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# Heuristic-based power management of a grid-connected hybrid energy system combined with hydrogen storage

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ABSTRACT

This paper discusses optimal energy management in a grid-connected hybrid generation system which consists of wind turbine, solar array, fuel cell and electrolyzer. There is also a hydrogen storage tank and a combinational heating system in the aforementioned system. This hybrid structure supplies the electrical and thermal demand of a building. Since the system has the capability to trade power with the grid, hourly tariffs of exchanging power have also been considered so that a wide range of operational modes are covered. Thermal demand of the building is supplied using recovered heat of the fuel cell and also electric heating system. Choosing the suitable model for each subsystem, the paper formulates energy management in this hybrid system in the form of a non-linear and constrained optimization problem and evaluates various well-known heuristic techniques to solve it. By comparative assessment of these techniques, Interior Search Algorithm (ISA) is suggested as the elite technique and the results of ISA-based stimulations are presented in detail. Moreover, the influence of initial state of charge of the hydrogen tank on operating cost as well as charge remained is discussed, proving that not only it has a determining effect on the two aforementioned terms but also it possesses an optimal point which is dependent upon operational parameters of the hybrid structure. To achieve this goal, a novel criterion is introduced in order to determine the optimal value of initial state of charge of the hydrogen tank. Finally, the price fluctuations of tank-stored hydrogen are discussed and it is shown that the final price is lower than the initial one.



## 1. Introduction

Hybrid energy-generation systems are achieved out of engineering progress in order to increase the reliability and efficiency of energy sources. According to the technological improvement of the elements of such systems, it is expected that hybrid systems be offered as an alternative replacement for classical ones. The main concern in these systems is the design of power management system among multiple sources of energy that is closely related to both the structure of the system and its subsystems' specifications [1]. The complexities of hybrid systems, uncertainty, non-linear behavior, different operating modes, etc. warn the need to design an intelligent power management strategy. In this paper, the system under study is a grid-connected hybrid structure consisting of fuel cell, electrolyzer, wind turbine, photovoltaic array, hydrogen storage tank and a combinatorial heating system. Furthermore, it also includes power exchange with local grid. Some of aforesaid subsystems even in simple models are considered as a complex system and included nonlinear characteristics. Optimal power management in such a structure is associated with processes, parameters and variables such as decision making on how to divide power, uncertainties in the pattern of consumption, the accessible capacity of the storage system, the price of power exchanged with local grid, the status of the current set point and the operating mode, the dominant dynamics, etc. [2,3]. Therefore, in such systems the energy management unit should be responsible for collecting data and issuing commands by considering degrees of freedom available and dynamic order of elements to manage power among subsystems to follow an optimal operation. Accordingly, the control strategy in the energy management system should be able to show an adaptive behavior with respect to the uncertain conditions of future and to provide the required coordination between various power converters. Thus, the design of the optimal power management strategy will be based on predicting three structural layers. The first layer is the observer; the second layer is responsible for selecting the operating mode and the third layer pursues the set

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point and the direction of energy flow provided by the second layer [1].

Based on these facts, the aim of this paper is to design an off-line energy management strategy in which load profile is prespecified and the data is given to a power management system. The power management system attempts to choose the most suitable energy management strategy usually based on a smart and intelligent algorithm. In this environment, since the demand is completely predetermined, the control unit is expected to choose the globally best energy management strategy. The reason for the importance of off-line energy management studies is that it is a way to design an on-line energy management system. As an instance [2], used pattern recognition technique to implement on-line energy management in a hybrid electric vehicle. Before one can do this, an off-line energy management must be solved in regard to different load scenarios which provides the necessity for performing on-line optimal energy management through utilizing neural network or pattern recognition.

In this paper, in order to solve the energy management optimization problem in the mentioned hybrid generation system, several heuristic optimization algorithms are used and algorithms priority is specified in terms of their performances to solve the problem. Furthermore, the role of the initial state of charge of the storage tank in total operation cost and also the changes in the price of capsulated hydrogen will be discussed in detail.

