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The Study and Exploration of a New Generation of Photovoltaic Energy Storage System

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Abstract

This article introduces the existing compositions of solar photovoltaic power generation systems. An analysis of current problems of such system is given. And then, we propose an optimization system and functional requirements for DANCI. The problems of storage cells pollutions and grid-connected will be solved through adding hydrogen electrolysis unit, hydrogen storing device, and hydrogen storage cells in the traditional photovoltaic power generation system.

Keywords: Solar Photovoltaic Power Generation; PEM FC; Grid-connected; Fuel Cell; Battery

1. Introduction

At present, with the global economic growing rapidly, the traditional fuel energies, such as coal, oil, gas and other conventional energy sources, are being reduced day by day for large-scale using and mining, that has caused global warming and ecological environment deteriorating, therefore, sustainable development of energy and environment has become a major concern of mankind. Developing renewable energy technology is an effective way to solve this problem. As an important part of new and renewable energy with inexhaustible and no-pollution character, solar energy, one of clean and natural resources from distributives, can be exploited and used in everywhere, and will not damage the ecological balance.

The solar photovoltaic power generation system has lots of problems such as serious harmonics, frequency instability, and great impacts from the grid-connected; therefore, it will be a great task how to optimize photovoltaic power generation system. The article will connect it with fuel cell power generation, and then use hydrogen as inter-media and add hydrogen storing devices to link with the fuel cell power

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generation in order to solve problems of highly effective uses of electricity and grid. Finally, through the fuel cell power generation exothermic chemical reactions for heating, it may instead of steam stations in per-urban areas so as to reduce cities' pollution.

2. The Introduction of Photovoltaic Power Generation System

Photovoltaic power generation system is divided into grid-independent photovoltaic systems and grid-connected photovoltaic systems. Alone PV power station includes power supply systems in remote villages, household solar power systems, communications signal power, catholic protection, solar street lights and other batteries which can run independently.

Grid-connected photovoltaic power generation system is connected to the grid and transmits electricity. It can be divided into the one with a battery and the one without batteries. The power generation system with battery has schedulability, which can be incorporated into or out of power as needed, also it has a standby power function, that is, the emergency power supply when the grid power for some reason, therefore, it is often installed in residential buildings; The power generation systems without batteries do not have schedulability and backup power function, so it is usually installed in larger systems.

2.1. The grid-connected processes of stand-alone power generation system

1) The solar controller regulates and controls the energy. On the one hand, send the adjusted energy to the DC load or AC load; on the other hand, send the excess storage of energy to the batteries. When the electricity does not meet the load necessary, the controller will send the solar energy in the battery to load. When the battery is fully charged, the controller has to control the battery not overcharged. When the energy is stored in the battery discharge end, the solar controller has to control the battery not over charged in order to protect the battery. If the controller has poor performance, there will be a great impact on battery life, and ultimately, will affect system reliability[1].

2) The great task of solar batteries is for storing energy in order to ensure normal electricity supply at night or rainy day.

3) Solar Inverter is responsible for turning the direct current into alternating current for the exchange of load to use. Photovoltaic solar inverter is a core component of the wind power generation system. Because it is usually used in the relatively backward and remote regions, there are many difficulties for maintaining. In order to improve the overall performance of the solar wind power system and to ensure long-term stable operation of power stations, it has to propose high demands on the reliability of the inverter. In addition, as the high cost of new energy power generation, the efficient operation of the solar inverter seems more important[2].

2.2. The current form of photovoltaic power generation system

1) System equipment

Photovoltaic solar power generation system is made up of solar cell matrix, batteries, charge and discharge controller, inverter, solar tracking control system and other equipment components. The whole system shown in Figure 1 consists of the following. The role of some equipments as follows:

2) Solar cell matrix

In a light case, cells absorb light energy, and then the accumulations of different signs appear at both ends of battery charges. There is "photovoltaic", that is, the "photovoltaic effect". Influenced by the photovoltaic effect, solar cells generate force at both ends, turning the light energy into electrical energy as an energy conversion device. Silicon solar cells are generally divided into single crystal silicon solar

cells, polycrystalline silicon solar cells and amorphous silicon solar cells.

