One Approach to Optimization of Standalone Hybrid Power Systems for Customer Located in Novi Sad

Marko A. Gecić, Vladimir A. Katić, Darko P. Marčetić
Faculty of Technical Science
Novi Sad

Abstract— **The paper presents one example of the optimization of standalone hybrid system for electric power load, which is located in Novi Sad, Serbia. Standalone system consists of photovoltaic panels, electrolyser, hydrogen storage tanks, fuel cells and consumers. The program that was used to simulate the operation and optimization (component selection) of the system is HOMER Energy Software. The results of simulation and optimization are presented.**

Keywords- Hybrid power system, PV, fuel cell, hydrogen

I. Introduction

Solar energy is an inexhaustible source. If used, it may meet all energy needs of mankind for the future. Conversion of solar energy into hydrogen is carried out without any emissions of greenhouse gases. Because of its distributed nature in terms of energy production, it can contribute to energy independence and distribution security of any country [1].

However, there are some challenges related to the use of solar energy. The biggest challenge is intermittent nature of the sun, both on a daily and on a seasonal basis. The solution is backup power supply system that will provide the energy during the periods when there is not enough solar one. Application of modern technology and using combine effects of different renewable energy sources enables design of a suitable system.

There are many ways to use modern technology for exploitation of renewable sources. In the case of standalone renewable energy source (RES) systems, common solution is a hybrid system. Typical hybrid RES system includes photovoltaic module, wind generator and fuel cells or batteries, which are used for storage and to compensate variable nature of sun and wind. However, in this paper solar energy based system is considered, only. The solar energy usage is preferred as average solar radiation in Serbia is about 40% greater than the European average. The potential of solar energy is 16,7% of total of useful potential of RES in Serbia. Average daily energy of global radiation for flat surface during winter ranges between 1.1 kWh/m² in the north and 1.7 kWh/m²in the south, and during the summer period between 5.4 kWh/m² in the north and 6.9 kWh/m² in the south [2].

The aim of this paper is to analyze and optimize the system that contains photovoltaic panels and fuel cell, only. Also, it is assumed that the system is used for isolated loads (islanded operation) in a region where public grid is not available. Finally, the situation in which energy is not supplied is not allowed, so system should provide energy supply in all weather conditions.

The analysis is based on the average value of solar radiation and clearness index data collected during the last 10 years for given location. For that purpose the HOMER software is used [3].

II. HYBRID POWER SYSTEM

The hybrid system considered in this paper consists of photovoltaic (PV) panels, electrolyser, hydrogen storage tanks, fuel cells and DC load (Fig. 1).

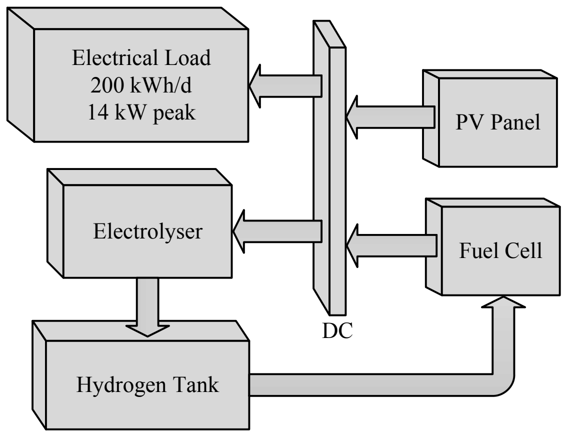

Figure 1. Model of hybrid power system

A. Photovoltaic panels

PV cell is the basic element constituting light conversion of solar energy into electrical energy. It is also the basic blocks of a photovoltaic system. Usually, the cell size of a few square centimeters provides the power of 1-2W. In order to obtain more power, a larger number of cells are mechanically and electrically connected to the larger units called modules.

