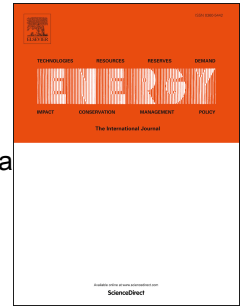


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Integrating a wind- and solar-powered hybrid to the power system by coupling it with a hydroelectric power station with pumping installation

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

**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

23	<b>Abbreviations</b>	52	$h_1$	wind turbine hub height [m]
24	<b>PSH</b> pumped storage hydroelectricity	53	$h_2$	height of the reservoir/dam [m]
25	<b>HPSPI</b> Hydroelectric Power Station with a	54	$h_3$	basic head of the hydropower [m]
26	Pumping Installation	55	$n$	number of wind turbines [-]
27	<b>PV</b> photovoltaics	56	$P^{PV}$	installed capacity in PV [kW]
28	<b>WT</b> wind turbine	57	$P^{TW}$	rated power output of wind turbine [kW]
29	<b>NPS</b> National Power System	58	$p(v)$	polynomial approximating wind turbine
30	<b>MINLP</b> Mixed Integer Nonlinear Programming	59		power curve [kW]
31	<b>LCOE</b> Levelized Cost of Electricity	60	$Q$	water flow [m <sup>3</sup> /s]
32	<b>Indices</b>	61	$Q^{Dis}$	volume of water discharged to propel
33	$i$ index of days (1, ..., 730)	62		turbine and generate electricity [m <sup>3</sup> ]
34	$j$ index of hours (1, ..., 24)	63	$Q^{Pump}$	volume of water pumped to the upper
35		64		reservoir from the lower reservoir [m <sup>3</sup> ]
36	<b>Parameters/Variables</b>	65	$Q^T$	water turbine throughput [m <sup>3</sup> /s]
37	$a$ length of the reservoir [m]	66	$R$	ramp value [kWh]
38	$b$ width of the reservoir [m]	67	$t$	time [hours]
39	$E^B$ energy balance [kWh]	68	$v$	wind speed [m/s]
40	$E^D$ energy demand [kWh]	69	$V$	volume of water stored in the reservoir
41	$E^{Def}$ energy deficit [kWh]	70		[m <sup>3</sup> ]
42	$E^H$ energy generation from water turbine	71	$V^M$	upper reservoir water storing capacity [m <sup>3</sup> ]
43	[kWh]	72	$x^J$	binary variable [-]
44	$E^{PV}$ energy yield from PV [kWh]	73	$\beta$	parameter used to estimate the maximal
45	$E^S$ energy surplus [kWh]	74		occupancy of the reservoir [-]
46	$E^{WT}$ energy yield from wind turbine [kWh]	75	$\eta^{PV}$	overall efficiency of PV system [%]
47	$g$ gravitational acceleration [m/s <sup>2</sup> ]	76	$\eta^H$	water turbine efficiency [%]
48	$G^{STC}$ irradiance in standard testing conditions	77	$\rho$	water density [kg/m <sup>3</sup> ]
49	[kW/m <sup>2</sup> ]	78	$Z$	objective function [kWh]
50	$H$ head [m]			
51	$H^{PV}$ irradiation [kWh/m <sup>2</sup> ]			

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