A Novel Heuristics-based Energy Management System for a Multi-Carrier Hub enriched with Solid Hydrogen Storage

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ABSTRACT
In this paper, an efficient optimization algorithm for the energy management of a grid-connected energy hub plant is proposed. The Simulated Annealing algorithm is adopted for the solution of the energy management problem aiming at the profit maximization for the owner of the energy hub plant. The use of a heuristic algorithm was required by the non-linearity of the efficiencies of each component in the energy transformation stages. The proposed heuristics is applied to a large energy hub, corresponding to the simulation of the test-bed that is being designed and developed inside the ongoing INGRID European research project.

Categories and Subject Descriptors
H.4 [**Information Systems Applications**]: Decision Support.

General Terms
Algorithms, Management, Measurement, Design.

Keywords
Energy Management Systems, Energy Storage, Electric Grid balancing, Renewable Sources integration, Simulated Annealing, Energy supply and demand matching.

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1. INTRODUCTION
The distributed energetic production from Renewable Energy Sources (RES) is rapidly expanding so that, sometimes, in particularly sunny or windy places, the "green" energy produced is comparable to, or greater than, the energy adsorbed by the loads connected to the distribution grid. Because of their inherent non-controllable variability as well as partial unpredictability the power produced by RES can cause stability issues and can degrade the quality of the power in the grid. In order to address these issues, the INGRID FP7 European co-funded project [1] is studying several solutions to balance power supply and demand by shifting the electricity adsorption or modulating the energy injected into the grid in cooperation with the Distribution System Operator (DSO). The main objective of this work consists of designing, implementing and testing an innovative Energy Management System (EMS) [2][3] by means of a heuristic based methodology.

2. SYSTEM DESCRIPTION
The system currently under development will be instantiated in a concrete 39 MWh energy storage facility that will be deployed and will operate in Troia (Puglia region, Italy). The system reported in Fig. 1 is composed by the following subsystems: an internal RES based plant, a Water Electrolyser (WE) for hydrogen production, a Hydrogen Solid-state Storage (HSS) system, a Fuel Cell (FC) and an Electrical Vehicle Recharge System (EVRS).

The system takes into account the electric grid connection, the possibility to receive information from both the electricity and the hydrogen markets, and also the possibility to inject the produced hydrogen into the methane pipeline. The system communicates with the DSO, which provides the desired power consumption or generation profiles which are taken into consideration for the optimisation of the profit. The system may also provide ancillary services at the grid connection point by activating the FC when a specific function is requested by the DSO.

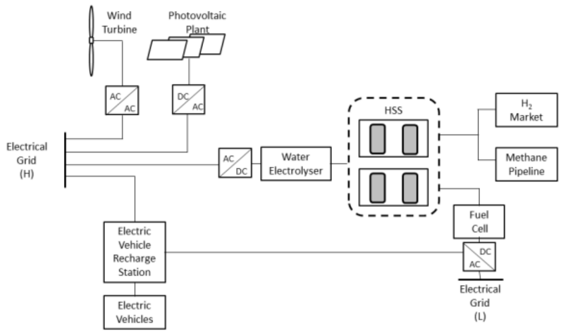

Fig. 1 Managed system block diagram

The HSS is based on a metal hydride technology and consists of two storage subsystems: one tailored to the hydrogen market and the methane pipeline (*open loop*), the other to the FC for the production of electricity (*closed loop*).

