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RESEARCH ARTICLE

ENVIRONMENTAL VALUE ANALYSIS OF WIND ENERGY CURTAILMENT-HYDROGEN ENERGY STORAGE- ELECTRIC VEHICLES ENERGY USE SYSTEM BASED ON VALUE CHAIN.

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Abstract

Wind power generation is restricted by many factors, so wind curtailment and energy loss is massive in recent years in China. Technology of hydrogen energy storage is regarded as a new solution to the problem. In this paper, we concern wind energy curtailment-hydrogen energy storage- electric vehicles energy use system as a value chain, and construct the environment value model of the system. Numerical example analysis will verify that the technology of hydrogen energy storage for resolving wind curtailment is economical, environmental, practical, and can bring value increment.

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Introduction:-

Installed capacity of wind power in China is highest in the world now, however, due to many factors' influence, wind curtailment and energy loss is massive.Wind power curtailment is 41.9 billion kilowatt hour in 2017 [1], and it is 22.2 billion kilowatt hour in the three previous quarters in 2018[2]. China National Energy Board has issued instructions about developing wind power consumptive ways. Government encourages the construction of new demonstration projects on hydrogen energy storage and high-energy load power supply with wind generation, in areas with appropriate conditions.

Hydrogen storage is an extension of chemical energy storage, whose principle is that hydrogen and oxygen are obtained by electrolysis of water. Hydrogen storage technology is considered as an important support for the development of smart grid and renewable energy power generation, and has become the focus of energy technology innovation and industry support in many countries [3,4]. Chinese Government has constructed energy storage demonstration projects about hydrogen fuel cell and hydrogen stations, which mainly used for demonstration of new energy vehicles and distributed power [5,6].Driven by the electric, new energy vehicles can reduce exhaust emissions during their travel, while they transform the exhaust emissions of traditional vehicles most driven by oil, and reduce the dependence on oil and CO_2, SO_2, NO_X and other emissions [7].

An example is cited, that the hydrogen storage energy with wind power curtailment integrates into power grid and is used for new energy vehicles (referred to below as wind-hydrogen energy storage system). Considering the environment impact of the use of hydrogen energy storage to resolve wind power curtailment, this paper analyzed the environmental value. Current environmental value analysis methods include Protection expenditure method, Production effect method, Disease cost method, Willingness value method [8]. Appling the theory of environmental economics, referring to Chinese total amount of sewage charges standards and the United States environmental value standards, Wei Xuehao et al. (2003) developed pollutants emissions environmental value standards in thermal power industry [9]. Based on Contingent valuation method, Jiang Shuyang (2015) evaluated the ecological environmental problems and environmental values in a certain place [10]. Ehtiwesh, Ismael A.S et al. (2016) addressed an exergetic and environmental analysis of concentrated solar power (CSP) plants combined with a Life Cycle Assessment [11]. From the perspective of environmental spillover effect, Bai Lifei (2016) calculated the environmental value in the wind power industry [12].Yu lina (2017)evaluated the environmental performance of iron and steel enterprises by collecting the energy consumption， environmental emissions and financial data[13]． Aiming at the resource and environment value analysis of new energy electric heating (NEEH), Liu Zhaoting(2018) presented an analysis method[14].Although there are many studies on the analysis of environmental value, the research which is combined wind energy curtailment-hydrogen energy storage- electric vehicles energy use system to form a value chain is not common. So, the value chain theory and environmental value analysis are combined to study the environmental value of each link in the value chain of the wind-hydrogen storage system, which can explore the ways to solute wind power curtailment and improve environmental benefit.

Environment value chain analysis of wind-hydrogen energy storage system

Porter has been proposed that the value chain is a combination of all business activities and a collection of value appreciation activitiesof enterprisesin a specific sector. It includes foundation activities, such as logistics, human resource management, technology development and procurement. Value chain analysisis an effective management tool for industrial value， while environmental benefitmanagement is a part of the managementbehavior, and those two parts can be fit. The enterprise internal value chain model proposed by Potter does not enable enterprises to find their own position in the whole value creation of products, and to establish the cost or value advantage. So,value chain will be extended to the entire product creation process [15,16].

