An Energy Management Strategy and Fuel Cell Configuration Proposal for a Hybrid Renewable System with Hydrogen Backup

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ABSTRACT
This paper presents a new and optimal proposal of energy management strategy for a solar panels/wind turbines/fuel cell/battery/alkaline electrolyzer on grid hybrid power system. These new proposal takes into account technical and economical optimization parameters, improving the system performance, the lifetime of different elements and reducing operation and maintenance cost. The features of the proposed energy management strategy are compared over other strategies found in the scientific literature. Additionally, another key parameter like fuel cell modularity has been considered. That is the effect over the whole system performance of using a single fuel cell with high rate power (P_{FC}) versus a modular configuration built from n stacks with P_{FC}/n rate power each one. Then, joining the new proposed strategy with the optimization parameter regarding the fuel cell modularity, it is possible to get the best solution for this kind of hybrid systems.

KEYWORDS
Energy Management, Fuel Cell Configuration, Hybrid Renewable, Hydrogen Backup, Simulator

1. INTRODUCTION
Nowadays it is an increasingly environmental problem the use of an energy system based on fossil fuels. Despite the efforts of governments and research teams, renewables energies have a number of associated problems such as dependence on environmental conditions, lifetime, high price, etc. In order to reduce these problems, the use of hybrid systems is presented as a technically feasible optimal solution. Recently, the use of hydrogen as an energy vector has been presented as a viable solution to improve the performance of hybrid system (García, Torreglosa, Fernández, & Jurado, 2013).

The proper energy management of hybrid systems requires the design of a control system and energy management strategy. For this reason, different works have been presented in order to make an optimal management, increasing system performance, providing a real alternative to current energy production. Most of these works are based on strategies whose sole propose is to keep the load as long as possible. The main target of these strategies is to ensure the power balance. This parameter is presented therefore as the only decision criteria to operate the system. These strategies base their efforts on maintaining the demand, ignoring technical or economic criteria associated with the proper operation of the equipment and its operating regimes. The use of fuel cell and electrolyzer is determined by the power balance, generating or absorbing energy based on the amount of excess/deficit.
energy. Strategies with grid connected configurations, use the grid as an active element of the system increasing security by having a solution in situations of excessive excess or defect energy (Ahmed, 2012), (Alkano, Kuiper, & Scherpen, 2015), (Mohammadi & Nafar, 2013), (Tesfahunegn, Ulleberg, Vie, & Undeland, 2011), (Giannakoudis, Papadopoulos, Seferlis, & Voutetakis, 2010). In isolated topologies, it will depend on the use of short-term energy storage elements. In most applications, batteries or supercapacitors operate in the first instance in situations of excess or defect energy, absorbing or supplying energy respectively. The use of fuel cells and electrolyzers is determined by the maximum or minimum predetermined operating margins for the above equipment (Sun, Lian, Wang, & Li, 2009), (Li, Jiao, & Wang, 2013), (Osman Haruni, Negevitsky, Haque, & Gargoom, 2013), (Tégani, Aboubou, Ayad, Becherif, & Bahri, 2014), (Feroldi, Degluomini, & Basualdo, 2013), (Mbarek, Belhadj, Le, & Tunis, 2009), (Bizon, Oproescu, & Raceanu, 2015).

In the same way, there are different works with strategies which objectives include some technical decision factors. The main target of these strategies is to reduce the degradation of the more critical equipment during the system operation. These elements are battery, electrolyzer and fuel cell. The solutions adopted in the literature are diverse and depend on the main goal to study. Strategies which choose to increase battery life, operate it with very low depths of discharge, a fixed load condition or a narrow range of SOC (Alkano et al., 2015), (Sacarisen & Parvereshi, n.d.), (Ipsakis et al., 2008). Other strategies are based on overcurrent control, improving the battery charge process (Kim et al., 2014). Strategies which choose to increase the electrolyzer lifetime are based on operate it with minimal power point. The use of this parameter will increase the performance but with low purity of products (Alkano et al., 2015), (Dash & Bajpai, 2015), (Uzunoglu, Onar, & Alam, 2009).

In order to reduce the degradation of the fuel cell versus dynamic conditions, it will operate in stable power (Brka, Kothapalli, & Al-Abdeli, 2015), (Dursun & Kilic, 2012).

On the other hand, to reduce the negative effect of starts-stops cycles of electrolyzer and fuel cell, two different solutions are adopted in the literature. The first one determines the start-stop points of the equipment according to the hysteresis of the SOC (Karami, Moubayed, & Outbib, 2014), (Dash & Bajpai, 2015), (Sacarisen & Parvereshi, n.d.). The second one uses generation and demand forecast to determine, based on the current system status, what element will be necessary in the next work cycle and its power reference (F. Segura, Durán, & Andújar, 2009), (Hussain, Member, Bingham, & Stone, n.d.). Such strategies have the disadvantage of relying on the precision of the forecast. Finally, (Behzadi & Niasati, 2015) presents a strategy which priority is based on the accumulated degradation for each element. The element with lower degradation will absorb or supply energy when it is necessary.

Other strategies have only economic goals, ignoring some real problems associated with the equipment degradation. The solutions adopted in the literature (Bordons, García-Torres, & Valverde, 2015), (Heymann & Bessa, 2015), (Zhou, 2008), (García, Torreglosa, Fernández, & Jurado, 2014), (Zhang et al., 2013), (Patsios, Antonakopoulos, Chaniotis, & Kladas, 2010), (Trifkovic, Marvin, Sheikhzadeh, & Daoutidis, 2013) are based on the use of different cost functions associated with the charge or discharge of the elements, which determine an optimization problem. The use of different algorithms will be used to calculate the solution of optimization problem.

Finally, this kind of strategy seeks to increase system performance, based on the proper supply to demand. Technical and economic criteria are taken into account to increase equipment life and reduce maintenance costs. This strategy has an optimal solution for a technical and economic point of view, compared to traditional generation alternative systems. The solutions adopted in the literature (Castañeda, Cano, Jurado, Sánchez, & Fernández, 2013), (Wang, Tong, Palazoglu, & El-farra, 2014) are based on nonlinear optimization problems, using cost and equipment depreciation and useful life functions.

On the other hand, most of studied hybrid systems (Ahmed, 2012; Das, Esmaili, Xu, & Nichols, 2005; Eid, 2014) consider a fuel cell as energy backup element to ensure the load demand and system stability as secondary long-time backup. In all these cases the fuel cell system is built from a single stack, and hardly we can find works, (El-Shater, Eskander, & El-Hagry, 2006), which mention the
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