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Design of a Solar-Hydrogen-Fuel Cell Unit for passive lighting and driving Small Electrical Loads in Residential Buildings of Saudi Arabia

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Abstract

The present paper proposes a new imaging of a Solar-Hydrogen-Fuel cell-stand alone-unit for passive lighting and driving small electrical loads in residential buildings of Saudi Arabia in order to save energy consumption. The designed system consists of a solar panel, PEM-electrolyzer for hydrogen production, hydrogen fuel cell and miscellaneous. The proposed system can be switched between day and night in order to obtain a continuous operation. The daylight cycle works directly from sun energy, while the night cycle is dependent on the storage of solar energy in form of hydrogen energy. The proposed stand-alone unit can become widely utilized not just for driving small electrical loads but for industrial process applications where different loads are required. The proposed system can be considered as a very promising candidate for transportation applications since it is compact, lightweight and delivers the required power.

Keywords: Energy saving; Solar energy; Hydrogen Fuel cell, Residentail buildings. Introduction

INTRODUCTION

Recently, the most important issue in residential building is energy saving due to high energy consumption in warming or cooling. The challenge now is how to produce energy from renewable energy sources. Moreover, the application of such renewable energy in households applications is the most important topics in last decades.

In spite of the vast reserves of oil and gas in Saudi Arabia, recently, an increase attention has been internationally turned to the replacement of fossil fuels with solar hydrogen as an essential step towards the shift to a clean energy [1]. This trend is motivated by the high potential of solar energy in Saudi Arabia, (as shown in Fig. 1), and the possibility of converting a large amount of such energy, over a large scale production, into hydrogen via electrolysis of water [2]. Moreover, as the meeting energy demands for 21st century is an enormous challenge for our society and environment, the environment must be, simultaneously, safeguarded when meeting people's need for lighting, power, heating and cooling. Therefore, there is, more recently, an increase interest to define and assess a renewable energy sources for households use in form of fuel cell units.

