

Electrification of Remote Clinics by Photovoltaic – Hydrogen Fuel Cell System

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Abstract

Palestinian health clinics in remote areas suffer mostly from lack of electric networks due to Israeli restrictions and lack of infrastructure fund from National Authorities. Most of these areas are far from the main medium voltage transmission lines, which makes it unfeasible to connect them with the main electric power grids. Therefore, renewable energy sources especially as solar and bio-waste can represent a more clean, reliable and feasible solution. Typical energy consumption pattern of a small health clinic is illustrated. Modeling of a proposed PV-Fuel Cell system will be provided. Experimental results obtained from a reduced scale model, built in the lab to give insight into the system technical details, will be presented.

Fuel availability and clean energy production by fuel cell, giving its chemical reactions occurring inside the cell as well as production of electricity for unlimited time, are of the main system topics in this paper. The paper provides also a power management strategy for solar and fuel cell system to cover the power demands of a typical small clinic in rural areas of Palestine. The proposed control strategy is based on a logic-based method that considers the status of power supply sources and the load demands to combine and switch in between giving priority to the more stable source. In addition, experimental results for a scaled system built in the lab are presented. Finally, a financial comparison between using storage batteries and fuel cells for electrification of rural clinics is discussed in this paper. It was found that using of fuel cells is economically more feasible.

Keywords: Photovoltaic , Fuel Cells, Rural Electrification, Energy Storage.

1. Introduction

Remote areas far from cities mostly lack water and electronic networks. The inhabitants of these areas face considerable difficulties since they have to depend on small inefficient electric diesel generators and obtain their drinking water at expensive cost from tractor tanks. The distance of these areas from the main medium voltage transmission lines (33kV) and their low power demands make it unfeasible to connect them with the main electric power grids. Solar electric power systems (photovoltaic generators) represent an effective appropriate solution to these villages to cover the power demands of the most necessary equipment such as

Lighting, TV, computer, water pumps, refrigerators, etc. . . . As known, health clinics that serve all villagers are very necessary. These clinics depend mostly on their own small electric diesel generators or they obtain the electric power from some houses, which possess diesel generators, at very high cost. The electric loads in such clinics are small and consume only small amount of daily energy. The electric loads are mainly represented in lighting (florescent or CFL-lamps), small vaccine refrigerator (196 litre), computer, sterilizer, small water pump, centrifuge, weight and overhead fan [1]. The total daily energy demand of such appliances is relatively low and lies mostly in the range between 2 and 5kWh which can be easily supplied by means of solar photovoltaic

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DOI: 10.5383/ijtee.10.01.008

generators especially in countries of high solar energy potential as Palestine where the daily average on annual basis exceeds 5.2 kWh/m²-day while the registered annual sunshine duration exceeds 2800 hours. Providing electric power to isolated rural clinic is not a new application since it has started during the seventies of the last century [2].

A large number of remote health clinics especially in Africa, Latin America and south Asia have been successfully operated by photovoltaic generators with consequently positive impact on the health sector of those areas. However, the new issue in this paper is the use of a photovoltaic generator with hydrogen and fuel cell instead of using the traditional lead acid batteries as a storage media. The new system with fuel cell is promising to be more efficient and economic than the traditional system [3]. Furthermore the new system is friendlier to environment since it produces no toxic polluting gases as CO₂, CO...etc, and has no lead or mercury in its components [2].

The backup system is the fuel cell which is known with its high efficiency and fast response, fuel flexibility and clean energy production, since chemical reactions occurs inside the fuel cell [4]. In addition production of electricity for unlimited time are of the main system specifications. The photovoltaic generator (PV) produces, during the day light, (variable solar radiation) enough electric power to cover the requirements of the different loads in the clinic while the excess power would be used to supply the electrolyser producing hydrogen. In the night the fuel cell will provide the clinic with the necessary power without using storage batteries.

The system under study in this paper consists of PV generator and water electrolyser to produce hydrogen that would be stored in a special storage tank, to be used in periods of low solar radiation by proton exchange membrane (PEM) fuel cell to produce electric power [5].

2. Photovoltaic-Hydrogen Fuel Cell System

The system includes a source of power (PV), a hydrogen generator and hydrogen utilization units. The system provides electrical energy continuously without interruption. Photovoltaic power generation, which converts sunlight into electricity, and has many advantages, including the inexhaustible it's free and environment-friendly. The system consists of hydrogen production units called electrolyzers, which operates on hydrogen generation through separation of the water using photovoltaic as a power source. Hydrogen which is produced by electrolyzer, has the advantage of being highly purified, and without emission of any greenhouse gases. Battery pack is one of the popular options in energy storage. Stability of battery pack depends on some factors such as: response time of battery, discharge rate, life time and battery life cycle cost. Batteries can be used for daily storage but for seasonal storage, batteries are not practical because of the low storage capacity. As fuel cells can convert hydrogen energy to electrical energy, storing energy, in the form of hydrogen, is another solution for both daily and seasonal storage of

electrical energy. Hydrogen tanks are less costly than batteries and despite longer life, they need less maintenance [6].

