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Optimal sizing of a stand-alone hybrid power system via particle swarm optimization for Kahnouj area in south-east of Iran

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A B S T R A C T

In this paper a novel intelligent method is applied to the problem of sizing in a hybrid power system such that the demand of residential area is met. This study is performed for Kahnouj area in south-east Iran. It is to mention that there are many similar regions around the world with this typical situation that can be expanded. The system consists of fuel cells, some wind units, some electrolyzers, a reformer, an anaerobic reactor and some hydrogen tanks. The system is assumed to be stand-alone and uses the biomass as an available energy resource. In this system, the hydrogen produced by the reformer is delivered to the fuel cell directly. When the power produced by the wind turbine plus power produced by the fuel cell (fed by the reformer) are more than the demand, the remainder is delivered to the electrolyzer. In contrast, when the power produced by the wind turbine plus that produced by the fuel cell (fed by the reformer) are less than the demand, some more fuel cells are employed and they are fed by the stored hydrogen. Our aim is to minimize the total costs of the system such that the demand is met. PSO algorithm is used for optimal sizing of system's components.

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1. Introduction

The major application of the stand-alone power system is in remote areas where utility lines are uneconomical to install due to terrain, the right-of-way difficulties or the environmental concerns. According to the World Bank, more than 2 billion people live in villages that are not yet connected to utility lines [1]. These villages are the largest potential market of the hybrid stand-alone system using fuel cell with wind for meeting their energy needs.

In previous studies, the optimal sizing problem is solved for wind-fuel cell hybrid system [2], and for wind-solar-fuel cell hybrid system [3]. Furthermore the optimal sizing of wind-solar-battery hybrid system is performed by means of genetic algorithms [4], in these studies optimal sizing of hybrid power system using genetic algorithm [5] and optimal sizing of grid connected hybrid power system [6] were investigated. In this paper, the optimal sizing of a wind-fuel cell hybrid system is considered. The system uses the biomass to produce its required hydrogen.

The optimization is carried out via Particle Swarm Optimization (PSO) algorithm.

Generation of hydrogen by the reformer causes a higher reliability for the system.

In this paper we first consider the hybrid power system and then the cost of the system presented by an objective function. Then we review PSO algorithm and finally some simulation results are presented. This study is performed for Kahnouj site in south-east Iran. It is located in a village with a population of 2000. The waste is used to produce hydrogen. This village is far from the grid.

2. Description of the hybrid system components

2.1. Wind turbine

The outlet energy of a turbine could calculate from its power–speed curve. Such a curve is illustrated in Fig. 1 [4].

The power of the wind turbine is described in terms of the wind speed by Ref. [7],

$$\begin{cases} 0 \quad V < V_{\text{cut-in}}, V > V_{\text{cut-off}} \\ P_{\text{wg-max}} \times ((V - V_{\text{cut-in}})/(V_{\text{rated}} - V_{\text{cut-in}}))^3 \quad V_{\text{cut-in}} \le V < V_{\text{rated}} \\ P_{\text{wg-max}} \times \frac{P_{\text{furl}} - P_{\text{rated}}}{V_{\text{cut-off}} - V_{\text{rated}}} \times (V - V_{\text{rated}}) \quad V_{\text{rated}} \le V \le V_{\text{cut-off}} \end{cases} \tag{1}$$

In which $V_{\text{cut-in}}$, cut-in wind speed [m/s]; $V_{\text{cut-off}}$, cut-out wind speed [m/s]; V wind speed [m/s]; V_{rated} nominal wind speed [m/s]; $P_{WG\text{-max}}$, maximum power of wind turbine [kw]; and P_{furl} power of

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Nomenclature

P_{wg_conv}	Power delivered from wind turbines to converter (kw)
P_{wg_el}	Power delivered from wind turbines to electrolyzer (kw)
P_{el_tank}	Power delivered from electrolyzer to hydrogen tank (kw)
$P_{tank\text{-}fc}$	Power delivered from hydrogen tank to fuel cell (kw)
P_{fc_conv}	Power delivered from fuel cell to converter (kw)
P_{conv_load}	Power delivered from converter to load(kw)
P_{ref_fc}	Power delivered from reformer to fuel cell (kw)
P_{comp_tank}	Power delivered from compressor to hydrogen tank(kw)
P_{wt}	Power generated by wind turbines(kw)
P_{load}	Load power(kw)
E_{tank}	Stored energy in the hydrogen tank(kwh)
η_{fc}, η_{el}, η_{conv}	Efficiency of fuel cell, electrolyzer, converter
NPC_{index}	Net present cost (the index shows the corresponding component)
K	Single-payment present worth factor
R	Lifetime of project (year)
L	Lifetime of each components (year)
Ir	Interest rate
F_{opt}	Optimal cost ($)
N_{index}	Optimal number (the index shows the corresponding component)

wind turbine in cut out wind speed [kw]. In this analysis, Bergey Wind Power's BWC Excel-R/48 is considered. It has a rated capacity of 7.5 kw and provides 48 V dc as output. Cost of one unit considered is 19.4 $k while replacement and maintenance cost are taken as 15$k and $75/year. Lifetime of a turbine is taken to be 20 years (20a) [7].

