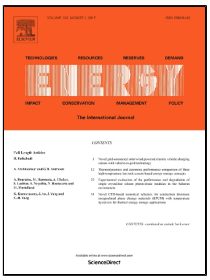
# Accepted Manuscript



Dynamic Modeling of Gravity Energy Storage Coupled with a PV Energy Plant

Asmae Berrada, Khalid Loudiyi, Raquel Garde

| | |
|---|---|
| PII: | S0360-5442(17)31023-X |
| DOI: | 10.1016/j.energy.2017.06.029 |
| Reference: | EGY 11037 |
| To appear in: | *Energy* |
| Received Date: | 21 January 2017 |
| Revised Date: | 05 May 2017 |
| Accepted Date: | 06 June 2017 |

Please cite this article as: Asmae Berrada, Khalid Loudiyi, Raquel Garde, Dynamic Modeling of Gravity Energy Storage Coupled with a PV Energy Plant, *Energy* (2017), doi: 10.1016/j.energy.2017.06.029

# Dynamic Modeling of Gravity Energy Storage Coupled with a PV Energy Plant

Asmae Berrada [a,b1], Khalid Loudiyi [b], Raquel Garde[c]

[a]Faculty of Sciences Dhar El Mehraz, Sidi Mohammed Ben Abdellah University, Fez, 35000, Morocco
[b]School of Science and Engineering, Al Akhawayn University, Ifrane, 53000, Morocco
[c]CENER-National Renewable Energy Centre, Ciudad de la Innovacion 7, 31621 Sarriguren (Navarra), Spain

**Abstract**

The growing interest in renewable energy systems has led to the development of energy storage to overcome their inherent intermittency. Currently, the most used storage technology for large scales systems is pumped hydro energy storage. This system is recognized for its economic viability in large scale applications. Another new alternative for large-scale energy storage is gravity storage system. The dynamic behavior of gravity storage including the mechanical machines and the hydraulic storage components is analyzed to gain insight into the performance of this system. An analytical model has been developed through interconnection of the different plant equipment models using Matlab/Simulink application. This paper details the operation modeling of a hybrid renewable energy system. The proposed model is able to simulate the interaction between the power plant, the storage system, and the electric grid. To evaluate the performance of the Simulink model, a simulation study is carried out on a large scale system.

*Keywords:* Gravity storage; System modeling; Circuitry; Hydraulics; Simulink model.

## 1. Introduction

The increasing penetration of Renewable Energy Sources (RES) into the grids and their unreliability and fluctuating nature cause concerns in terms of security of supply and grid stability. The intermittency and variability of wind power and PV energy impact the grid operation at diverse time scales. From seconds to minutes more regulation reserves and frequency control are needed to overcome frequency and voltage related issues; from minutes to hours, additional capacity for load levelling services is required and at larger scale effects on the schedule and generation portfolio are observed [1,2]. To deal with those challenges different methods to provide additional flexibility to the energy System are being developed and analysed such as demand response technologies, electromobility or new flexibility capabilities of conventional generation. Energy Storage Systems (ESS) take part of these flexibility solutions as well not only due to the numerous available technologies but also the wide range of functionalities or services they can provide [3-5].

In spite of some studies have been developed in the last years to evaluate the performance and dynamic behavior of these systems while being connected to the grid, additional work to analyse their effect on the networks and Renewable Energies integration, is necessary. Some of those studies focused on modelling off-grid and isolated systems where the tandem RES-ESS has proved to be competitive compared to conventional solutions for energy supply. Thus, Maclay et al. [6] analysed the performance of diverse configurations of a hybrid storage system to support the integration of PV energy for residential energy supply in a stand-alone system and concluded that the use of Reversible Fuel Cells in collaboration with batteries ensure grid independent operation while the hybrid based on supercaps and RFC has not enough energy density to meet the load demand. Similar analyses were developed by C.-H. Li et al. [7] in order to optimize the size and operation of hybrid PV/storage systems using batteries and Fuel Cells. Jayalakshmi N.S. et al. [8] investigated a detailed dynamic model and the control strategy developed in the MATLAB/SIMULINK platform of a hybrid solar-battery system and determined that the control strategy is capable of controlling the voltage and frequency irrespective of the load variability and PV power uncertainty. Regarding grid connected systems, there are interesting results published as well. Among others, we can mention the studies focused on microgrids applications in [9,10] and power systems with high RES shares [11-15].

[1] Corresponding author.
E-mail addresses: as.berrada@aui.ma (A. Berrada), k.loudiyi@aui.ma (K. Loudiyi)