

Conceptual Design of the Hybrid Solar Energy and Fuel Cell System for Cooling-Heating-Power Co-Generation

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Abstract: Based on the application of solar energy, the principle of a distributed energy system for cooling-heating-power cogeneration for a single building was discussed. Solar energy was used as the only heat source to drive a closed Brayton cycle to generate power. The waste heat dissipated by the turbine was utilized by a recovery refrigeration cycle to provide cooling or was directly transferred by heat exchangers for heating. When the system was further combined with a fuel-cell stack, the whole system can provide cooling-heating-power continuously in day and night. The system did not consume fossil fuel and dissipate no pollutant with a high energy efficiency. It's worthy further study and introducing to practical application to solve the power crisis.

Keywords: solar energy, fuel cell, cooling-heating-power cogeneration, distributed energy system

1. INTRODUCTION

With the development of modern economics, people are seeking a more and more comfortable environment in public buildings, which leads the necessary requirement of HVAC design. Whether the central air-conditioning system or the heating system must rely on a certain energy to run. Usually the energy is provided by a local boiler or the electricity power, which consumes the primary energy from fossil fuel. Fossil fuels are not renewable and produce large amounts of pollutant during the combustion. Furthermore, the supply of fossil fuels, e.g., crude oil and coal, is becoming shortage and most of the countries are facing the crisis of energy which limits their economy development. Therefore, the research and development of renewable energy is at present the hot subject all over the world. Solar energy is a good and plentiful green energy and is a hot topic concerned by the researchers around the world.

Distributed energy is independent of central energy such as electricity power net and thermal power plant and can provide a single large building the needed energy without any influence from central energy system. Recently the power crisis is becoming a major problem at Beijing, Shanghai and other regions especially in summer due to the fast development of the local economics. The HVAC system of public buildings and household conditioners consume a considerable part of the total power supply. If a distributed power system was developed to supply the power for a single building or a small living community, the power crisis could be solved partly.

The authors proposed a concept of a hybrid system of solar energy and fuel cell for cooling-

heating-power co-generation which can be applied to eco-buildings as a distributed energy system.

2. SOLAR ENERGY

The exquisite thermonuclear fusion reaction of hydrogen to form helium inside the sun releases radioactive energy about 3.8×10^{20} MW per second into the space, among which about one per 2,200 million radiates to the earth. Besides these radiative energy reflected and absorbed by the aerosphere, about 70% left could reach the ground and amounts to be 1.05×10^{18} kWh totally in one year that is equivalent to 1.3×10^6 million tons of normal coal. The total solar energy received by the land of China per year is equivalent to 2.4×10^6 million tons of normal coal. According to the calculation, the thermonuclear fusion reaction inside the sun can last 6×10^{10} year which is everlasting relative to the evolution of human being. China is one of the nations that have abundant solar energy. The sunlight hours exceeds 2000 hours at two third of the China total area.

So far there are two ways of solar energy conversion. One is solar-heat conversion and the other is solar-power conversion. Solar-heat conversion is to converse solar radiation into heat, including solar water heater and solar absorption refrigeration. Solar-power conversion technique is mainly referred to the direct conversion by photovoltaic cells. The second way to converse solar radiation to power is through a heat engine thermodynamic cycle which is driven by solar energy as the origin heat source. Compared with PV cells, the thermal dynamic system is more compact and high efficiency. The waste heat during the cycle can

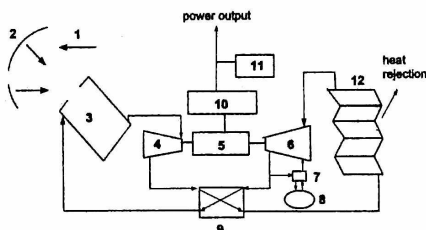
be used for heating-cooling-power cogeneration, as discussed in the following.

3. SOLAR ENERGY COOLING-HEATING-POWER CO-GENERATION SYSTEM

3.1 Solar dynamic power system

Solar dynamic power system is a heat engine thermodynamic cycle system that is driven by solar energy as the origin heat source. Phase-change material is used for thermal energy storage so that it can provide a continuous power supply without the electrochemical battery. Three kinds of dynamic system are available, i.e., Rankine cycle, Brayton cycle and Stirling cycle, where closed Brayton cycle (CBC) solar dynamic power system was selected and studied intensively by NASA as the future power supply of space station Freedom when its power demand was increased from 75kW to 300 kW^[2]. A 25kW CBC solar dynamic system was developed by NASA^[5] and a 2 kW ground demonstration system was experimentally studied^[4]. The results showed that the efficiency of the heat engine thermodynamic cycle is as high as 27%^[5,6] and the total efficiency of sunlight-electric power conversion exceeds 17%^[6,7] for a state-of-the-art CBC solar dynamic power system.