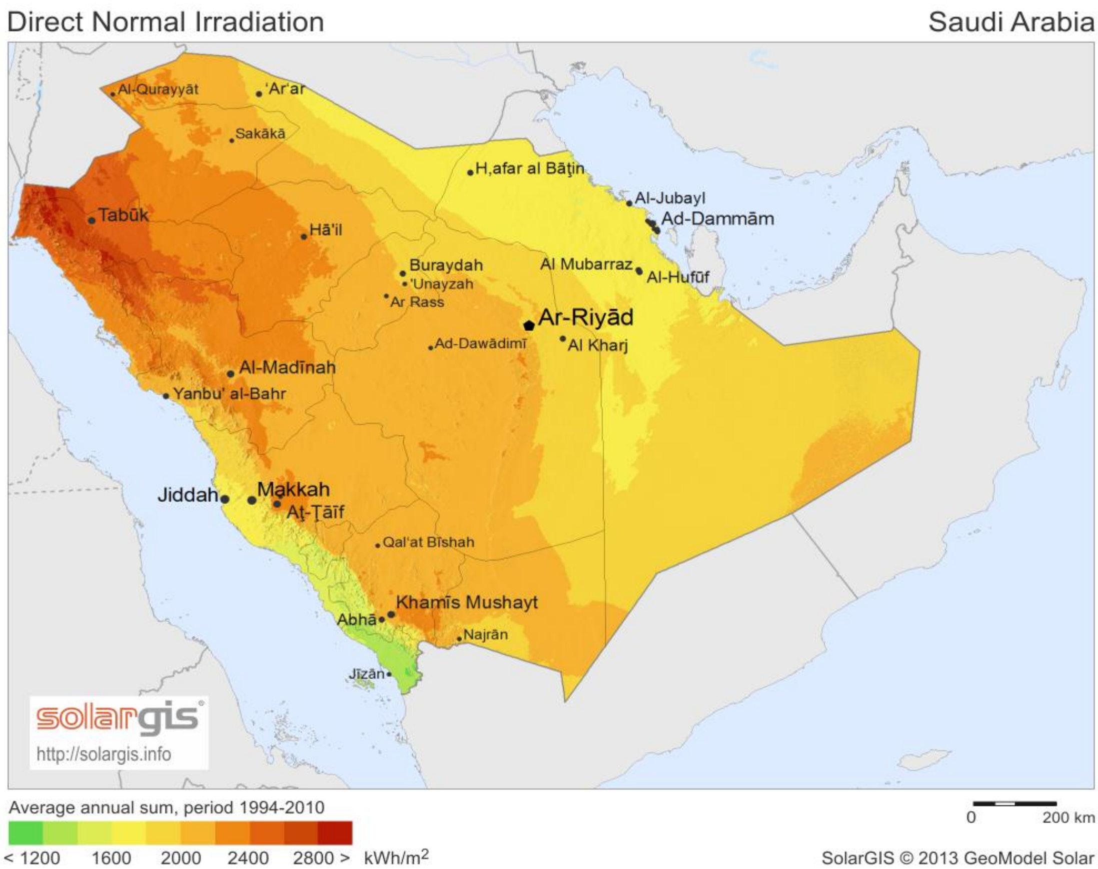


Figure 1: The Direct Normal Irradiation of Saudi Arabia (1994-2010)

Accordingly, Saudi Arabia has started major developments either internationally and locally. Since 1985, the government of Saudi Arabia has initiated a long term research and development project in collaboration with Germany. The project was named

"HYSOLAR" and it was allocated a budget of DM 39.2 million for the first phase of four years [3, 4].
In Saudi Arabia, as a case study, the adopting of the solar-hydrogen energy system would extend the availability of oil resources, reduce pollution, and establish a permanent energy system for Saudi Arabia and it could become an exporter of hydrogen forever [5]. Moreover, Saudi Arabia could be a leading producer and exporter of solar energy in the form of electricity. The geographical location of the country, its widespread unused desert land, and year-round clear skies, all make it an excellent candidate for this [6].

Nevertheless, the power generated by a solar PV system is influenced by the different weather conditions. In addition, it is difficult to store the power generated by a PV system for the future use. The best method to overcome such problem is to integrate the PV system with other power sources such as an electrolyzer, hydrogen storage tank, and fuel cell system [7].

The first commercial use of fuel cells was in NASA space programs to generate power for probes, satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are used to power fuel-cell vehicles, including automobiles, buses, forklifts, airplanes, boats, motorcycles and submarines [8].

Fuel cells come in many varieties; however, they all work in the same general manner. The category of the so called Polymer Electrolyte Membrane or also known as Proton Exchange Membrane (PEM) have received major efforts of research and more attention because of their advantages such as low-temperature operation, rapid start-up and high power density.

In our previous research [9], a proposed solar hydrogen energy system is partially analytically and experimentally examined. Recently, we have performed a research project, which is financially supported by Taif University [10], to design a solar hydrogen production unit under the operating conditions of Taif city, Saudi Arabia [11].

Concluding, the present research, as shown in Figure 1, will try to design a solar hydrogen PEM fuel cell unit for small energy applications. This energy unit could be applied in the near future for households use. The advantages and problems of such energy system from technical, economic and environmental points of view, and the feasibility of applying such solar hydrogen system into Saudi Arabia will be investigated in more details in next researches.

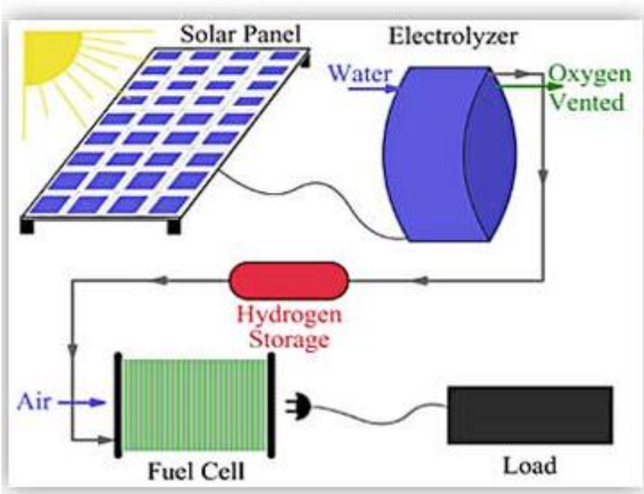


Figure 2: The schematic diagram of the solar hydrogen fuel cell system.