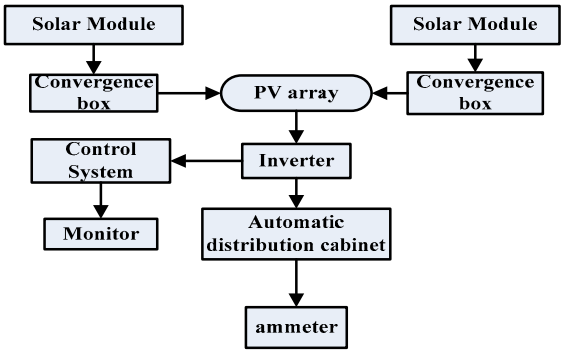

Fig. 1. Constitute a photovoltaic system

3) Batteries

The role of the storage battery is ready to load the electricity energy which the solar cell matrix irradiated by the light energy emit. The basic requirements of solar power batteries of are:

a. Self-discharge rate is low;
b .Long life;
c. Deep-discharge capability;
d. Charging efficiency;
e. Low-maintenance or maintenance-free;
f .Wide operating temperature range;
g. Low prices.

4) Charge and discharge controller

Charge and discharge controller is a device which can automatically prevent the battery from overcharge and over discharge. As the number of battery charge and discharge cycles and the depth of discharge battery are important factors in the decision of battery life, so it is an absolutely necessary device to control the battery charge or over discharge.

5) Inverter

The inverter is the equipment which turns direct current into alternating current. Since solar cells and batteries are DC power, the inverter is essential when the photovoltaic power generation load is AC load. From modes of operation, inverter can be divided into stand-alone inverter and grid-connected inverter. Stand-alone inverter is used for stand-alone solar power generation system as an independent load, and grid inverter used for grid solar power generation systems. From ways of output waveform, Inverter can be divided into the square wave inverter and sine wave inverter. Square wave inverter circuit, simple, low cost, but the harmonic large, is generally used for several hundred watts less and less demanding on the harmonic system. Sine wave inverter costs high, but can be applied to a variety of load [3].

2.3. Problems in the current PV

1) When the PV system is directly connected into the grid it is influenced by the weather in large degree. If the sun is not sufficient, or it is cloudy, rainy, or the hot weather, the solar conversion efficiency of the photovoltaic effect will be reduced in the large scale, however, continuous power supply system is also needed. It will cause voltage instability, harmonic serious, and bring many difficulties for the stable operation of the power grid and it is the main problem for the distributed energy generation.

2) For stand-alone photovoltaic power generation system, the higher quality and the higher fraction of power supply users require, the larger quantity of battery system needs. In the long time, the dependency on batteries (primarily lead-acid batteries) is one of significant reasons which affect the independent operation of photovoltaic power generation system promoting and application in a large number.

3) BESS disadvantage is the high initial investment, short life, high depreciation, and increasing cost from the surface of the system generation; for lead-acid batteries, there are lots of workload for running and maintaining. Environmental problems exist as well. Moreover, the technology and reliability problems of battery charge and discharge are also paid close attention to by photovoltaic system designers and users. But nowadays, the limited capacity and the energy limited storage are major problems for the current battery technology.

3. PV Power System Optimization

View of the city features needing for clean energy, the independent operation of photovoltaic power generation system still has a large market, so it is great task to develop high-density, low-cost, long life, pollution-free energy storage system, to reduce dependence on natural conditions and improve the stability of power photovoltaic system for popularizing photovoltaic technology and further developing the market.

During the day, in the presence of light, the solar modules produce a certain force, and then the solar cell matrix is formed by the series-parallel components in order that the voltage reaches demands of the system input voltage. Then through the electrolysis system, it will produce the direct current electrolysis electrolyte to produce hydrogen, and a large number of hydrogen is stored in hydrogen storage made of alloys, and then the stored hydrogen will generate power through the hydrogen fuel cell, while the chemical reaction heat will be collected. Beside of the energy used to loop, the excess heat, instead of thermal power plants, can be used to heat input for urban users and will make pollution to a minimum. The PV power plant system should have the limited load protection and lightning protection devices to protect the system equipment from overload and lightning operation, and ensure safe use of equipment maintenance system.