3. THE ENERGY MANAGEMENT SYSTEM

In the energy management problem, the objective function is the economic benefit for the plant owner. The function to be optimized has many additive terms. Some of them have non-linear coefficients considering the Water Electrolyser or the Fuel Cell efficiencies, basically derived from the converters used as systems to interface the grid. In order to correctly manage the INGRID system, the Simulated Annealing (SA) algorithm was implemented and appropriately fitted. The EMS sets the plant configuration on the basis of the input data coming from each subsystem in order to modulate the electricity adsorption/supply. The EMS operates considering a reference time horizon, which is subdivided in elementary time slots. The architecture consists of the overlapping of two operational time stages: scheduling time and real time. The scheduling and real time are superimposed in the same time slot and the EMS re-schedules for the entire time horizon [4]. The EMS is connected to the Distribution Management System (DMS), the Electricity Market, the RES forecasting system, the Hydrogen Production and Distribution System (H2P&DS), the Fuel Cell management system, and the Intelligence Dispenser (ID) that manages the EVRS. In particular, the H2P&DS is the system that manages the WE, the HSS, and receives information about the hydrogen sale. The DMS represents the DSO interface which communicates with the EMS by means of the IEC 61850 protocol.

4. SIMULATIONS RESULTS

A MATLAB script has been designed, written and successfully tested to implement the SA based EMS. The following data refer to the MATLAB implementation and to the plant depicted in Fig. 1. The WE rated power is equal to 1152 kW and its minimum value has been set to 460 kW. The FC nominal power is 1000 kW, the hydrogen storage capacity of the *closed loop* tanks is equal to 556.16 Nm^3 of hydrogen, while the *open loop* tanks has a capability of 4449.28 Nm^3.

In our simulation, the system has to satisfy a hydrogen request equal to 1012 Nm^3 for the *open loop* at the end of the day. The round trip efficiency is set to 0.4, the parameter to convert electricity into hydrogen is equal to 5 kWh/Nm^3 (WE parameter), and a parameter equal to 0.56 Nm^3/kWh is considered to convert hydrogen into electricity. In the following figure, how the EMS operates is reported.

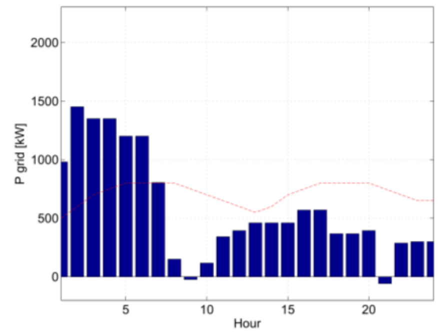

Fig. 2 Electricity adsorbing from electric grid (H)

The blue histogram in Fig. 2 shows the optimal plant configuration during 24 hours, whereas the dashed trend represents the DSO request. The economically optimal solution carried out by the EMS is far from the DSO request because the demonstrator does not follow a master-slave approach. The simulation shows that the integration of a metal hydride based storage as a buffer system in *closed loop* requires that a considerable incentive has to be given to obtain an economically sustainable solution. Despite the poor *closed loop* efficiency, the demonstrator allows to adsorb and convert the excess of electricity coming from the grid, e.g., in presence of power reverse flow, exploiting the *open loop* features.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] INGRID (High-capacity hydrogen-based green-energy storage solutions for grid balancing) European FP7 co-funded project: http://www.ingridproject.eu.

[2] D. Arnone, M. Bertoncini, A. Rossi, F. D'Errico, C. García-Santiago, D. Moneta, C. D'Orinzi "An ICT-based Energy Management System to Integrate Renewable Energy and Storage for Grid Balancing", in *Proceedings of the fourth international conference on Future energy systems* (e-Energy '13). ACM, New York, NY, USA, 259-260.

[3] A. Rossi, D. Arnone, M. Bertoncini, D. Moneta, "Sistema di gestione energetico innovativo con stoccaggio a idrogeno per l'integrazione di fonti rinnovabili a supporto del bilanciamento della rete", accepted to AEIT 2013, October 2013, Palermo, Italy.

[4] Eleonora Riva Sanseverino, Maria Luisa Di Silvestre, Mariano Giuseppe Ippolito, Alessandra De Paola, Giuseppe Lo Re, "An execution, monitoring and replanning approach for optimal energy management in microgrids", Energy, vol. 36, n. 5, pp. 3429-3436, May 2011.