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Research on non-grid-connected wind power/water-electrolytic hydrogen production system

*Gu Weidong**, *Yan Zhuoyong*

Jiangsu Academy of Macroeconomic Research, Nanjing 210013, China

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ABSTRACT

Hydrogen has been recognized as the most promising future energy carrier. At present, industrial hydrogen production processes are not independent of traditional energy resources, which could easily cause secondary pollution. China has abundant wind energy resources. The total installed capacity of wind power doubled every year in the last five years, and reached 26 000 MW by the end of 2009, but over 9880 MW wind turbines were not integrated into grid because of the peak shaving restraint. In this paper, wind power is directly used in water-electrolytic process by some technical improvements, to design non-grid-connected wind power/water-electrolytic hydrogen production system. The system all works properly, based on not only the wind/grid complementary power supply but also the independent supply of simulation wind power. The large-scale fluctuation of current density has little impact on current efficiency and gas quality, and only affects gas output. The new system can break through the bottlenecks of wind power utilization, and explore a diversified development way of large-scale wind power, which will contribute to the development of green economy and low carbon economy in China.

1. Introduction

Hydrogen has been recognized as the most promising future energy carrier. At present, industrial hydrogen production processes are mainly using coal, naphtha, coke oven gas, and natural gas as raw materials for steam conversion hydrogen production at high temperature, as well as the water-electrolytic hydrogen production, and so on. The water-electrolytic hydrogen production generally uses grid power, and more than 75% of electricity in grid is from thermal power in China. Therefore, these processes are not independent of traditional energy resources, which could easily cause secondary pollution, and have a greater impact on the environment. "Green hydrogen" [1] means to use renewable energy sources (wind, solar, etc.) to produce hydrogen, which has no pollution. In the current various technologies, the water-electrolytic hydrogen production using wind power, is one of the most mature and most promising industrial technologies.

China has abundant wind energy resources and has invested a great deal of manpower and resources into the development of wind power. The total installed capacity of wind power doubled every year in the last five years. By the end of 2009, the total installed capacity of wind power reached 26 000 MW [2], which added 13 800 MW new installed capacity to achieve 113% growth. But over 9880 MW wind turbines were not integrated into grid because of the peak shaving restraint, up to 38.0% of the total installed capacity [3]. The wind power, which was not integrated into grid, is a tremendous waste.

At present, wind power grid connection is the only application of large-scale wind power farm in the world. High randomicity of wind affects the quality of wind power, and the contribution rate of wind power on the grid is hardly beyond 10%

* *Corresponding author*. Tel.: +86 25 8339 1672; fax: +86 25 8339 1800.
E-mail address: gu-wd@hotmail.com (G. Weidong).

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[4] if there is no gas-fired power or hydropower for peak shaving. In addition, the wind-powered generator need to meet the requirements of power grid such as the stabilization of frequency, voltage and phase, which increases the complexity, the manufacturing costs as well as the price of wind power indirectly. As a result, the applications of large-scale wind power are limited. "Non-grid-connected wind power" theory was first suggested by the author paper in 1985 [5] and improved continuously. Large-scale non-grid-connected wind power system [6,7] means that the terminal load is not a single traditional grid, but a series of high energy-consuming industries and other special areas which are adapt to the characteristics of wind power, which could avoid the development bottlenecks of wind power, save a large number of auxiliary equipments for wind power grid connection, and increase the utilization rate of wind power.

According to the characteristics of wind power, non-grid-connected wind power/water-electrolytic hydrogen production system was designed and the output power of wind turbine was simulated. The system could be operated at the independent supply of simulation wind power or the wind/grid complementary power supply. The effects of wind power on current efficiency and hydrogen production equipment, etc. were investigated, which showed a fundamental basis for industrial water-electrolytic hydrogen production using large-scale non-grid-connected wind power.