MAIN COMPONENTS OF THE PROPOSED SYSTEM

The proposed system of the hydrogen fuel cell system consists of the following components:

A. SOLAR PANEL

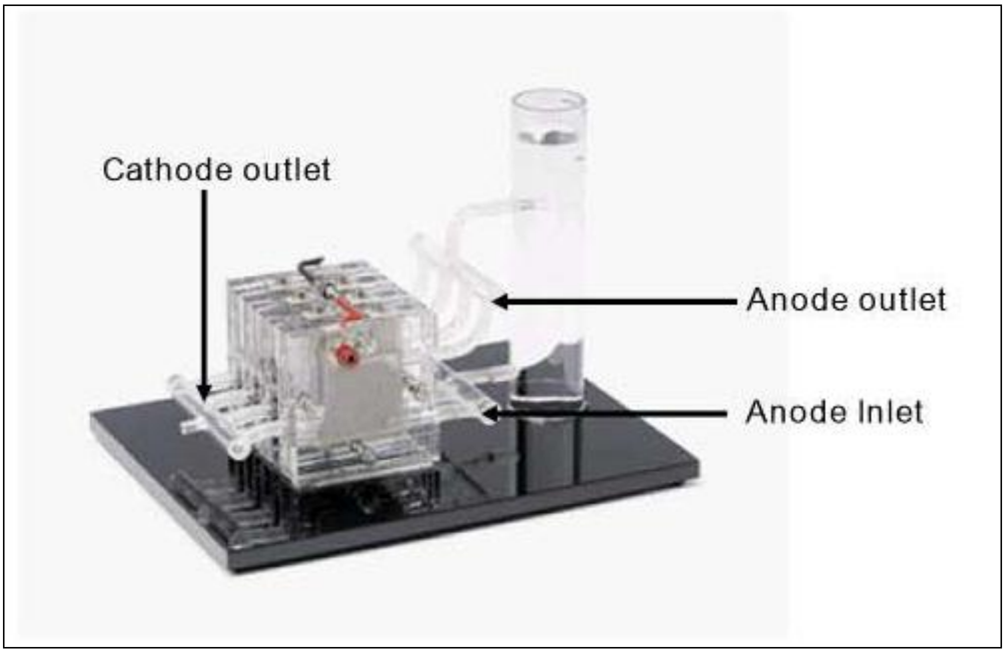
The characteristics of the PV solar panel used for the proposed system are as follows:

Solar Panel	
Weight	8.5 kg
Voltage	17.9V
Current	5.31A
Power	95 W
Manufacturer	Japan
Dimension	90x60 cm

Figure 3: The charateristics of PV-solar panel.

B. PEM-ELECTROLYZER

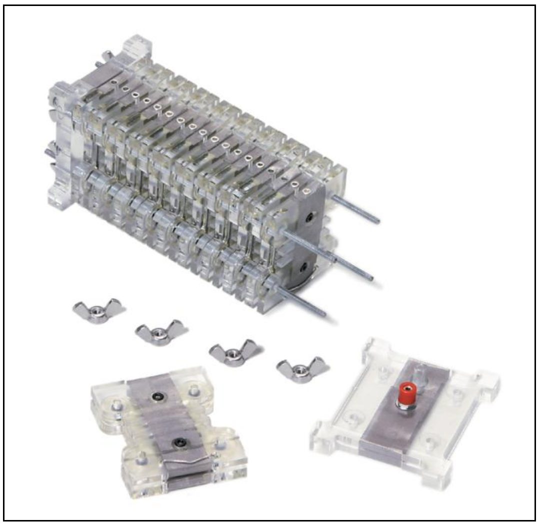
The chosen electrolyzer is a 7-cell 50 W H-TEC PEM Electrolyzer with an active area of 16 cm^2, a Nafion 115 electrolyte and a membrane thickness of 130 cm^2, as below:



PEM electrolyzer 230	
Weight	1.48 kg
Voltage	14 V DC
Current	4 A
Power	50 W
Manufacturer	Germany
H_2 Production	230cm^3/min
Dimension	19x26.4x20 cm

Figure 4: The charateristics of PEM Electrolyzer.