Series-parallel connection of several PV modules makes a photovoltaic panel. Usually, panels are of 1.6 m2 in area and of 240 – 300 W of power. Connection of number of PV panels configures a PV unit, a valid entity that meets the voltage and

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current opportunities that require a system in which the panels are joined. This unit is called a photovoltaic array.

B. Electrolyser

Hydrogen can be produced from water using the process of electrolysis to separate water into its components: hydrogen and oxygen. Electrolysis technologies, which have been in use for decades, are used for the separation of water and storage of oxygen and/or hydrogen, primarily for the chemical industry.

Electrolysis is considered a potentially viable method of production of hydrogen in the distribution and extent of the costs that are acceptable in meeting the challenges of supplying hydrogen required for the early generation of fuel cell vehicles. Electrolysers are compact and can be located at existing filling stations.

Electrolysis is a way for the production of hydrogen from renewable energy sources. From an energy standpoint, electrolysis is literally a way to transform electrical energy into fuel. Thus, electrolysis is a means of connecting renewable energy to the market for transportation fuels.

There are three types of water electrolysis:

- Alkaline,
- Electrolysis with solid polymer electrolyte (SPE / PEM),
- Steam electrolysis (electrolysis with solid oxide).

C. Hydrogen tank

From the primary source to the end consumer, energy storage is a key process in almost all parts of the system. This process allows maximum satisfaction of energy demand when consumption exceeds production capacity as well as saving energy in the reverse situation. It is also essential for all mobile and portable applications. In this sense, any liquid or gaseous fuel has a big advantage over electricity.

Liquid fuels allow storing large amounts of energy in small tanks (i.e. car), and gaseous fuels, with their relatively small densities, requiring special storage conditions.

In gaseous form, hydrogen can be stored efficiently under pressure. Volume of one kilogram of hydrogen gas at atmospheric pressure is about 11 cubic meters. Gas must therefore be compressed to several hundred atmospheres and kept in specially designed pressure vessels.

In liquid form, hydrogen can only be stored at cryogenic temperatures in a well-insulated storage tanks.

D. Fuel cells

A fuel cell is an electrochemical generator in which the direct conversion of energy takes place. It releases a chemical reaction between the fuel medium, usually hydrogen (today and many other compounds) and oxygen (less pure, usually taken from the air) thus transforming it into electricity and heat. The essential structure of each fuel cell consists of two electrodes-the anode and cathode on which reduction and oxidation reactions of electrolytes (impermeable membrane) are played respectively, allowing the movement of ions, which closes a circuit and established power [4].

Isothermal mode is required for the fuel cell operation, so its temperature must be kept constant [5]. This is achieved by the cooling system, which drains excess heat, thus providing cogeneration process (using the free heat to generate electricity). Fuel cells are based on low operating temperatures and have low reactivity in the reaction of the participants, As a consequence a catalyst must be present (some precious metals and other compounds) to intensify the reaction.

E. Load

The load is a type of DC load. Its averaged daily profile during each month can be seen in Fig. 2. According to the figures the load is at the highest level in the afternoons.

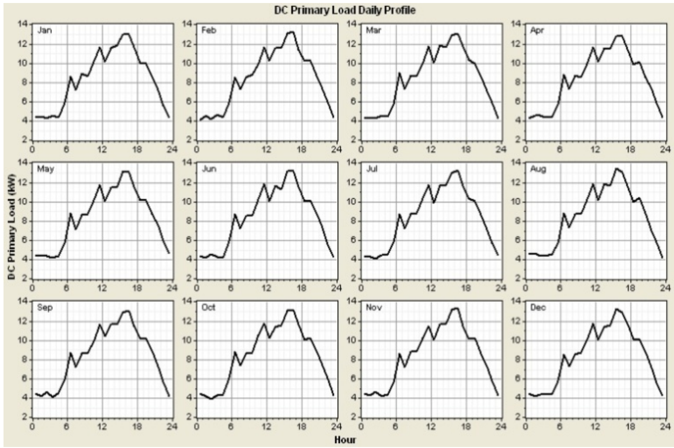

Figure 2. DC primary load daily profile

Results given in the next section will be based on the load profiles shown on Fig. 2.

