and efficiency improvement [20–22] of renewable energy resource. But the complex interactions within energy system under the influence of government policies have not been taken into account. And none of the existing models could be applied to China's current development environment. China's PV power development driven by incentive policies is a complex dynamic evolution process concerning many fields. System dynamics (SD) method can not only model system's real behavior but also explain the relationship between main variables within the system [17]. It enables us to stimulate the cost decline, investment fulmination and scale expansion, and optimize development patterns of China's PV power industry in the new policy situation.

The research method to be used in this paper is a simulation model of the key variables which influence or involved in PV power

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system based on the SD approach. The method has been previously used to simulate the evolution of energy system [23–25] and national incentive policies [26–29]. After analyzing the policy environment, the structure of this model is built according to the interactions between involved variables. The simulated results enable us to predict the developing trend of China's PV power, and evaluate the rationality and effect of these incentive policies. Further, sensitivity analysis is made to analyze the sensitivities of variables and provide reference for policy-making institutions.

2. Policy environment

2.1. China's air-pollution prevention policy

In September 2013, the state council issued *The Action Plan for the Control of Air Pollution*, which clearly pointed out that China's proportion of non-fossil energy consumption should increase to 13% by 2017 and the promotion of green building with distributed rooftop PV installation particularly. These distributed PV power technologies can help China improve energy efficiency and air quality.

In May 2014, China's National Development and Reform Commission (NDRC) set the clear development target of PV power generation. China's cumulative installed PV capacity should reach 35000 MW in 2015 and 70000 MW in 2017. It also proposed the regional development plan of PV power. Distributed photovoltaic power should be constructed in economically developed regions such as Beijing-tianjin-hebei and Yangtze River delta area. These regions are more proper and eager to develop distributed PV power. The construction of PV plant should be steadily progressed in western regions such as Gansu and Xinjiang which have rich solar energy resources and idle lands.

In August 2014, as the air quality got worse, the state council issued *The Action Plan for Energy Development Strategy* (*2014–2020*), which set the target of installed PV capacity to 100 GW by 2020. This action plan also announced that the subsidy of distributed PV power generation will continue to 2020. China's National Energy Chief Wu Xinxiong pointed out that the key of PV power development is the implement of supporting policies. First, China should expand the market of domestic PV power by increasing the price subsidies of renewable energy generation. Second, technology advancement and cost reduction can help PV power replace fossil energy and guarantee clean electric power supply. Further, the development of distributed PV power is significant in increasing the proportion of clean energy and optimizing the structure of energy consumption.

2.2. China's PV power development policy

In order to stimulate the technological advance and scale development of PV power generation, in January 2012, National Energy Administration issued *The Regulation of Golden Sun Demonstration Project* (*The Golden Sun* for short), which gave subsidies to 50–70 percent of the PV system investment. But this subsidy program was stopped in December 2013, because of many deceptive behaviors. Although national government stopped investment subsidies provincial governments give subsidies to 50–70 percent of local PV system investments.

In March 2013, NDRC issued *The Announcement of Improving PV Power Electricity Price Mechanism*, which set benchmark prices for PV power plants in four solar energy resource areas, and set a full electricity price subsidy of distributed PV power generation as 0.35 CNY/kWh. But PV industry widely believed that this feed-in tariff was too low.

In July 2013, the state council issued *Some Suggestions to Improving PV Industry Development*, which encouraged power consumers to feed PV power to grid after self-consumption at coal-fired benchmark price. These suggestions brought great developing opportunities to distributed PV power.

In August 2013, NDRC issued *The Announcement of Promoting PV Industry Development using Price Adjusting Leverage Function*, which further improved the PV power electricity price mechanism, and increase the electricity price subsidy of distributed PV power generation to 0.42 CNY/kWh (see Table 1).

In September 2014, NEA issued *The Announcement of Promoting PV Industry Development using Price Adjusting Leverage Function*, which announced that power consumers can choose to feed total or partial PV power to grid in areas with significant declining load.

The above policies bring development opportunities to PV industry. It is a big challenge to analyze the dynamic changing process of PV development course under the new circumstance. Considering its advantages on integrity and dynamics during the complex analysis, this paper plans to establish a SD model to simulate the development processes of PV power generation. The simulated results can help us figure out the policy mechanism and the development pathway of PV power industry.

3. Methodology

3.1. Model structure analysis

SD is a systems modeling and dynamic simulation methodology for analysis of dynamic complexity in socio-economic and biophysical systems [30]. Based on the principle of system thinking and feedback control theory, SD helps in understanding the time-varying behavior of complex systems [31]. Although other types of quantitative modeling can do the impact analysis, SD model with the advantage of solving dynamic problems is the only method which can better simulate the development process of China's PV power system. According to the above policy analysis, these incentive policies will influence the dynamic system mainly from four respects:

(1) Increase the proportion of PV generation by limiting thermal-power generation;

Table 1
FIT for PV power plants and subsidy for distributed PV.

		Solar irradiation zone		
PV power plant	Feed in tarrif	I	II	III
		0.90	0.95	1.00
	Investment subsidy	0-0.40		
Distributed PV	Subsidy for self-consumed PV electricity	Retail price of grid-electricity	national	0.42
			local	0–0.30
	Subsidy for surplus PV electricity feed-back to grid	Wholesale tariff of coal-fired power	national	0.42
			local	0–0.30