Solar energy conversion process → chemical energy → electrical energy → electrical energy → heat energy.

The system adds three steps into the original photovoltaic power generation system, that is, the DC hydrolysis process, storage process, and the PEMFC power generation systems.

In recent years, the hydrogen energy progress and proton exchange membrane fuel cell technology breakthrough in the field of hydrogen technology have provided possibilities for the stand-alone photovoltaic power generation system in changing the original way that the energy stored in batteries and finding the innovative system operation mode. This advantaged solar photovoltaic power generation system operation mode is: in the photovoltaic power generation system, hydrogen storage alloy will be instead of the traditional battery storage. When the sun is good, through electrolysis of water for hydrogen, the excess energy will be stored up; When the sunshine cannot make the photovoltaic power generation system work as normal, the stored hydrogen will be converted into electricity through fuel cells, and will continue to send power to the load, thus ensure the continuity of hydrogen energy storage, and then consider hydrogen gas as a fuel cell power generation system, while collect heating which is released in the fuel cell power generation process to provide exothermic heat in the replace of power plant for the city power supply.

The system has the following advantages:

Energy density, long life, low operation cost, almost no pollution, heat and electricity supply, without geographical constraints, and maximizing the generation capacity of PV systems.

4. Electrolysis for Hydrogen Production

Water electrolysis hydrogen H_2, prepared to achieve industrialization as an important mean in the cheap way, can obtain pure productions from 99% to 99.9%. Our electricity consumption has reached (1.5×107) kw·h or more in water electrolysis hydrogen production each year. When the current passes from the electrode, the cathode produces hydrogen; oxygen produces at the anode, that is, the water electrolysis out. Electro-bath is in the core part of water electrolysis hydrogen generation equipment, and the electrode material is the key of electro-bath. Electrode performance, good or bad, will determine the voltage level of electro-bath and energy measurement to a large extent, and will affect costs directly. Decomposition of water can provide the use of power efficiency makes the efficiency of water electrolysis hydrogen H_2 in 75% -85%, and the process is simple, no pollution, but large power consumption, so its applications generally receives from certain restrictions.

The catholic reaction: $4H_2O + 4e = 2H_2 + 4OH^-$ φ=-0.828V

Anodic reaction: $4OH^- = 2H_2O + O_2 + 4e$ φ= 0.401V

Alkaline water electrolysis hydrogen is commonly used in preparation of hydrogen and it is a more mature approach. It doesn't need high requirement for equipments of the Act, but the investment is high relatively; it can produce high purity hydrogen, but efficiency is not satisfied. The process is relatively pollution-free environment, but consumes a lot of power, so subject to certain restrictions. The pressure of industrial electrolysis water is generally in the 1.65 ~ 2.2V.

4.1. Principle of hydrogen storage alloy

The hydrogen absorption process of hydrogen storage alloys is in three steps:

1) After absorbing a small amount of hydrogen, it will form hydrogen solid solution, and the alloy structure remains unchanged, and its solubility $[H]_M$ and the equilibrium solid solution are proportional to the square root of hydrogen pressure PH_2:

$P^{1/2} \propto P_{H2} \propto [H]_M$

2) With further hydrogen absorption, hydrogen solid solution phase MHz reacts with hydrogen to produce phase change and then generate metal hydrides:

$2/(y-x)MH_x + H_2 \longleftrightarrow 2/(y-x)MH_y + Q$

x is a solid solution of hydrogen equilibrium concentration, and y is a metal hydride hydrogen concentration ($y>>x$).

3) To increase hydrogen pressure and then more metal hydride hydrogen will be produced.