2.2. Fuel cell

Proton exchange membrane (PEM) fuel cell is an environmentally clean power generator which combines hydrogen fuel with oxygen from air to produce electricity. The efficiency of the fuel cell is fed to the program as the input. The equivalent heating value of hydrogen is 3.4 kwh/m^3 in the standard conditions and its density is around 0.09 kg/m^3. Therefore, the amount of energy yielded per kg by hydrogen is

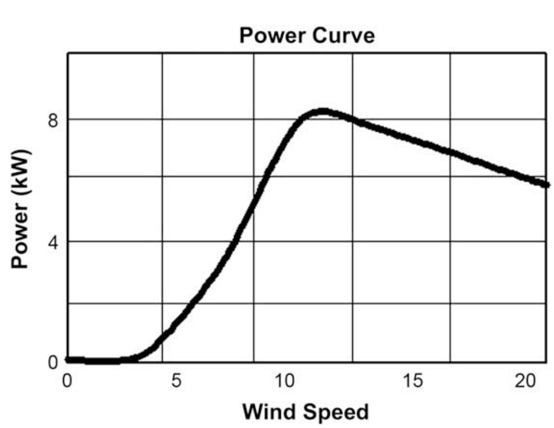

Fig. 1. Wind turbine power versus wind speed characteristic [7].

$$\frac{3.4(\text{kwh/m}^3)}{0.09(\text{kg/m}^3)} = 37.8(\text{kwh/kg}) \tag{2}$$

Therefore,

$$\text{Electricity produced by the fuel cell (kwh)} = \text{consumed hydrogen(kg)} \times \eta_{fc} \times 37.8$$

η_{fc} is the efficiency of the fuel cell.

The capital cost, replacement costs and operational cost are taken as 3$k, 2.5$k and $.02/h for a 1-kw system, respectively. Fuel cell lifetime and efficiency are considered to be 5 years (5a) and 50%, respectively [7].

In this analysis Ballard fuel cell is considered [8].

2.3. Electrolyzer

Electrolysis to dissociate water into its separate hydrogen and oxygen constituents has been in use for decades, primarily to meet industrial chemical needs. Considering an efficiency of 90 percent for the electrolyzer. The amount of energy used to produce 1 kg hydrogen is calculated:

$$\text{Energy consumed by the electrolyzer} = \left(\frac{3.4(\text{kwh/m}^3)}{0.09(\text{kg/m}^3)/90}\right) \times 100 = 41.97\ \text{kwh/kg} \tag{3}$$

The weight of hydrogen produced per hour is calculated by dividing the amount of energy flowed from the wind turbine to the 41.97.

$$\text{Hydrogen produced (kg)} = \frac{1 \times P_{wg\_el}(\text{kwh})}{41.97(\text{kwh/kg})} \tag{4}$$

In this analysis Avalence electrolyzer is considered [9].

In this analysis, a 1-kw system is associated with 2$k capital, 1.5$k replacement and $20/year maintenance cost and efficiency considered as 90% [7].

2.4. Anaerobic reactor

Anaerobic reactor is a natural process that takes place in the absence of oxygen. The anaerobic reactor provides efficient two-stage digestion of wet biomass. Fig. 2 illustrates this process [10].

The municipal waste is gathered daily and fed to the anaerobic reactor to produce methane.

2.5. Reformer

Hydrogen can be produced from methane using high temperature steam. This process is called steam methane reforming [25]. In this study, MAHLER reformer is considered [11].

It is assumed that the residential area has a population of 2000, and each person produced 600 g waste per day. The hydrogen produced by the waste is constant per day. Furthermore, the hydrogen produced by the waste is 50 kg which equivalent to 1890 kwh.

In this study, anaerobic reactor and reformer are considered as one system. Such that, the waste and hydrogen are its input and output respectively. The relation between the weight of waste and the weight of resultant hydrogen is as follows:

$$H_2(\text{kg}) = 0.0454(\text{waste(kg)}) \tag{5}$$

The capital, replacement and O&M costs for 1 kg hydrogen per day are 1.45$k, 1.3$k and $100 respectively. The lifetime of reformer and anaerobic reactor are 20 years (20a).

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