III. RESULT OF OPTIMIZATION AND SIMULATION

HOMER Energy Software package was used for simulation and optimization. The input parameters are the locations, where the hybrid system is implemented and solar radiation for such a location. HOMER ranks systems based on the total net present cost. The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating that component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties [3]. As a case study, the simulation is performed for a hybrid RES system located in Novi Sad, Serbia.

Novi Sad is located at 45° 20' 0"N, 19° 51' 0"E. Table I contains the values of the daily sums of global solar energy radiation on a horizontal surface and the clearness index for each month of a year. Maximum average radiation is expected in July and it is 5.94 [kW/m2/day], while minimum in December: 1.12 [kW/m2/day]. Clearness index decreases if the area has a higher occurrence of cloudiness. According to data obtained from the NASA organization, the sunniest month is August with clearness index 0.539, while the lowest index is in

December, 0.388. It is assumed that the lifetime of the system is 20 years.

TABLE I. AVERAGE DAILY VALUES OF GLOBAL SOLAR ENERGY RADIATION ON A HORIZONTAL SURFACE AND THE CLEARNESS INDEX FOR THE AREA OF NOVI SAD

Month	**Clearness** *Index*	**Daily radiation** *[kWh/m2/d]*
January	0.422	1.40
February	0.477	2.27
March	0.49	3.38
April	0.466	4.28
May	0.49	5.33
June	0.501	5.80
July	0.53	5.94
August	0.539	5.28
September	0.502	3.85
October	0.47	2.53
November	0.394	1.43
December	0.388	1.12

Photovoltaic panels produce electricity to provide power to an electric load. Excess solar energy is used for supply of an electrolyser, which generates hydrogen. Hydrogen is then stored in a tank. When photovoltaic panels do not produce electricity during the night or when the input energy is not sufficient to cover needs of the load, the fuel cell produces electricity using hydrogen as a fuel.

In order to reach the optimal solution for the standalone hybrid system, in addition to solar radiation data, it is necessary to enter data of system components and parameters. Cost of each component is also an important criterion. The photovoltaic array is set at an angle of 35 degrees to the horizontal surface. It is assumed that the cost of 1kW photovoltaic series is $2000, while the replacement after the lifetime is $1600. Electrolyser is a DC type with efficiency of 85%. It is assumed that the cost of 1 kW power electrolyser is $2000. Service lifetime is around 20 years, so during this period electrolyser doesn't need a replacement. Reservoir tank for storing the production of hydrogen costs 500 $/kg, while its replacement 450 $/kg. The assumed cost of 1 kW fuel cell stack is $ 3000. Lifetime of a fuel cell is 40,000 working hours.

Results of the optimization, obtained for the proposed system configuration (Fig. 1) are: Needed photovoltaic power is of 160 kW, fuel cell power is of 12 kW, power electrolysis unit of 74 kW, while the selected tank is of 200 kg.

One of the problems with such a RES system is round-trip efficiency of the hydrogen storage system which is less than 50%. Because so much power is lost in the storage system, the energy production of the PV array must greatly exceed the electrical load. Also, the requirement that nominal load energy must be supplied in any day or part of the day greatly increased the system price. As a result, although the average electric load is only 8.3 kW, the optimal PV array size is about 160 kW. PV array of power lower than 160 kW is not able to supply sufficient energy to the load during the most critical winter days.

Regarding costs, results show that one needs to invest around $ 600k for system components, and for replacing some of the components it requires an additional $ 38,727. The cost of each RES system component is shown in Fig. 3. As expected, the biggest investment is in PV panels.