The business activities, which are hydrogen production by wind power curtailment and hydrogen integration into power grid to use for electric vehicles, constitute a complete industry value chain. Its flow chart is shown in Figure 1. Basic processes include electrolysis of water into hydrogen and oxygen and hydrogen storage by using wind power curtailment, when the wind power is sufficient but is unable to integrate into power grid. And when electrical energy is needed, the stored hydrogen is converted to electrical energy through different ways (internal combustion engines, fuel cells, or other means). We assume that the hydrogen storage is all used for new energy vehicles in the paper.

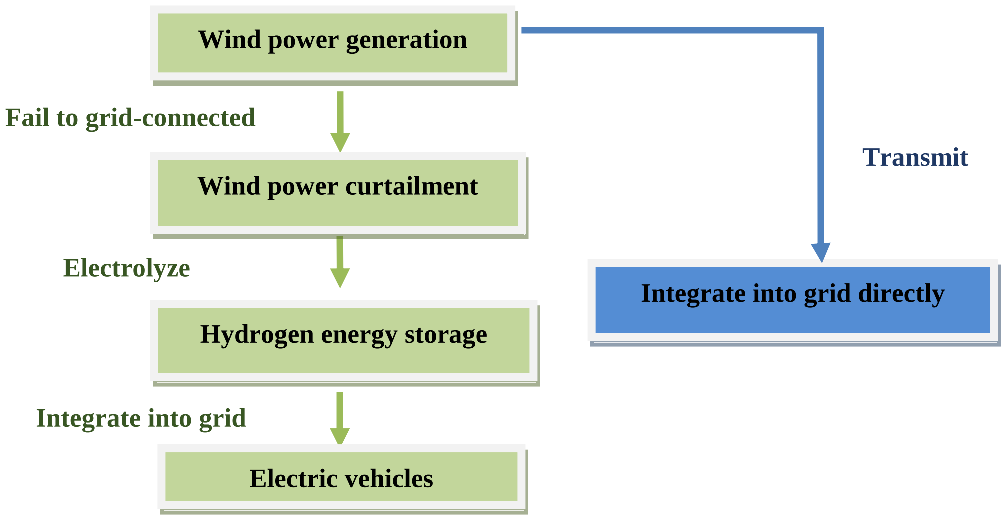

Fig. 1:-The value chain flow chart of the wind-hydrogen energy storage system

The whole process can bring environment value increment. Wind power is a clean energy[17]. And when hydrogen burns, it gives out enormous energy but produces water only, which makes it an effective and clean energy and brings large environmental value. The environmental benefits of the wind-hydrogen energy storage system are analyzed by the equivalent emission reduction of pollutant in the process and its environmental value in the paper.

Hydrogen energy storage system internal value chain analysis

In general, the hydrogen storage system is a cycle of hydrogen and electricity [18-20], which is different from the conventional lithium battery, lead acid battery. The front part of the system, water electrolysis represents the "charge" power. The back end part, fuel cell represents the "discharge" power. Those two capacities are most calculated by power (kW). The middle part is the hydrogen storage, whose capacity is calculated by hydrogen volume (Nm^3). The internal value chain model is constructed as following Figure 2.