This reaction is a reversible reaction, that is, when hydrogen is absorbed, heat is released; when decalescence happens, hydrogen will be released. Hydrogen storage alloy absorbs hydrogen to produce metal hydride, or metal hydride decomposes, and then hydrogen is released. In addition, it will be restricted by temperature, pressure and alloy composition[4].

4.2. The heating process using hydrogen

In the fuel cell system, because hydrogen storage alloy is used as the installation of hydrogen, and when hydrogen input or output, heat will be output or input, and with the reciprocal reaction, it will finish the switching process of heat energy- chemical energy- heat energy so as to store heat energy. With these characteristics, hydrogen storage alloys provide a continuous, steady and effective way and an important direction of development for renewable sources of energy such as solar, wind, ocean energy, geothermal, that is to convert such energy into chemical energy through the hydrogen storage alloy and store energy which waits for provide a stable heat when necessary, and then it will be used by city users instead of

heating power plant so as to reduce city's pollutions produced by the thermal power plant.

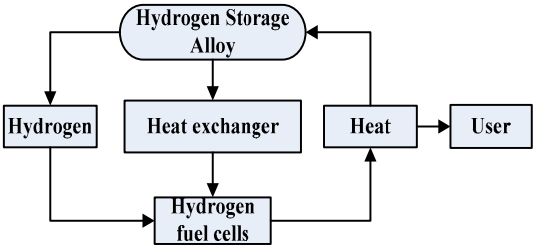

Fig. 2. Hydrogen storage alloy thermal cycle

This figure 2 shows the core of participation of user in at present, as a mature technology, the solar MgH_2 hydrogen circulation system combines hydride hydrogen storage cycle system with solar to achieve energy conversion and storage. Solar collector systems concentrate heat during the day, and high-temperature hydrogen storage material MgH_2 release hydrogen which will be stored in high pressure vessels or cryogenic hydrogen storage materials, and it will finish the process of hydrogen absorption while providing heat;

At night, hydrogen will be back into magnesium which released it during the day, and then will re-generate MgH_2. With this process, the energy released can make the temperature rise 350 ~ 400° C. However, cold storage units can be used for refrigeration while hydrogen gas emitting. In addition, the process of releasing hydrogen in the decomposition of metal hydride can make the pressure reaching the equilibrium dissociation pressure at this temperature; therefore, it also can finish the conversion among chemical energy-mechanical energy-electrical energy. Certainly, when the metal hydride generates, through increasing the hydrogen pressure, it will be input heat, that is, to converse mechanical energy into heat energy whose conversion and storage will have attractive prospects [5].

4.3. For hydrogen storage and transport

If Hydrogen wants to be one of pillars of new and clean energy in the future, besides continuous research and development on hydrogen technology and utilization, hydrogen storage and transport will be the other significant and integrant problem required to be solved. There are great weaknesses on unsafe, high energy consumption and poor economy in the transportation of high pressure gas cylinders and liquid hydrogen storage. The most promising safe and economical way of hydrogen storage and transportation is using metal hydride hydrogen storage material. Metal hydride hydrogen storage density is higher than liquid hydrogen. Hydrogen is stored in the alloy as atoms. When they are re-released, they will experience diffusion, phase change, combined processes, and because of thermal effects and speed constraints, there is high degree of safety.

5. Hydrogen Fuel Cell Power Generations

5.1. Proton exchange membrane fuel cells

Proton exchange membrane fuel cell has fast start, low operating temperature, high current density and small volume, especially for constructions of portable power and distributed power plant. As a new, efficient and environmental power generation technology, it has great commercial potential. In recent years, hydrogen-air proton exchange membrane fuel cells, as simpler and more efficient fuel cells has

made great progress, and has begun to enter the practical stage. To study reliability on a small system of hydrogen proton exchange membrane fuel cell power generation system reliability studies, on one hand, it will greatly improve operating life, reduce failure rate, and prolong the average time between failures, thereby improving its economic feasibility; on the other hand, it can improve working ability of system in order to make it more suitable for varieties of conditions. Now the PEMFC power generation system is widely used [6] [7].