For assumed service lifetime of 20 years, the system will produce in total around 700,000 kWh of electrical energy. Therefore, the average cost of electricity production will be about 0.86 $/kWh. With the present electricity cost available from the public grid (in USA it is in average 0.215 $/kWh, in Serbia in average 0.08 $/kWh), it is four times higher price for a case in USA, or more than 10 times for the case in Serbia ($600k compared to $150k, or $55k, respectively). However, the $150k or $55k does not include the initial costs of construction of the power grid infrastructure.

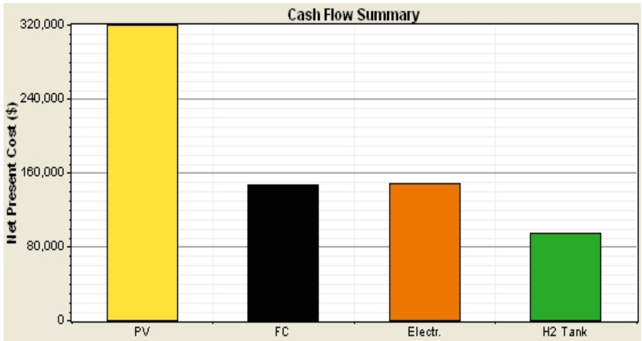

Figure 3. Cash flow summary

Yearly data of solar radiation and the amount of stored hydrogen are shown in Fig.4. It can be concluded that the most hydrogen is produced from mid-April to late October, obviously because during that period was the most sunny days.

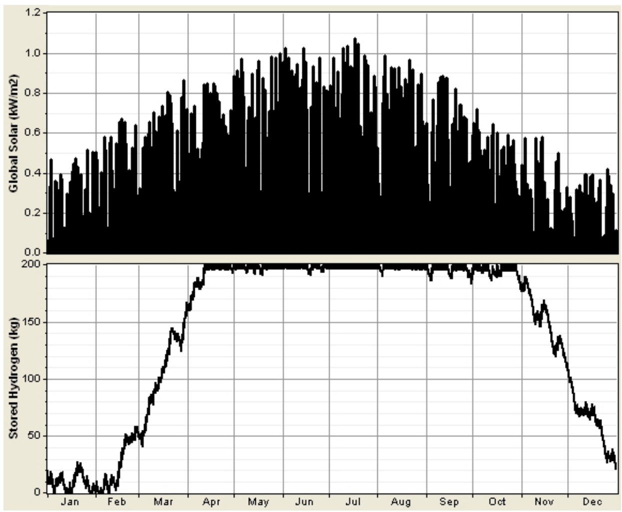

Figure 4. Yearly data of solar radiation (top) and the amount of produced hydrogen (bottom)

Yearly data on solar irradiance (top) and power (bottom) produced by photovoltaic panels and the power produced by the fuel cell are shown in Fig. 5. One can find that the average consumption of fuel cells is about 15 kW.

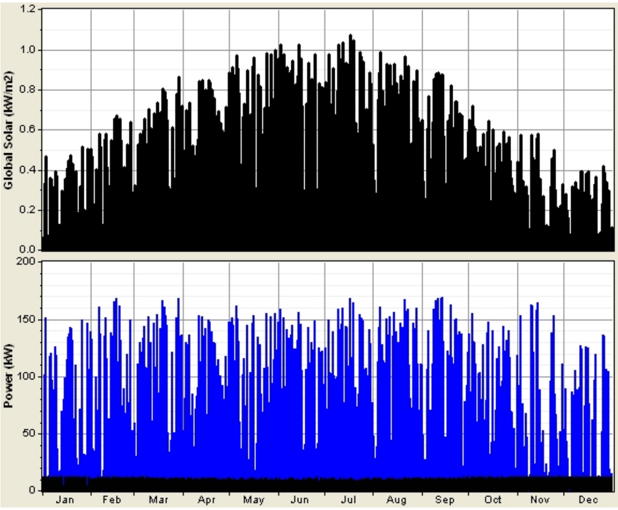

Figure 5. Yearly data on solar irradiance (top) and power (bottom) produced by photovoltaic panels (blue) and the power produced by the fuel cell (black).