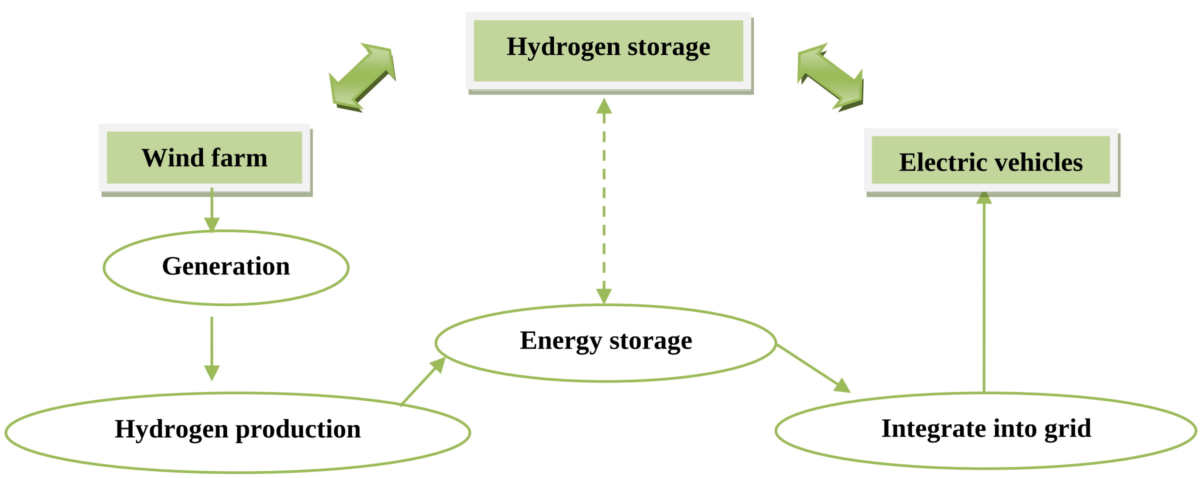

Fig. 2:-Internal value chain model

Hydrogen energy storage system external value chain analysis

The external upstream of wind-hydrogen energy storage system is wind farm, which is the power generation side. Wind farm use wind to generate electricity, which can cause wind power curtailment, then product hydrogen with wind power curtailment. The external downstream is demand side, namely, vehicles driven by electricity from hydrogen energy storage. The external value chain model is constructed as following Figure 3.

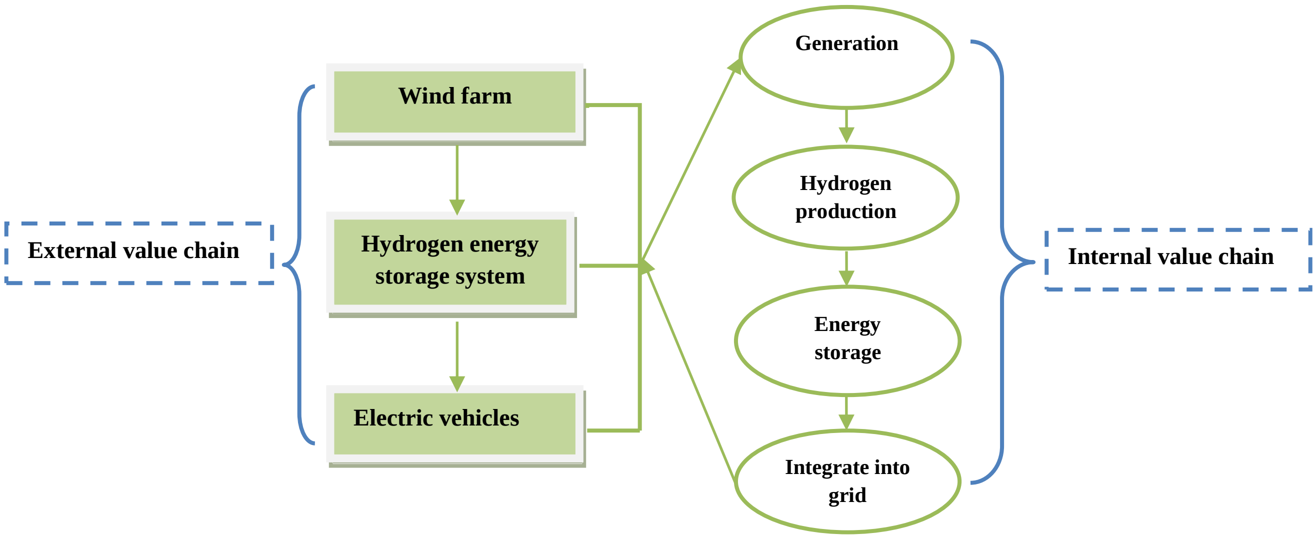

Fig. 3:-External value chain model

Because wind power and hydrogen are both clean and non-polluting energy sources, suppose there are no environmental pollutants among stages of wind generation, hydrogen production, energy storage and integration into grid. The pollutant equivalent emission reduction of environment value chain's upstream is analyzed by pollutant emissions from thermal power generation when it produces the same electricity as wind power generation. And it of downstream is analyzed by pollutant emissions from fossil-fueled vehicles when they drive the same mileages as new energy vehicles.