2.1. Experimental Results

The evaluation of the system components (photovoltaic, electrolyzer, fuel cell) was performed, the efficiency of each component was measured. Practical experiments on the characteristics and performance of the system components was carried out under the variable load. For the purpose of this study, a lab unit (PEMFC) produced by HELEX company, "Solar and Hydrogen Fuel Cell Trainer".

2.1.1. The I-V Characteristics of Photovoltaic

The photovoltaic panel output is a DC voltage when illuminated by either sun or lamp. In order to measure the (I-V) and (P-V) characteristics of the used photovoltaic panel, a variable load was connected to the PV panel. The solar radiation intensity on the surface of the PV module was measured to 580 W/m². From the measured data the V_{mpp} is equal 2.073V and I_{mpp} is equal 129mA and the maximum power point (MPP) is 267.4mW under the condition 580W/m² and the room temperature amounting to 27 °C.

2.1.2. The Efficiency of Electrolyzer

The method used in this experiment to produce hydrogen is electrolysis of water. The chemical reaction at the anode and cathode is as follows: At the anode, the water decomposed into positively charged hydrogen ions (H⁺) and Oxygen. The values of V, I and t where measured. The measured average value of electrical energy to produce 10 ml H₂ is 137.42 W.s, which results an efficiency of electrolyzer amounting to 86.7%. It should be mentioned that the hydrogen bubbles started forming at V=1.45V.

2.1.2. The Voltage-Load Characteristics of Fuel Cell

The type of fuel cell utilized in this experiment is proton exchange membrane fuel cell (PEMFC). The maximum theoretical output voltage of fuel cell which is a result of reaction between H₂ and O₂ is 1.23V. This theoretical voltage isn't reachable because the various losses happen during practical actual application. Both sides of electrolyzer are filled with distillate water and connected to the current source. When the hydrogen gas is formed and the stored capacity is 10 ml the current source must be switched off. At this time started the experiment for the characteristics of the PEM fuel cell, changing the value of the load and recording the values of voltage and current for the PEM fuel cell.

The PEMFC maximum output power is achieved between (0.25 and 2) ohm and this is shown in figure 4. The maximum power point drops after the fuel cell has consumed the remaining gas within its casing. The rate of consumption of gases is not constant and is affected by the power delivered to the load. The output power would drop when preventing the gas flow into device. The electrical energy output delivered to the load from the PEMFC is equal (47J) and from the experiment the hydrogen is 10 ml, so the energy

contained in it is equal (119J). Therefore the efficiency of the PEM fuel cell is 39.5%.

2.3. System Sizing

The energy demands of a health climate condition will be critical factors in the selection of the most appropriate renewable electrification technology. The electrical devices used in rural health clinics are vaccine refrigeration, lighting, blood chemical analyzer, sterilization, a microscope apparatus, a centrifuge.

2.3.1 System Sizing of Small Clinics Electrification

The photovoltaic generator produces power, when solar radiation is sufficient, for electric power demands different loads while the excess power will be stored and partially used for hydrogen production. When solar radiation is absent, the fuel cell will provide the necessary power.

A typical daily load curve for a small clinic is given in Fig.1. The maximum consumed power during a day is 670W and energy consumption is 8.2kWh/day. The important parameters for system sizing are the average daily solar radiation energy and the load consumption. These parameters can be used to calculate the peak power of the PV generator.

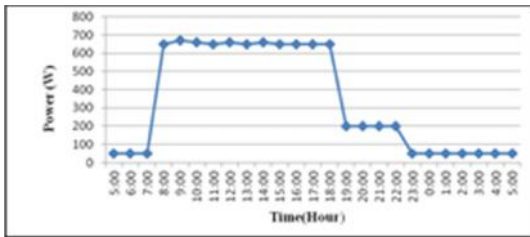


Fig. 1. Daily load curve of small clinics

2.3.2 Case Study

A typical solar radiation pattern is for one average day at southern Palestinian villages shown in Fig.2. The solar radiation is obtained for 24 hour on 24/4/2012, and the solar radiation average in this daylight (6:30 AM to 19:30 PM) is 0.538 kW/m².

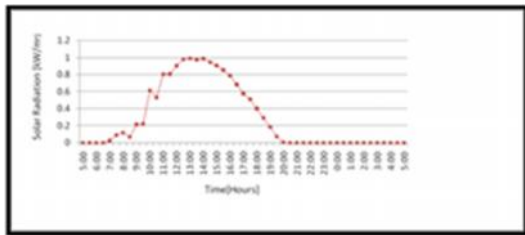


Fig. 2. Solar radiation pattern obtained on 24/4/2012.

The main aim for the applied Power Management Strategy (PMS) in the adopted system is to satisfy the load requirements of the clinic use. The operation of the fuel cell should satisfy the load pattern requirements in terms of duration and power level for the various operation times.

The adopted PMS must be built to provide the operating modes under variable weather conditions to ensure the satisfaction of the power requirements. The logical block diagram for PMS is shown in Fig.3.