Next two figures (6 and 7) show daily duty cycle of system components. Figures show the PV power, the amount of stored hydrogen, DC load and fuel cell power. Figure 6 shows summer daily rate. During the morning, when photovoltaic panels do not produce enough electricity consumer is firstly supplied by power by a fuel cell and then comes to the consumption of hydrogen. After the increase in solar radiation, photovoltaic panels produce more energy, which is then sufficient to supply the load and electrolyser and then begins the process of filling the tank of hydrogen and fuel cells stop working. During the evening, the PV panels do not produce electricity, fuel cells are used again, which results in reducing the amount of hydrogen in the tank.

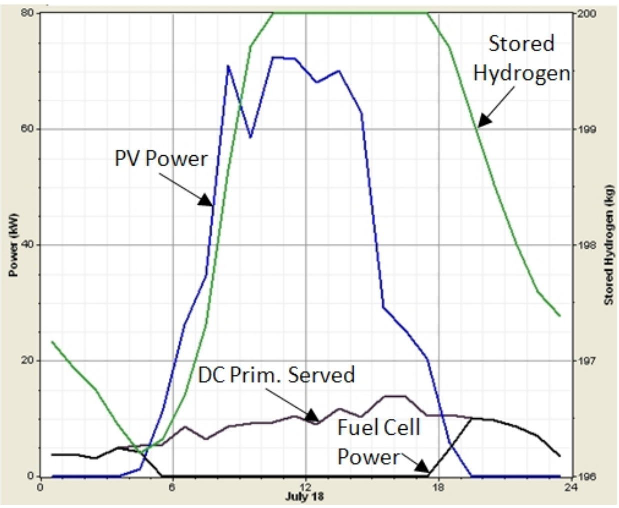

Figure 6. Daily duty cycle of system components and amount of stored hydrogen (summer)

Figure 7 shows winter daily rate. During the winter days the photovoltaic panels frequently produce insufficient power for the load. In that case, the stored hydrogen is consumed by fuel cell even during the day.

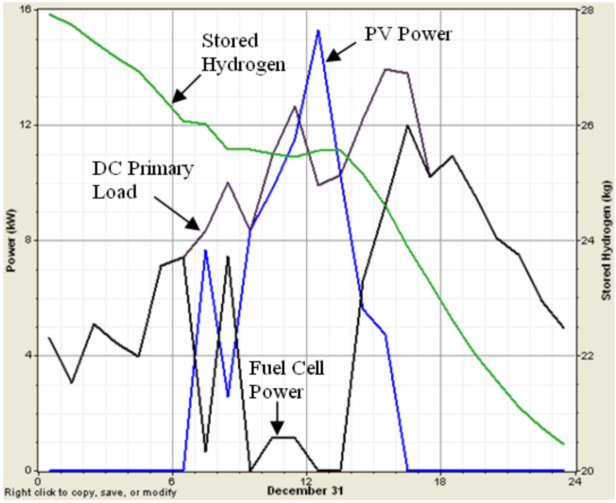

Figure 7. Daily duty cycle of system components and amount of stored hydrogen (winter)

IV. Conclusion

This paper presents a hybrid system that consists of a photovoltaic panels, electrolyser, hydrogen storage tank, fuel cells and DC consumers. The system has no wind turbines and it is presumed that consumer can't be powered from the power system, i.e. it is dedicated to isolated locations. Main results of system optimization show that net costs of a kWh are four times higher in case of energy prices in USA or even 10 times higher in comparison to public grid connection prices in Serbia. Yet, the grid construction costs to such a remote location are not included. The most restricting criteria for this RES system optimization turned out to be the demand that nominal energy must be supplied in any day or any part of the day. The optimal solution based on total net cost consists of photovoltaic panel of 160 kW, fuel cells of 12 kW, electrolyser of 74 kW and a hydrogen tank of 200 kg. This solution is still very costly and makes the usage of this standalone RES system without government subventions not feasible in Serbia.

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