Environment value chain model of wind-hydrogen energy storage system

Pollutant emission in generation side of upstream

Suppose S is total annual electricity generation in a wind farm. Let k be the proportion of wind power curtailment and it is all used for hydrogen production. E_e is the electricity consumption of hydrogen production. V is the hydrogen capacity. E_h is the electricity with hydrogen power generation, about 1.25kwh/Nm^3. A the is standard coal consumption of electricity supply in thermal power plants, about 0.315kg/kwh. Suppose B is the coal consumption of thermal power when it generates the same electricity as hydrogen power generation, as shown in Equation (1), (2).

$$V = S \bullet k \bullet E_e \tag{1}$$

$$B = A \bullet V \bullet E_h \tag{2}$$

The main pollutants in coal-fired thermal generation are: CO_2, SO_2, NO_X, and dust. The calculation models are as follows:

Calculate the CO_2 emission with Equation (3).

$$G_{CO_2} = B \bullet 4.184 \bullet Q \bullet E \bullet \lambda_{CO_2} \bullet K_{CO_2} \tag{3}$$

G_{CO_2} is the emission mass of CO_2, and B is the coal consumption. Q is the calorific value of coal, and take the coal used in a power company in Zhangjiakou as an example[21]. The coal calorific value is 5500kcal/kg. E stands for the potential carbon emissions per unit calorific value and it is 24.74kg/MJ. λ_{CO_2} is the ratio of CO_2 to C mass, about 3.667. K_{CO_2} stands for the mass fraction of carbon oxidized, and it is 0.9.

Calculate the SO_2 emission with Equation (4).

$$G_{SO_2} = 1.6 \bullet B \bullet 10^3 \bullet \lambda_{SO_2} \bullet (1-\eta s) \tag{4}$$

G_{SO_2} is the emission mass of SO_2, and B is the coal consumption. λ_{SO_2} is the total Sulphur content, about 3%. ηs stands for desulfurizing efficiency, which is 95%.

Calculate the NO_X emission with Equation (5).

$$G_{NO_x} = 1.63 \bullet B \bullet 10^3 \bullet (\beta \bullet n + 10^{-6} \bullet V_Y \bullet C_{NO_x}) \tag{5}$$

G_{NO_x} is the emission mass of NO_X(with NO_2), and B is the coal consumption. β is the conversion ratio of fuel nitrogen to fuel NO, which is associated with fuel nitrogen content n. And it is about 20-25% under ordinary combustion conditions[22]. Let it be 23%. n is N content in fuel, 0.47% here. V_Y is the amount of smoke generated by 1kg fuel, about 7.75Nm3/kg. Let the concentration of temperature type NOx generated during combustion be C_{NO_x}, which is usually about 93.8mg/Nm^3.

Calculate the dust emission with Equation (6).

$$G_d = B \bullet 10^3 \bullet D \bullet d_{fh} \bullet (1-\eta) \tag{6}$$

G_d is the emission mass of dust, and B is the coal consumption. D is the coal ash,12%. d_{fh} is the dust content in ash,20%. η is the efficiency of dust collection,95%.

Pollutant emission in demand side of downstream

Assume the grid-integrated electricity from hydrogen storage is all used for new energy vehicles and there is no emission and adverse effect to environment.

Q_L stands for power consumption per hundred kilometers of electric vehicles. It is about 17kwh of a vehicle now. Let fuel vehicles replace electric vehicles, and y_i is pollutant emissions per kilometer of fuel vehicles. Emissions of each pollutant from fuel vehicles when they travel the same mileages as new energy vehicles are shown in Equation (7).

$$Y_i = V \bullet E_h / Q_L \bullet y_i \bullet 100 \tag{7}$$

Environment value model

$$W = \sum_{i=1}^{N} \left[R_i \bullet (Q_i + Y_i) \right] \tag{8}$$

W stands for the environment value of wind-hydrogen energy storage system used for new energy vehicles. R_i is the environment value of pollution. Q_i is the equivalent emission reduction of pollutant in hydrogen energy storage with wind power curtailment generation which is the generation side. Y is the equivalent emission reduction in using hydrogen energy for new energy vehicles which is the demand side.

