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Sizing and maintenance visits optimization of a hybrid photovoltaic-hydrogen stand-alone facility using evolutionary algorithms

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ABSTRACT

This paper tackles the optimization of a stand-alone hybrid photovoltaic-batteries-hydrogen (PV-hydrogen) system, using an evolutionary algorithm. Specifically, a stand alone power system for feeding a remote telecommunications facility is studied. The considered system is specifically designed to cover the power necessities of remote, isolated telecommunications facilities, so it must be able to work in an unattended way during a long time period. On the other hand, if maintenance visits are scheduled, it is intuitive that the cost of the stand alone system could be reduced. Thus, two different optimization problems have been considered in this work. The first one consists in the obtention of the optimal number, distribution (two different arrays of batteries must be fed) and disposition (slope and azimuth) of the PV panels in the facility, for the case of autonomous operation of the telecommunication system during at least two years. The second problem considered consists of scheduling a maintenance visit per year, where a technician is able to reconfigure the system. In this case, the problem consists of obtaining the optimal number, distribution, disposition of the PV panels, and also the time of the year where the maintenance visit should take place. An evolutionary algorithm, able to tackle both problems with very few changes, is described in this paper. The proposed evolutionary algorithm has been analyzed in a simulation of a real PV-hydrogen system sited at National Spanish Institute for Aerospace Technology (INTA), at Torrejón de Ardoz, Madrid, Spain. The well-known software TRNSYS has been used in order to simulate the behavior of this PV-hydrogen system. Several simulations of the system recreating different weather conditions of three Spanish cities (Madrid, Barcelona and La Coruña) have been carried out, and a comparative analysis of the results obtained by the evolutionary algorithm has been done. The results obtained in the first problem tackled showed that in Madrid the system was able to work in an unattended way during 23 months with 6 PV panels, whereas adding one extra panel, the system was able to work in an unattended way for more than 24 months. In the case of Barcelona and La Coruña solutions with 6 PV panels provide 21 and 20 months of unattended work of the system. In the second problem tackled, we have obtained an important reduction in the number of PV panels needed for obtaining an unattended work of the system between two maintenance visits.

1. Introduction

Isolated systems, such as remote stand-alone applications, usually lack the possibility of being fed from the electrical grid connection. In these cases, photovoltaic (PV) power systems are a reliable and economical solution to cover the demand of electricity of these systems [1,2]. Moreover, if they are hybridized with storage solutions and/or wind [3], diesel [4] or hydrogen production [5,6], the system may produce power even under low insolation situations, improving the performance of the system and enabling unsuspended continuous service [7–15]. Climate can also make some of these hybrid solutions more profitable than others [16,17]. There are different important applications where PV or hybrid PV systems have been successfully applied, such as telecommunications systems (antennas or mobile base stations) [18], desalinization plants feeding [19] or remote areas power supply [2,20,21].

There are several works in the literature devoted to the sizing of hybrid PV systems using soft-computing algorithms, such as neural

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networks or evolutionary-type techniques. In Ref. [22] a neural network approach to obtain the main parameters of the sizing curve of stand-alone systems is proposed. That work has been recently extended using a neural network-genetic algorithm combination in Refs. [23,24]. Neural networks can also be applied to the estimation of electric load of a given system, either isolated or grid-connected such as in Ref. [25], what may be significant to predict system's consumption and sizing it accordingly. Another recent work on sizing PV systems is [26], where a particle swarm optimization algorithm is used in order to obtain the optimal sizing parameters of a hybrid PV system. There are some other works on hybrid PV systems where sizing and optimization of the system is performed using evolutionary computation algorithms. Specifically, in Ref. [17] an evolutionary algorithm is applied to the optimization of a hybrid PV-wind-diesel-batteries-hydrogen system. The algorithm searches for the optimal values of number and type of PV panels, number and type of wind turbines, type of hydroturbines, type of electrolyzer, number of batteries and type of AC generator. In Ref. [27] a genetic algorithm is proposed to optimize a hybrid stand-alone PV-diesel system, considering sizing of the system (optimal configuration of PV panels, batteries and diesel). The system is applied to the optimization of a real PV-diesel system in Bangladesh. In Ref. [28] the optimization of a PV-wind-batteries stand-alone system is carried out using a genetic algorithm which also takes into account the loss of power supply probability of the area.