2. Experimental principle and equipment

2.1. Principle and equipment of water-electrolytic hydrogen production

The principle of water-electrolytic hydrogen production shows that water molecules are decomposed into hydrogen and oxygen on the electrodes when the electrochemical reaction occurs. Because water is a typical weak electrolyte with low conductivity, some strong electrolyte (such as sodium hydroxide, potassium hydroxide, etc.) should be added, to increase the solution conductivity and make water smoothly decomposed. When direct-current (DC) plays role in potassium hydroxide (KOH) aqueous solution, water molecules (H_2O) are broken down into hydrogen ions (H^+) and hydroxide ions (OH^-) in the cathode zone. Hydrogen ions generate hydrogen atom with the electron, and further generate hydrogen molecule (H_2). Hydroxide ions (OH^-) are forced by electric field through the ion-exchange membrane to reach the anode area, and lose electron to form water molecules (H_2O) and oxygen molecules (O_2). The anodic and cathodic reactions are as follows [8]:

Cathodic reaction:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (1)$$

Anodic reaction:

$$2OH^- \rightarrow \frac{1}{2}O_2 + H_2O + 2e^- \quad (2)$$

Overall reaction:

$$2H_2O \xrightarrow{\text{Electricity}} 2H_2 + O_2 \quad (3)$$

Pressure-type alkaline water-electrolytic hydrogen production equipment is shown (10Nm^3/h) in Fig. 1. The core device is the electrolyzer including several small cells, of which the rated voltage is 50 V DC. When the operating voltage is higher than the threshold voltage of gas production, the equipment is to begin production. Hydrogen and oxygen are produced in cathode area and anode area, respectively. To meet the requirements of industrial production, high pressure hydrogen and oxygen should pass through cooled unit, purified unit, and dried unit sequentially. In the operation, water consumed by electrolysis process is added by the circulation pump continuously. The electrolyte temperature is controlled by a water cooler system, in order to keep operating temperature normal.

2.2. Power supply of water-electrolytic hydrogen production system

Theory basis of coupling system between non-grid-connected wind power and water electrolysis is that, large-scale fluctuation of wind power current density has little impact on water electrolysis efficiency in the electrolyzer when “three fields” were balanced including temperature field, electric field and flow field. To solve the impact of wind power fluctuation on the production process, water-electrolytic technology, cooling unit and power supply should be improved. The electrolyzer uses the intelligent power controller which achieves “seamless connection without disturbing each other”, to make “wind power-based, grid power-supplemented”, and has two supply models named as wind/grid complementary power supply and wind power independent supply. No matter wind is strong or weak, wind power will be consumed totally. There are three situations: no grid power is consumed when wind power is higher than rated power of electrolyzer; grid power is complementary when wind power is lower than rated power of electrolyzer; and grid provides all power when no wind. The water circulation pump and other auxiliary equipment use gird power. The flow of cooling water is also controlled according to the wind conditions. So “three-field” balance for the improving water electrolyzer was achieved. The circuit diagram of non-grid-connected wind power/water-electrolytic hydrogen production system is shown in Fig. 2.

Fig. 1 – Pressure-type alkaline water-electrolytic hydrogen production equipment.

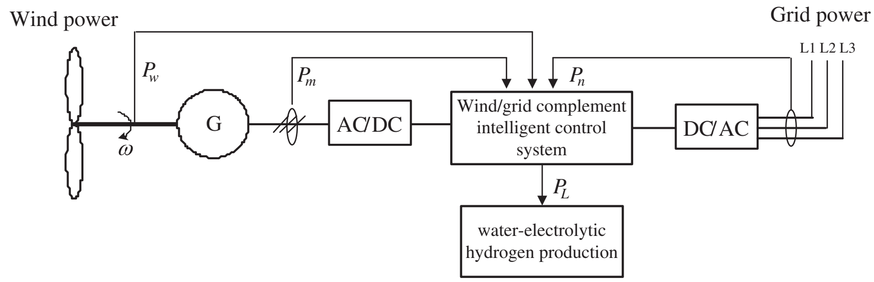

Fig. 2 – Circuit diagram of non-grid-connected wind power/water-electrolytic hydrogen production system.

3. Results and discussion

3.1. *Independent supply of simulation wind power*

In the independent supply circuit of simulation wind power, the voltage of grid power stabilized at zero, and the corresponding output current is zero. In this case, the power of entire equipment is independently supplied by simulation wind power, which was used to study the impacts of output power changes on entire equipment, current efficiency and flows of hydrogen and oxygen, adjusting the voltage of wind power simulation circuit between 0 V and 55 V.