C. PEM-HYDROGEN FUEL CELL



PEM Hydrogen Fuel Cell	
Weight	430 g
Power	2 W
Dimension	60 x 175 x 70mm

Figure 5: The charateristics of PEM Hydrogen Fuel Cell.

CONTINOUS OPERATION OF THE PROPOSED SYSTEM

The complete proposed system for power generation can be seen in Figure 6. The system can be switched between day and night in order to obtain a continuous electrical power supply. The daylight cycle works directly from sun energy, while the night system is dependent on the storage of solar energy in form of hydrogen energy using PEM electrolyzer. The hydrogen is then delivered to a hydrogen-fuel cell unit for electricity production.

In order to calculate the overall efficiency of the designed solar-hydrogen-fuel cell unit, the out power of the fuel cell is measured via a suitable power measuring device such as Wattmeter. The solar power is measured before connection to the electrolyzer and it is consider as the input power to the system. The efficiency of the solar-hydrogen-fuel cell unit is calculated according to the following relation:

$$\eta_{SHFC} = \frac{P_{out}}{P_{solar}}$$

After connecting the load and the other miscellaneous to the designed system, the overall efficiency of the proposed system can be calculated according to the following relation:

$$\eta_{Overall} = \frac{P_{Load}}{P_{solar}}$$

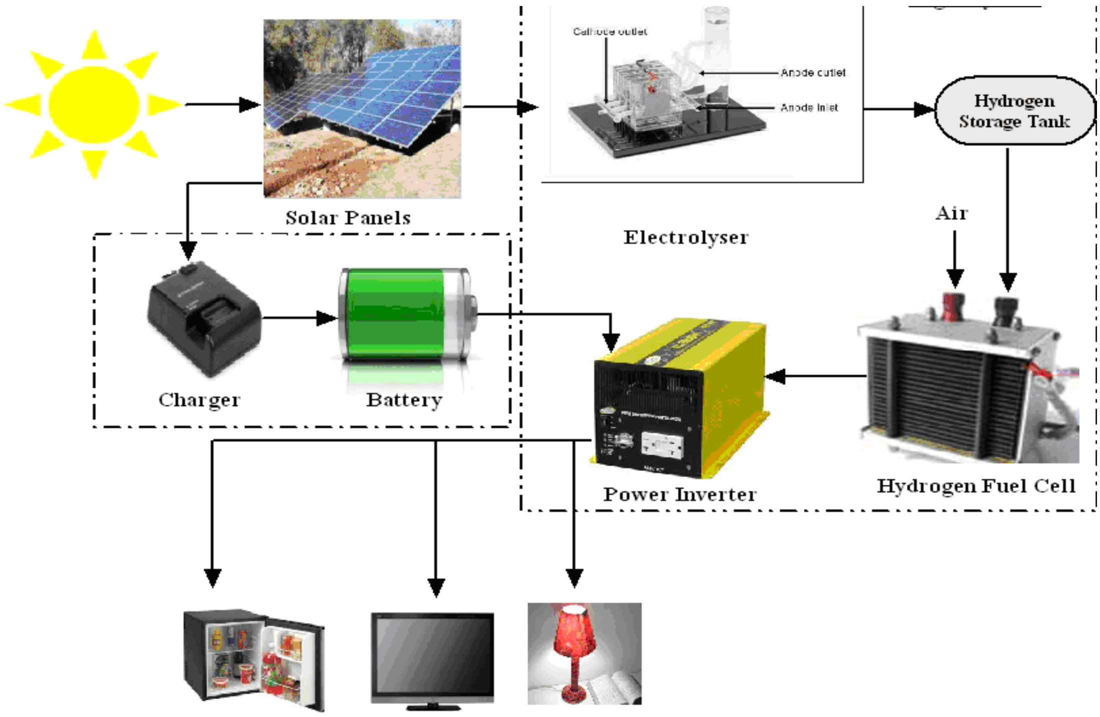


Figure 6: The proposed solar Hydrogen Fuel Cell system

PASSIVE SOLAR ENERGY CONCEPTS

Solar energy can be used in different ways to provide mechanical power, electricity, heat and lighting. Passive solar electricity, heating and cooling can save substantial bills of electricity in residential buildings of Saudi Arabia. By placing solar panels on the roofs of the building or through the exterior building elements; such as windows, electricity can be produced. Figure 7 shows different ways for installing the solar panels using the exterior building elements. This electricity can be used directly for passive lighting purposes or driving small electrical loads. In case of no need of such electricity in lighting, hydrogen can be produced and stored for operating fuel cell systems at night. Passive solar heating try to store thermal energy from sunlight directly and use it if needed. However, passive cooling reduces the effects of solar radiation through shading or generating air flows with convection ventilation. Both are considered at the main solar concepts.