The solar dynamic system based on closed Brayton cycle consists of a solar concentrator, a solar receiver with heat storage, a power conversion system, a waste heat rejection system and the control and power conditioning system, as shown by Fig 1.



1: solar input; 2: concentrator; 3: receiver; 4: turbine; 5: alternator; 6: compressor; 7: valve; 8: accumulator; 9: recuperator; 10: power conversion device; 11: power conditioning; 12: heat rejection system

Fig 1 solar dynamic power system

The solar dynamic electric power system was first developed for space station Freedom by NASA and is based on the closed-loop form of the Brayton thermodynamic cycle. Heat is supplied to the cycle by means of a reflecting concentrator that focuses incident solar energy into a cavity type of heat receiver. The receiver includes heat exchanging tubes through which the gaseous working fluid for the closed-loop Brayton cycle heat engine passes. A quantity of a eutectic mixture of lithium fluoride-calcium fluoride (LiF-CaF₂) salts is contained in capsules around the receiver tubes for storage of thermal energy by the salt mixture's heat fusion. The

Brayton cycle is a single phase gas cycle. In the closed-loop cycle a compressor raises the pressure of the gaseous working fluid that then flows to a recuperator. There its temperature increases by transfer of heat from another part of the cycle. From the recuperator the gas passes to the receiver, where collected heat is added and the gas temperature rises to the maximum level in the cycle. The high temperature and high-pressure gas then flows to the turbine, where it expands to a lower temperature and pressure to produce mechanical work. A portion of the work drives the compressor and the remainder drives the alternator, producing electric power. After leaving the turbine the gas passes through the low pressure side of the recuperator, where it transfers heat to the high pressure gas from the compressor. From the recuperator the gas passes through the heat rejection system and gives up its more heat via radiation to the space. The cold gas then returns to the compressor and goes on the cycle.

The power output of the solar dynamic system in daylight can drive the devices in the building and the remainder can be stored by accumulator or connected with the electricity network which then can be used in the night. This distributed system is very suitable for the jumping-off and high altitude regions where it's difficult to install the electricity network. For the intown building, it can provide power without any pollutant emission and it's renewable and very compact. The whole system can be installed at the roof of the building.

3.2 Cooling-heating-power co-generation based on solar dynamic cycle

The solar dynamic system shown by Fig 1 produces electric power during the thermodynamic cycle, at the meat time, it dissipates the waste heat of about 450K by radiator to the space. This waste heat is worthy of value in use by several ways. It can be used directly as heat source by a gas-gas heat exchanger to heat the fresh air of the air-conditioning system for heating in winter. It also can be used as the heat source to drive a waste heat refrigeration system for cooling in summer. The total thermal efficiency of the dynamic cycle will be increased when this waste heat is utilized. Fig 2 shows the principle of the cycle.

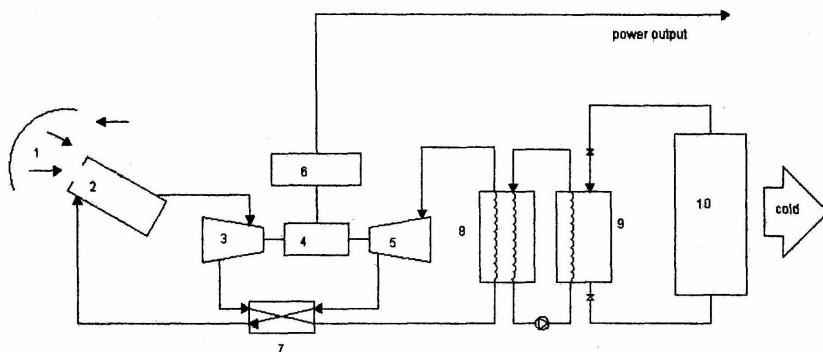
3.3 Cooling-heating-power co-generation based on solar energy and fuel cell: regenerative system

Both the photovoltaic panel and the solar dynamic power system depends on the sunlight to run. Hence they will not work in night or cloudy day. The conventional way to solve this problem is to prepare a heat storage device which can store enough heat for night or cloudy day. But the more the heat is stored, the more voluminous the device is and the more investment is needed. Therefore, the heat storage device is usually provides the heat which can drive the cycle to run for 2-3 hours. Then the device will be driven by a boiler in the night. That's to say, the whole system is hybrid combining the solar energy and conventional energy.