The voltage(U)–current(I) operating curve of water-electrolytic hydrogen production equipment is shown in Fig. 3. In working, the DC voltage of electrolyzer must be greater than the theoretical decomposition voltage of water, in order to overcome the voltage drop of various resistances and the electromotive force of electrode polarization. The operating voltage must be over a certain voltage value (threshold voltage of gas production). If it is less than the value, it can't work and no gas is produced. Therefore, to keep it working normally, it must guarantee that the wind turbine has a minimum output voltage-threshold value. Above the threshold voltage, current increases with voltage. So, voltage can be regulated to adjust current value and hydrogen output.

The output power (P) of a certain type wind turbine in a day is shown in Fig. 4. Hydrogen output (Q) of water-electrolytic equipment at the simulation power for the wind turbine is shown in Fig. 5. With the fluctuation of output power, the flow of hydrogen has the same trend of fluctuation. The unstable power output of wind turbine only affects the output of hydrogen, but does not affect the equipment performance, which indicates that wind power is fully feasible to be used for water-electrolytic hydrogen production. Its working area is very wide, which almost covers all values of the output power from zero to rated power. As long as the work voltage is higher than the threshold voltage, it will be able to fully meet the instability of wind power.

As shown in Fig. 6, the large-scale change of current density (J) has little impact on current efficiency (φ) and gas quality (The concentrations of hydrogen and oxygen measured by hydrogen analyzer and oxygen analyzer (xi'an tiger Co., Ltd) were stabilized at more than 99.8% and 99.3%, respectively.), but only affects gas output. It indicates that water-electrolytic technology can match the characteristics of wind power, and the fluctuation of wind power has no effect on the current efficiency of water electrolysis.

3.2. *Wind/grid complementary power supply*

In the wind/grid complementary power supply circuit, when the output power of wind turbine is high, the power is mainly supplied by wind power, and the output power of grid power is restrained. When the output power of wind turbine is low, the grid power will keep a proper output power to ensure the equipment work properly.

When the grid power voltage is set at 50 V, and the wind power voltage is regulated from 0 V to 55 V, the operating

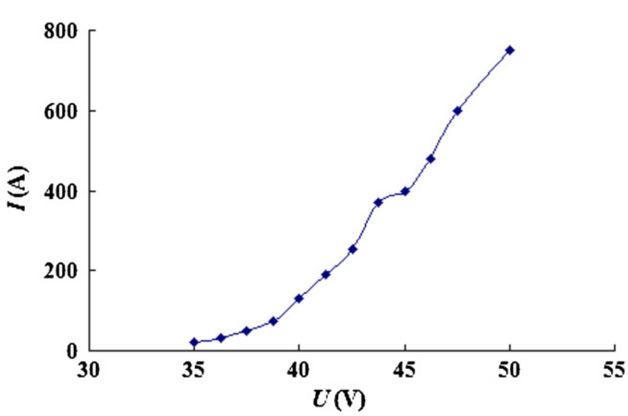

Fig. 3 – Voltage–current operating curve of water-electrolytic hydrogen production equipment.

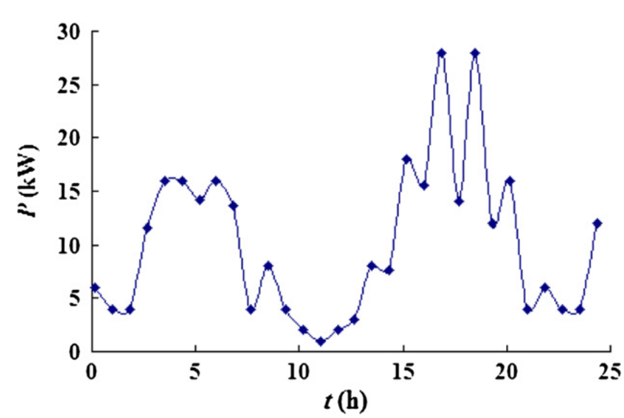

Fig. 4 – Output power of wind turbine.

