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Technical–economic analysis of wind-powered pumped hydrostorage systems. Part I: model development

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Abstract

In this paper a model is presented for the technical and economic sizing of the various components that make up medium sized wind-powered pumped hydrostorage systems. A further aim of this model is the optimisation of the operation of such systems, thereby making full use of the synergy of the unit as a whole.

A general model is described for use as an analytical tool in implementing such systems in topographically suitable sites with sufficient wind resources. The general model developed allows for six strategies for the system operating configuration. Each strategy is based on the hypothesis that there is a centralised operator to control all the system components, except for the load systems.

The characteristics and unit energy cost of each technically feasible combination of components are determined by applying the model. This enables the selection of the most viable composition for the system from an economic point of view given certain technical restrictions.

Keywords: Wind penetration; Pumped storage; Model

1. Introduction

In order to satisfy demand the energy producing companies have traditionally used electricity generating plants that employ a variety of economic and technical characteristics. Conventional, high output, generating plants are generally employed to cover the basic demand. Peak demand times are usually covered by smaller sized cyclically operating plants which work with coal, oil, gas and particularly with cyclical water-pumping systems (Ramage, 2000). These latter systems use the excess electrical production in periods of low demand to pump water to a reservoir situated at a certain height. When required it is then recovered by means of a turbine

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Nomenclature

α maximum percentage of electrical energy demand that can be met by electrical wind-sourced energy without affecting the safety and stability of the system, %
β parameter which can take a value between 0 and 1
δ the percentage δ of peak demand which has to be covered with hydraulic energy, %
η' efficiency of the PS
η efficiency of the HP and its electrical system
η'_1 efficiency of the pumps P1
η'_2 efficiency of the pumps P2
φ wake factor
ρ water density, kg/m^3
ξ reliability factor of the WT
$C(k,j)$ cost of the unit energy supplied by the configuration system k operating in accordance with strategy i, Euros/kW h
$C(j,i)$ minimum local cost of unit energy supplied which is obtained amongst the N_j configurations, Euros/kW h
$C(P_{CP}(t))$ CP production cost, Euros/kW
CF capacity factor of the WP, %
CI the investment costs of the electrical and control infrastructure, Euros
C_{min} minimum overall cost of the unit energy supplied, Euros/kW h
CP conventional electrical generator set
CPS conventional electrical power system
CS control system
$D_{LS}(t)$ electrical demand in time t, kW h
$D_{LS,max}$ maximum peak demand, kW
$E_{CPS}(t)$ conventional energy of the CPS in time t, kW h
$E_{HP}(t)$ hydraulic energy of the HP in time t, kW h
$E_{total}(t)$ the total energy generated by a combination of components which must satisfy the demand $D_{LS}(t)$, kW h
$E_{WP}(t)$ wind energy of the WP in time t, kW h
g acceleration due to gravity, m/s^2
h_e height of the rotor shaft of the WT, m
H_g gross height, m
H_l hydraulic losses, m
H_n net height, m
HP hydroelectric plant
h_r height of wind speed measurement, m
HT hydraulic turbine and its corresponding electrical generator
H_u useful height, m
IRR the internal rate return, %
L number of years over which the investment in the system is to be recovered, years
LR lower reservoir
LS load system
M number of initial different configurations of the system which can be analysed on the hypothesis that each subsystem can meet the demand by itself
n_c number of conventional generator sets that make up the CPS
n_{c_c} number of CPs connected
$n_{c_{0,j}}$ initial number of CP units of type j ($j = 1,\ldots,N_{cp}$)
N_{cp} number of different types of CP
N_{ht} number of different types of HT
N_j number of configurations which are analysed, from an initial configuration j ($j = 1,\ldots,M$), in order to determine the optimum economic configuration
N_{p1} number of different types of pumps P1
N_{p2} number of different types of pumps P2