In order to get all the heat from solar energy and consume no fossil fuel, we designed the solar energy

and fuel cell regenerative cooling-heating-power co-generation system as shown by Fig 3. The characteristics of this system is that the solar dynamic power system generate power from solar energy in daytime, a portion of the power is output to the user and the remainder is used to electrolyse water to produce hydrogen which then is used as the fuel for

the fuel cell system to generate power and hot water in night. The waste heat from the dynamic system and the hot water can be used for heating or cooling. The water will be recycled. There is no pollutant emitted and the only energy origins from the solar energy. Hence it's absolutely renewable.



1: concentrator; 2: receiver; 3: turbine; 4: alternator; 5: compressor; 6: power conversion device; 7: recuperator; 8: heat exchanger; 9: hot water tank; 10: waste heat refrigeration

Fig 2 Solar dynamic cooling-heating-power co-generation system

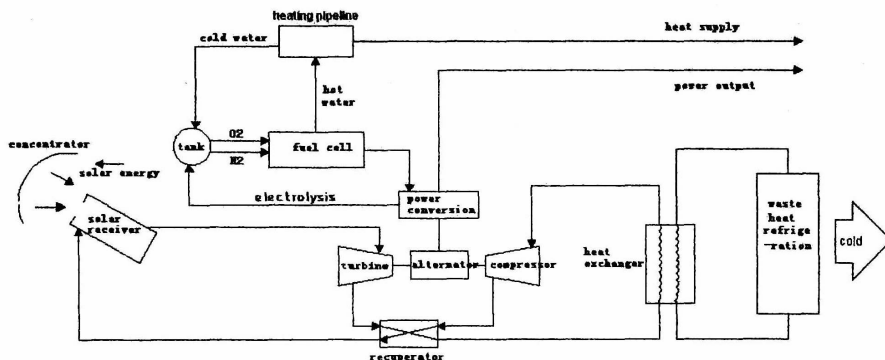


Fig 3 Solar energy and fuel cell regenerative cooling-heating-power co-generation system

4. CHOICE OF REFRIGERATION BY WASTE HEAT AND THE TYPE OF FUEL CELL

There are several techniques available for waste heat refrigeration. Among these techniques, the low temperature hot water two-stage absorption lithium bromide (LiBr) refrigeration can work if the heat source exceeds 60 °C. The temperature of the exhaust gas from the solar dynamic cycle during the power generation is around 200 to 300 °C, therefore, the waste heat can drive the lithium bromide (LiBr)

refrigeration device running to produce cold water of 6 °C for the cooling.

The fuel cell suitable for heating-power cogeneration includes middle temperature (160-220°C) fuel cell, e.g., phosphoric Acid Fuel Cell, PAFC and high temperature (600-1000°C) fuel cell, e.g., Molten Carbonate Fuel Cell, MCFC, Solid Oxide Fuel Cell, SOFC. The former is technically developed, but its electrical efficiency is less than 40%. The latter is more expensive, while its electrical efficiency exceeds 50%. At present, the PAFC can be chosen for power generation in night, at the same while it produces by-

product hot water of 160–220°C, which can be used for direct heating and bath in winter or for waste heat refrigeration in summer.

5. CONCLUSION REMARK

The fast development of the economy requires more power capability and the power crisis appeared in many regions in China, especially in summer when the buildings consume more power to run the air conditioning system. It's difficult to build new coal- or natural gas-fired power plants in short terms to solve the energy crisis. The conventional power plants consume fossil fuels and emit pollutant and require large investment. Distributed energy system of renewable energy is a good way for this problem. Based on the application of solar energy, the principle of a distributed energy system for cooling-heating-power cogeneration for a single building was discussed. Solar energy was used as the only heat source to drive a closed Brayton cycle to generate power. The waste heat dissipated by the turbine was utilized by a recovery refrigeration cycle to provide cooling or was directly transferred by heat exchangers for heating. When the system was further combined with fuel-cell, the whole system can provide cooling-heating-power continuously in day and night.

The closed Brayton cycle solar dynamic power system has been studied and developed for space station application by NASA and many authors and was shown to be a practical technique. Fuel cell has also been studied intensively and has been successfully applied to power generation and vehicles. The waste heat refrigeration is also a mature technique. So the system in this paper is technically practicable. The market investigation shows that the requirement for distributed power system is about 100 to 150 kW. The fuel cell can reach an electrical efficiency of 40% and a thermal-electrical efficiency of 80% in this power range. The whole system has a high reliability, little noise and a small volume and can be installed at a corner of the building roof. The

system did not consume fossil fuel and dissipate no pollutant with a high energy efficiency. It's worthy further study and introducing to practical application to solve the power crisis. The major disadvantage is that the beginning investment is expensive.

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