The rest of the paper is organized as follows: In the second section the literature and the energy management strategies are discussed. Moreover, beside presenting a descriptive expression of the hybrid systems and the energy management system, recent researches carried out in this field are also mentioned in the same section. In the third section, the problem of optimal energy management is comprehensively discussed in the form of a constrained nonlinear optimization problem and its formulation in order to design an off-line energy management system. The structure of the hybrid system under study is also described in this section. In the fourth section, the utilized heuristic optimization techniques are introduced. In addition to this, simulation results provided by the techniques, those obtained by the elite algorithm in particular, are also proposed. Finally, conclusions are presented in section five.

## 2. The literature survey and a review of performed studies

Indeed, a hybrid energy system is an integration of several power sources that are under the command of a control unit whose aim is to pursue the load continuously. The existence of multiple sources of energy in such systems provides a degree of freedom to apply energy management among different sources. On the contrary, in a single source generation system, following every requested set point is required. Currently, hybrid systems have been dedicated to a useful field of study in the topics related to control, mechanical systems, motor vehicle industry, converters, robotics, mobile systems, etc. [1]. The extension of this research area is so considerable that it is being used even in energy supplying of buildings [4]. To present a general definition of these systems, it can be said that hybrid systems refer to the structures including subsystems characterized by continuous time or discrete time associated with a set of decision making processes and commands that include time-driven or event-driven combined dynamics. These substructures may include a set of differential equations with the models of continuous time or discrete time mode that sometimes operate automatically or in most cases act as systems whose structure changes according to the situation of state variables and some conditions. This feature of hybrid systems impacts on all dynamic processes of these systems.

Meanwhile, paying attention to optimal power management in such systems is significantly important. Therefore, the control and operating modes of the system should be in such a way that the maximum embedded capacity in each subsystem be used so that the objective function be optimized subject to all technical constraints. Studies in the field of energy management show that optimal power flow in hybrid structures has a high complexity even under conditions that its elements are linear [5]. Hence, a desired response to this issue is one of the main focuses of this paper.

Although it is accepted that implementation of optimal power management system in a hybrid structure yields valuable qualitative characteristics, because of the complex structure of these systems, it is difficult to achieve the aforementioned advantages. In the following, the relationship between the optimal energy management system and the structure under study and also the introduction of energy management strategies will be discussed respectively and then an overview of studies performed in this field are presented.

### 2.1. Energy management system

In a hybrid structure, the most important issue is how different energy sources participate in supplying demand. On the other hand, although it is possible that each energy source has an exclusive feature, what is responsible for overall performance is the control model or the energy management system which can use dynamic potential and the capabilities of each subsystem appropriately. In fact, this model is a combination of math blocks and technical specifications that represents logic of operation for a hybrid system. Therefore, the major part of a hybrid structure is the power management model (PMM) which provides a coordination among various power sources so that the demand is continuously satisfied. Indeed, what makes power management inevitable in a multi-source system is the different output characteristics of each energy source. In order to implement the energy management system, designers are supposed to use mathematical model of system's components. These models can be either linear or nonlinear, dynamic, either static or quasi-static. Accordingly, the mathematical model discussed in a PMM represents the system and its variables. (see Fig. 1).

### 2.2. Energy management strategies

Most management strategies developed for hybrid energy generation systems are classified in four major categories. The first one considers the experimental use of the results and observations in the management strategy of the hybrid system through simple control algorithms. This type of strategy has been mainly implemented on the primitive generation of hybrid systems [2,3,7]. The second category is based on static optimization methods in which the contribution of subsystems in supplying demand has been determined according to zero-order model of the elements of hybrid system. In other words, static or quasi-static assumptions are used to exert energy management. These algorithms have been often pushed to linear optimization problems due to their relatively simple optimization nature. This strategy is mainly used in power management of hybrid vehicles [1–3,5]. The third category suggests using smart control techniques such as fuzzy, heuristic, neural networks, etc. in order to evaluate and develop the management strategy which has been applied to static or even dynamic models of hybrid systems. In some studies, due to the existence of nonlinear dynamics, parameters sensitivity to environmental factors, the complexity of load, uncertainty, etc. which make the system's operation difficult; investigators have focused on smart strategies. Also smart strategy is appropriate to use in cases in which on-line power management is needed. A real-time strategy usually