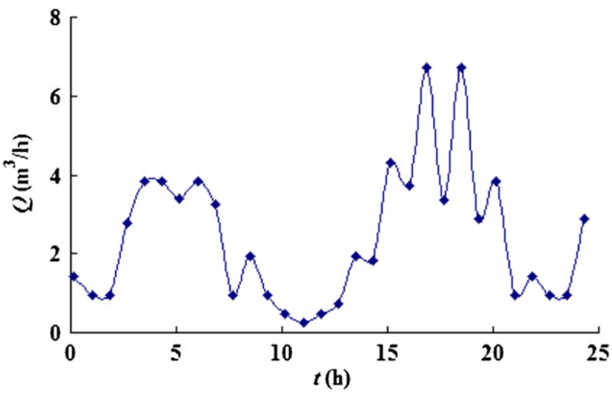

Fig. 5 – Hydrogen output of water-electrolytic equipment.

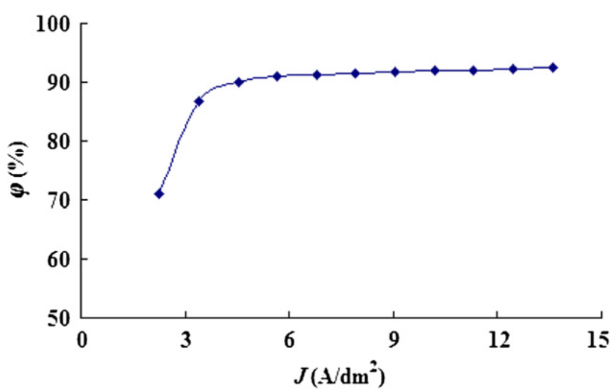

Fig. 6 – Curve between current density and current efficiency.

voltage and current curve is shown in Fig. 7. When the voltage of wind power is low and the current is small, the grid power current is high and the grid power mainly supplies to equipment. The wind power current increases with the increasing voltage of wind power. When the grid power current is smaller, wind power replaces grid power gradually as the main power supply, but the total current maintain stable, which ensures 100% utilization of wind power and maintains a stable gas output. If the design is reasonable, it will be operated at full load to increase gas production efficiency.

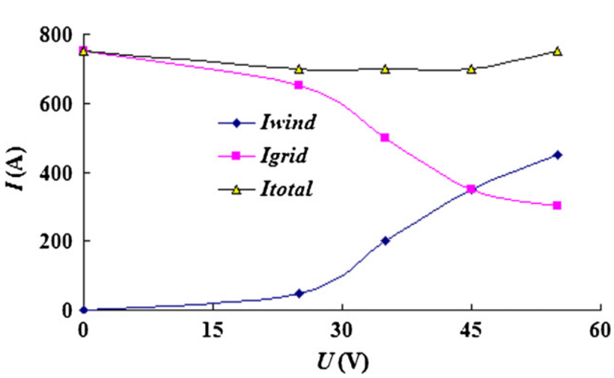

Fig. 7 – Voltage–current curve of equipment operating at wind/grid complementary power supply.

4. Conclusions

The water-electrolytic equipment has a strong adaptability to the unstable power output of wind turbine. The electrolyzer has a big operating space, and the equipment works properly in test conditions, in which the large-scale change of current density has little impact on current efficiency as well as gas quality, but only affects gas output, which indicates wind power is fully feasible to be used for scale water-electrolytic hydrogen production. The working power of water-electrolytic equipment in the experiment almost covers all values of the output power from zero to rated power.

Non-grid-connected wind power/water-electrolytic hydrogen production system can save a large number of auxiliary equipments for wind power grid connection, increase the utilization rate of wind power, and break through the development bottlenecks of wind power, which will explore a diversified development way of large-scale wind power, form hundred billions (Yuan) of the emerging strategic industry, and contribute to the development of green economy and low carbon economy in China. The achievement had passed the evaluation of National Hydrogen Power Standards Technology Association (SAC/TC309) of China, and become an important part of the national standard-"Appraising rules for performance of pint-size and integrative hydrogen energy system".

Acknowledgments

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