Numerical example analysis

A company in Hebei established technical cooperation with McPhy and Encon company in Germany， and imported the advanced technology and equipment for hydrogen production with wind power generation. It constructed a 200MW wind farm, 10MW electrolytic hydrogen production device, and the system of hydrogen storage and transportation and comprehensive utilization, in Guyuan County, Zhangjiakou City, Hebei Province. The project was started construction in April, 2015, and it can produce 17.52 million cubic meters hydrogen annually, becoming the largest demonstration project of hydrogen production with wind power in China.

Pollutant emission in generation side of upstream

Suppose the company produces 17.52 million Nm3 hydrogen annually with wind curtailment generation，so it can produce about 21.9 million kwh power each year. According to the Equation (2), the coal consumption of thermal power when it generates the same electricity as hydrogen power generation is 6898.5 tons. In accordance with Equation (3)-(6), we can calculate that the pollutant equivalent emission reduction of hydrogen energy storage, from the generation side, is as follows.CO_2 reduces 12960 tons. SO_2 reduces 16.556 tons. NO_x reduces 12.155 tons. Dust reduces 8.278 tons.

Pollutant emission in demand side of downstream

On the basis of "National major science and technology industrial engineering project electric vehicle implementation plan", we assume that the fuel consumption per 100 kilometers of fuel vehicles is 10L.For its pollutant components and emissions per kilometer, see below. CO is 17g/km, HC is 2.7g/km, NO_x is 0.74g/km, CO_2 is 320g/km, SO_2 is 0.03g/km. Greenhouse gas conversion coefficient was adopted by the calculation standard in the "Kyoto Protocol", and each gram of HC is equivalent to CO_2 23g.So the emission per unit after data reduction is as below. CO is 17g/km, NO_x is 0.74g/km, CO_2 is 382.10g/km, SO_2 is 0.03g/km [23].

The pollutant equivalent emission reduction in using hydrogen energy for new energy vehicles from demand side can be calculated with Equation (7). CO_2 reduces 49200 tons. SO_2 reduces 3.865 tons. NO_x reduces 95.329 tons. CO reduces 2190 tons.

Calculating environment value

Referring to Chinese total amount of sewage charges standards and pollutants emissions environmental value standards in thermal power industry, the value standards in this article is shown below. CO is 1yuan/kg, NO_x is 8yuan/kg, CO_2 is 0.023yuan/kg, SO_2 is 6yuan/kg. Dust which is difficult to monitor is charged by level 2, according to sewage charges of Ringelman blackness collection, about 3yuan/ton.

The company's annual environmental value of wind-hydrogen energy storage system is 3.71838 million, from Equation (8). The calculation results of environment value are shown in Table 1.

Table 1:-Environment value calculation results

pollutant kinds	value standards (yuan/kg)	emission reduction in generation side(ton)	emission reduction in demand side(ton)	environmental value(million yuan)	environmental value(million yuan)
CO	1	-	2190	2.19	2.19
CO_2	8	12960	49200	1.43014	1.43014
NO_x	0.023	12.155	95.329	0.859872	0.859872
SO_2	6	16.556	3.865	0.122526	0.122526
dust	0.003	8.278	-	0.000024834	0.000024834
total	-	-	-	4.602597	4.602597

Numerical example analysis illustrates that using hydrogen storage system tosolve wind energy curtailment is an economical, environmental and practical technology and can bring value increment.

Conclusion:-

The important method ,which is producing and storing hydrogen with wind power curtailment and using the energy for new electric vehicles, can reduce wind power curtailment rate and achieve high efficiency and low carbon utilization of wind energy. This article studied the environment benefits of integration into grid of hydrogen energy storage produced by wind power curtailment. Taking the hypothesis that grid-integrated electricity is all used to provide power for new energy vehicles as an example, combined with the theory of internal and external value chain analysis, a practical example shows that the wind-hydrogen energy storage system has a high environmental value, which can provide the reference direction for improving value benefit. There are some problems in the process of research. For example, the pollution of more aspects in value chain process and the refinement criteria of environmental value are not included in the scope of consideration, which are focal points in studies in the future.

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