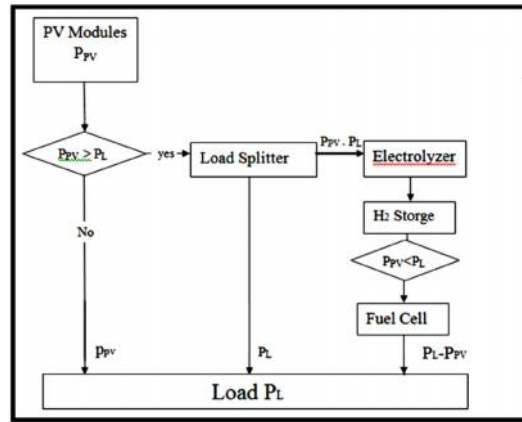


Fig. 3. Logical block diagram of PMS.

To determine the size of the PV modules during the day is divided into two periods, the first period is the period of solar radiation sufficient to provide the load demand. The energy consumed in this period is 7150Wh, The area of photovoltaic needed to supply the clinic load is about 11.6 m². Using Mono-crystalline with module area 1.67m², the number of modules to be installed is 7 module.

The exceeded energy of PV modules in the first period is 1.166 kWh, which used in the second period and the output energy of fuel cell is 0.460 kWh. The second period the fuel cell provides the demand load which is 1.920 Wh, and the maximum consumption is about 270W, the size PEM fuel cell is P_{FC}=300W. This mean the rated power of fuel cell is 300W. Stack electrical efficiency for commercial fuel cell is about 40%, nominal power is 300 W and operating temperature of fuel cell is 30°C. To determine the size of the PV generator we must take into account the efficiency of electrolyzer and the efficiency of the PEM fuel cell. The volume of hydrogen production during the day 24/4 is shown in Fig.4.

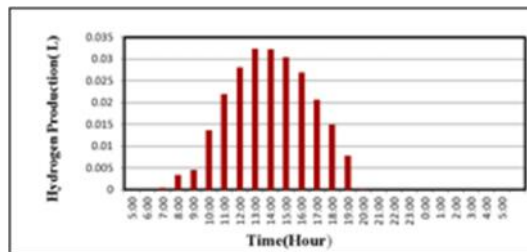


Fig. 4. The volume of Hydrogen production.

The total necessary PV modules amount to 11.3 modules therefore we use 12 modules with the following connections to produce a nominal DC voltage of 48V for supplying the electrolyzer and electrical appliance in the small clinics.

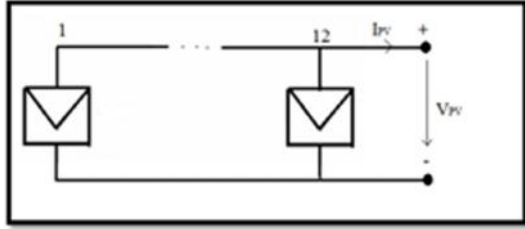


Fig. 5. Connection of the PV modules to build the PV generator.

The above PV generator Fig.5 has an open circuit voltage and short circuit 58V and 5.58A which correspond to a peak power of 3kW.

2.3.3 Cost Comparison between Fuel Cell and Battery

The capacity of the battery can be determined by the (Eq.1):

$$CAH = E_d / [DOD * \eta_B * V_B] \quad (1)$$

- E_d Daily energy consumption, kWh
- C_{AH} Ampere hour capacity, Ah
- DOD Depth of discharge, %
- η_B Efficiency of battery, %
- V_B Voltage of battery, V

Table 1: Comparison of the total cost between two systems.

	Cost system with Battery(\$)	Cost system used Fuel cell (\$)
Photovoltaic	1575	3500
Battery	13440	-
Electrolyzer	-	1000
Fuel cell	-	4500
Total	15015	9000

In table 1 the cost of using fuel cell is less than storage battery, the difference of the costs of the two designs is 6015 \$. The system depending on battery has higher cost because the system of fuel cell can store energy for long time at lower cost since storage of produced hydrogen is in tank.

3. Conclusion

Main purpose of this paper is to investigate electrification of health clinics far from the electric grid, by environment friendly system consisting of photovoltaic generators and fuel cells. The advantages of this system in comparison of using storage batteries are represented in the lower cost and in protection of the environment. Clinics need electrical power throughout the day without a break because they contain

vaccines and this system supplies electricity to the clinic load during daytime and night without interruption.

During the process of the fuel cell experiments show that it should be supplied with hydrogen for three minutes before taking readings because membrane initially need to stimulate the production of electricity and in order that the fuel cell operates at nominal efficiency. Distilled water should be used in the electrolyser where the membrane is put in the process of separating water into hydrogen and oxygen. Non- distilled water leads to the destruction of the membrane of the electrolyzer. In this system the electrolyzer to produce hydrogen consumes a part of electrical energy generated from PV, and can be dispensed with using other elements. Fortunately, hydrogen can be generated from bio-waste material available locally using economic technologies.

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