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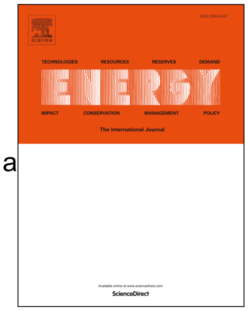

Integrating a wind- and solar-powered hybrid to the power system by coupling it with a hydroelectric power station with pumping installation

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Abstract: The high variability of solar and wind energy sources makes their integration into power systems complicated and in some cases unnecessarily delays their transition from centralised to dispersed energy sources. In this paper, a mixed-integer non-linear mathematical model has been developed for simulating the integrated operation of a novel hybrid involving wind- and solar power and a hydroelectric power station with pumping installation. This hydropower plant is a special case of pumped storage hydroelectricity which to some extent utilises the available flow of the river on which it is located. It is thereby able to compensate for the varying energy output from the wind turbines (WT) and photovoltaics (PV) by discharging water previously pumped to the upper reservoir (or held back from the available flow) when a surplus from WTs and/or PVs occurs. The impact on the national power system (NPS) has been investigated based on the energy exchange values (unexpectedly occurring deficits and surpluses) between the considered hybrid energy source and the grid. The obtained results indicate that such a hybrid energy source not only significantly reduces the total volume of the energy exchange with the grid but also minimises the ramp rate of those values. Accumulating water from available flow rate minimizes the need for oversizing the capacity installed in PVs and WTs. However, the inherent variability and typically low heads of existing run-off-river power plants with pondage lead to the size of the upper reservoir being prohibitive. The conclusions show that such a type of pumped storage hydroelectricity should mainly be used on a small scale.

Keywords: mathematical modelling, hybrid energy source, variable renewable energy sources

Nomenclature

Abbreviations

PSH	pumped storage hydroelectricity
HPSPI	Hydroelectric Power Station with a Pumping Installation
PV	photovoltaics
WT	wind turbine
NPS	National Power System
MINLP	Mixed Integer Nonlinear Programming
LCOE	Levelized Cost of Electricity

Indices

i	index of days (1, … ,730)
j	index of hours (1, … ,24)

Parameters/Variables

a	length of the reservoir [m]
b	width of the reservoir [m]
$\boldsymbol{E^B}$	energy balance [kWh]
$\boldsymbol{E^D}$	energy demand [kWh]
$\boldsymbol{E^{Def}}$	energy deficit [kWh]
$\boldsymbol{E^H}$	energy generation from water turbine [kWh]
$\boldsymbol{E^{PV}}$	energy yield from PV [kWh]
$\boldsymbol{E^S}$	energy surplus [kWh]
$\boldsymbol{E^{WT}}$	energy yield from wind turbine [kWh]
$\boldsymbol{g}$	gravitational acceleration [m/s^2]
$\boldsymbol{G^{STC}}$	irradiance in standard testing conditions [kW/m^2]
H	head [m]
$\mathbf{H^{PV}}$	irradiation [kWh/m^2]
$\mathbf{h_1}$	wind turbine hub height [m]
$\mathbf{h_2}$	height of the reservoir/dam [m]
$\mathbf{h_3}$	basic head of the hydropower [m]
n	number of wind turbines [-]
$\mathbf{P^{PV}}$	installed capacity in PV [kW]
$\mathbf{P^{TW}}$	rated power output of wind turbine [kW]
$\boldsymbol{p(v)}$	polynomial approximating wind turbine power curve [kW]
Q	water flow [m^3/s]
$\mathbf{Q^{Dis}}$	volume of water discharged to propel turbine and generate electricity [m^3]
$\mathbf{Q^{Pump}}$	volume of water pumped to the upper reservoir from the lower reservoir [m^3]
$\boldsymbol{Q^T}$	water turbine throughput [m^3/s]
R	ramp value [kWh]
t	time [hours]
v	wind speed [m/s]
$\boldsymbol{V}$	volume of water stored in the reservoir [m^3]
$\boldsymbol{V^M}$	upper reservoir water storing capacity [m^3]
$\boldsymbol{x^I}$	binary variable [-]
$\boldsymbol{\beta}$	parameter used to estimate the maximal occupancy of the reservoir [-]
$\boldsymbol{\eta^{PV}}$	overall efficiency of PV system [%]
$\boldsymbol{\eta^H}$	water turbine efficiency [%]
$\boldsymbol{\rho}$	water density [kg/m^3]
Z	objective function [kWh]