5.2. PEMFC power system

Hydrogen-air of proton exchange membrane fuel cell power generation system is mainly composed of body cell stack, fuel supply system, oxidizer supply system, water / thermal management system, DC/DC converter and control system.

5.3. PEMFC Basic principles

With the platinum catalyst, PEMFC will react as following: hydrogen molecules lose electrons in the anode and become hydrogen ions, while oxygen molecules obtain electrons in the cathode, and get proton from ion exchange membrane to form water molecules[8].
Electrode reaction is as follows,
Anode: $H_2 \leftrightarrow 2H^+ + 2e$
Cathode: $1/2O_2 + 2H^+ + 2e \leftrightarrow H_2O$

5.4. PEMFC system structure

The generated output of single PEMFC is determined by the effective working area and it is generally about 1V. Therefore, according to power and voltage requirements of the load, it needs to connect multiple single-cells into galvanic pile in series in the actual use. Only in certain operating conditions, PEMFC galvanic pile is able to generate direct current stably and reliably. Besides PEMFC galvanic pile, a complete power generation system requires some external auxiliary systems and control systems to ensure normal works of the system. Figure 3 is a typical PEMFC power system structure which includes the stack, the hydrogen supply, air supply, cooling water circulation system, the control unit and load[9][10].

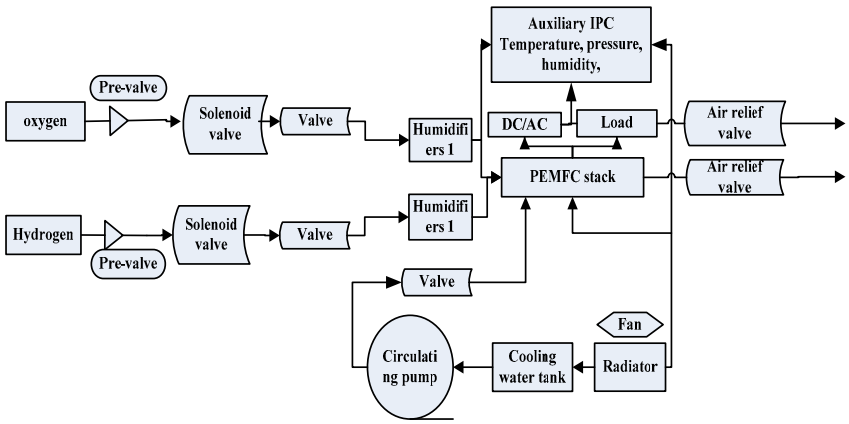

Fig. 3. PEMFC power systems.

Galvanic pile is a core part of PEMFC power generation systems; hydrogen supply and air supply is to provide fuel and oxidizer for galvanic pile, and the gas will go through reducing valves, solenoid valves, pressure regulators, pressure sensors, flow meter and humidifier. After satisfying with the requirements of galvanic pile, gases will enter the galvanic pile; cooling water system is responsible for regulating the internal temperature and humidity of the galvanic pile; based on fuel cell operating conditions and load on the power requirements, control unit controls and regulates the system in order to achieve working coordination among sub-systems[11][12].

6. Conclusion

The system can effectively use photovoltaic energy, and converse energy into hydrogen, and then provide a stable and lasting alternating current through the fuel cell, while sending excess heat out in the conversion of the fuel cell. This system does not use fossil fuels, so all intermediate products are clean, therefore, it can be built up around the cities instead of thermal power plants to ease the pollution problems rooting of city in the power plant. According to local conditions, we can use hydrogen energy storage technology to change the domestic stand-alone photovoltaic power generation systems. Not only it can save lots of renewal costs of batteries, but also reduce the pollution caused by batteries. With high efficiency of water electrolysis hydrogen and the low cost of metal hydrogen storage materials and proton exchange membrane fuel cell, solar power technology for hydrogen will inevitably generate far-reaching impact on the promotion and use of solar photovoltaic power generation. It avoids heavy and polluting batteries which have troubles of maintenance, and will be developed into a mobile power, military special power, etc. through rationally integrating each part, and then can further expand the scope of application of solar photovoltaic power generation.

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