Figure 7: Different ways for installing the solar panels using the exterior building elements

Passive lighting in building can reduce its electricity bill by using the overall light of the sun on daylight and night. Moreover, it can create a pleasant and comfortable environment and reduce air-conditioning costs by decreasing considerably the amount of heat that generated by the light bulbs or ballasts.

According to the rich solar energy availiable in different areas in Saudi Arabia, the application of passive lighting is a very important issue in reducing the elctricity cost produced from the traditional energy resources and helping in obtaining a cleaned environment.

Passive solar heating happens when an object and that object absorbs the heat coming by sunlight striking. It can occur in a building effectively if windows are oriented and places correctly in such a way that maximum solar energy is absorbed. Once the heat is trapped inside a building and that structure is air tight, heat loss can be avoided effectively. Double-glazed windows are not very effective in trapping the heat. Consequently, high performance windows, with multiple glazing, insulated frames, low-emissivity coating insulating glass spacers and inert gas fills, should be placed instead of the traditional windows. All these elements can reduce heat loss by 50 to 75 per cent.

Another technique opposite to passive solar heating is the passive cooling. In such concept, the buildings are designed to keep the solar and air heat away. Internal heating from animate and inanimate objects is reduced and dissipated in the environment through natural ventilation.

Shading devices adjustable or fixed can reduce solar radiation. Buildings can be shaded by natural vegetation and using special glazing in windows. External shading devices can minimize solar gains by up to 90 per cent, while still admitting a significant amount of indirect light.

External heat gain can also be reduced by good insulation, minimized window size and by the use of different reflective materials in the walls and roofs. Attention should also be paid to cross-ventilation and the direction of prevailing winds in the earlier stages of the building design.

Passive solar design for buildings is very effective way to enhance the energy efficiency of our building. A well-designed and properly oriented building capitalizes on solar heat gain in winter and deflects unwanted heat in summer. Consequently, building orientation design becomes an important issue in architecture engineering. Figure 8, shows different orientation of buildings with relation to solar energy.

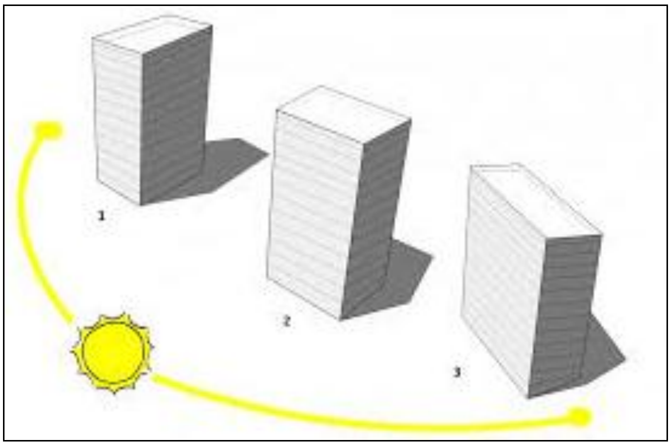


Figure 8: Different orientation of buildings in relation to solar energy

CONCLUSION

The present paper introduces a new Solar-Hydrogen-Fuel cell- stand alone-unit for passive lighting and driving small electrical loads found in residential buildings of Saudi Arabia. The proposed system can be switched between day and night in order to save energy consumption and to obtain a continuous power supply. The designed system consists of a solar panel, PEM-electrolyzer, hydrogen fuel cell and other required instruments such as power inverter, charger and battery. The proposed system can be considered as a very promising candidate for transportation applications since it is compact, lightweight and delivers the required power. Moreover, the proposed stand-alone unit can become widely utilized not just for driving small electrical loads but for industrial process applications where different loads are required. Further investigations are required in future work in order to study the efficiency of the proposed power conversion system and to decide its economical visibility.

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