This paper is focused on hybrid PV systems that include hydrogen production and energy storage. In these systems, storage of energy is based on the conversion of DC electricity generated into hydrogen, using an electrolyzer. Whenever energy is needed by the stand-alone system (i.e., PV does not provide enough energy), DC electricity is obtained in the fuel cells from the hydrogen stored. Considering a stand-alone system including all the aforementioned features, the complete sizing of the system is determined by many different parameters such as the average load energy demand (i.e., the telecommunication antenna energy demand in the case of the considered system), the average PV-array (PV-field) energy production (determined by the number of PV panels available in the array and very dependant on the climatology of the zone in which the facility is installed), the storage capacity (determined by the size of the batteries or accumulators, the hydrogen production capacity), etc. This paper tackles two different specific problems of a hybrid stand alone systems based on PV-hydrogen production, devoted to feed a remote telecommunications facility. First, the sizing of the system for an unsupervised (autonomous) operation of the telecommunication system during a long time period, we have considered at least two years. Second, the optimization of the system when a maintenance visit by a qualified technician is scheduled every year. In this case, the optimal range of dates of the year when the visit will be carried out must also be incorporated to the pool of variables to be optimized. An evolutionary algorithm is described in the paper, and applied to both optimization problems with very few changes. The proposed evolutionary algorithm has been tested in a simulation of a real PV-hydrogen system sited at National Spanish Institute for Aerospace Technology (INTA), at Torrejón de Ardoz, Madrid, Spain. The well-known software TRNSYS [29,30] has been used in order to simulate the behavior of the real PV-hydrogen system feeding a remote telecommunication antenna. Several simulations of the system recreating the weather conditions of each of the studied cities (the climatology of the cities considered in this paper, i.e., Madrid, Barcelona and La Coruña) have been carried out, obtaining interesting results, consisting in the minimum number of PV panels in each city for two years of unattended work of the system (first problem considered), and the number of PV panels and scheduling of the maintenance visits (second problem considered), respectively.

The structure of the rest of the paper is the following: next section presents the real system description and its simulation by means of the TRNSYS software. Section 3 presents the evolutionary algorithm proposed for the two different sizing problems considered. Section 4 shows the performance of this algorithm in three different climatic areas of Spain: Madrid, Barcelona and La Coruña. Finally, Section 5 closes the paper giving some concluding remarks.

2. System description and optimization

The PV-hydrogen system considered in this paper models the HIDROSOLAR_H_2, that was developed at INTA to enable powering of isolated remote-telecommunication stand-alone platforms (Fig. 1). The installation consists of:

- Two fields of PV-arrays (model ATERSA A-127P of 127 W and 12 V) with a variable number of panels in each field array (note that the number of PV panels is a variable to be optimized for the system).
- Two arrays of batteries (model Tudor type 6 EAN 55 of 396 A h).
- Water AC electrolyzer (model VENTUS NM-H2, power consumption 300 V A–200 V).
- Fuel cell (model BALLARD Nexa, maximum power 1.2 kW, maximum hydrogen consumption 18.5 slpm).
- Four metal hydride tanks, 0.90 Nm^3 (model Ovonic TM).
- Two compressed hydrogen cylinders, 8 m^3 at 18 bar (standard model).

The structure of the platform is shown in Fig. 2. There are two fields of PV panels, with n_1 and n_2 pairs of panels, respectively (a total of $n = n_1 + n_2$ pairs of PV panels in the system are considered). These panels feed up two different groups of batteries, each one consisting of a 12 batteries' array. The first group of batteries is used to directly feed the load (the telecommunication load, i.e., an antenna, etc.) while the second group of batteries is mainly used to feed the electrolyzer for hydrogen generation. If the first group of batteries is empty, then the second group of batteries would directly feed the load (instead of feeding the electrolyzer). If both battery groups were in a charging state, the hydrogen stored would be used to feed the load. In order to lengthen batteries' life, deep discharge cycles have been avoided, considering that once the accumulators' charge is under 52%, that particular group will not be used again until recharged to its full capacity.

The water AC electrolyzer produces 0.5 slpm (standard liters per minute) of pure hydrogen at 10.5 bar, that is fed to four metal hydrides bottles where up to 3.56 Nm^3 is stored. In addition to this, two compressed hydrogen cylinders of 8 m^3 at 18 bar were added as an auxiliary power system, that could be used during the unattended use of the telecommunication stand-alone platform. Note that these auxiliary cylinders cannot be recharged and are only used to feed the fuel cell.

2.1. System modeling and simulation using TRNSYS

TRNSYS is a well-known, flexible and modular software tool designed by the University of Wisconsin–Madison Solar Energy Lab. and the Colorado State University Solar Energy Applications Lab., to simulate the transient performance of thermal energy systems. TRNSYS provides components able to handle weather data, and libraries that include most of the components commonly found in thermal and electrical energy systems. Due to its modularity, new mathematical models defining energy components not included in the program can be easily added. Therefore, it has been used in this work to model and simulate the aforementioned HIDROSOLAR_H_2 system's behavior, where the stand-alone system