Università degli Studi di Padova

DEPARTMENT OF INDUSTRIAL ENGINEERING

Smoothing of offshore wind power variations with Norwegian pumped hydro: case study

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5th International Workshop on Hydro Scheduling in Competitive Electricity Markets

Trondheim, September 17th - 18th 2015

Agenda

- introduction

- case studies

- models

- results from M-Year
from the yearly optimization model

- results from M-Day
from the daily optimization model

- conclusions

Introduction

Introduction

Current trends in energy supply and use are unsustainable
economically, environmentally and socially;

Achieve a low-carbon economy in the long term
low-carbon energy technologies will have a crucial role to play;

Increase of electricity generation from variable renewable energy sources (VRES)
i.e. renewable energy sources with fluctuating production according to the natural variation in weather variables;

New measures to guarantee power grid stability and security of supply
increasing transmission grid capacities, improving resource forecast methods and introducing demand side management, establishing energy storage infrastructure is among the options that allow reducing imbalances between generation and load;

Introduction

CEDREN outlined a new generation capacity of 18.2 GW in South-Western Norway

achieving 20 GW including some plants in Northern Norway;

The object of the paper is to investigate the smoothing of offshore wind power variations from the North Sea

focussing on three upgraded pumped storage plants in Southern Norway;

Two optimization models have been developed

considering the environmental issues like seasonal water levels fluctuations and the regulations for reservoirs limits and ramping;

Case studies

Pumped hydropower storage plants selected:

- different storage volumes
- different gap between high and lower regulated levels
- different machineries rated power

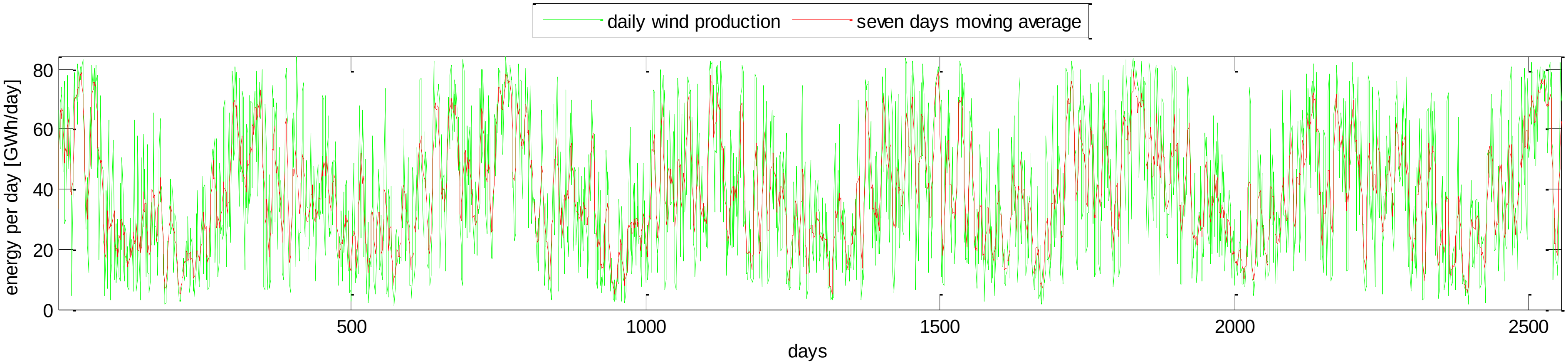
PHSP	Power (*MW*)	Reservoir	Volume (*Mm*^{3})	HRWL (*m*)	LRWL (*m*)	HRWL - LRWL (*m*)
Holen	1000	Urarvatn	253	1175	1141	34
		Bossvatn	296	551	495	56
Rjukan	2000	Møsvatn	1064	919	900	19
		Tinnsjø	204	191	187	4
Tonstad	1400	Nesjen	275	715	677	38
		Sirdaslsvatn	56	51	47.5	3.5

Offshore wind installation:

- 94.6 GW in the North Sea in 2030 based on the data series from 2000 to 2006

Balancing request scenarios:

- 7Days-Avg: 66,439GWh



Models

Models

The two developed models:

- yearly optimization model (M-Year)
- daily optimization model (M-Day)

Allowed working bands around the historical reservoir levels:

- ±0.5m
- ±1.5m
- ±3.0m

Environmental details

- seasonal water levels fluctuations (from 2000 to 2006)
- regulated water levels for reservoirs

Technical details

- variable speed, variable efficiency, minimum load
- head losses

Models

Optimization technique:

differential evolution optimization technique (DE/best/1/bin)

Objective function:

$$\mathrm{F}(x) = \mathrm{f}(x) + \sum_i \lambda_i \cdot \phi_i(x)^2$$

Energy balance

$$E_{ue} = E_{br} + E_{hp}$$

$$E_{be} = E_{br} - E_{ue} = |E_{br}| - |E_{uel}| - |E_{uee}|$$

Overall penalties functions

$$\sum_i \lambda_i \cdot \phi_i(x)^2 = \sum_i \lambda_i \cdot [\max(0, \mathrm{c}_i(\mathrm{x}) - \mathrm{u}_i)]^2$$

Results from M-Year

yearly optimization model

Results from M-Year

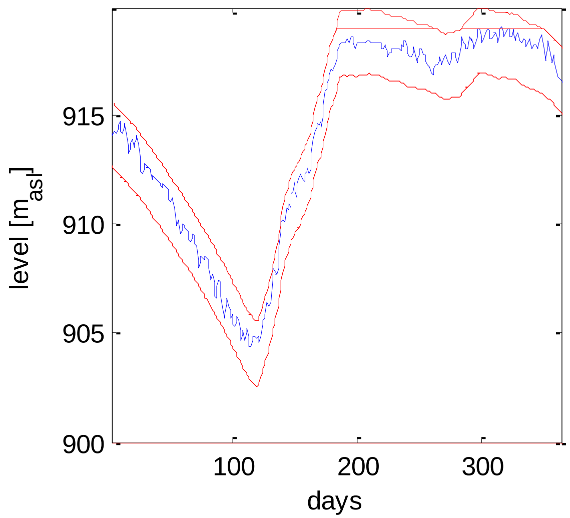
yearly optimization model

Results:

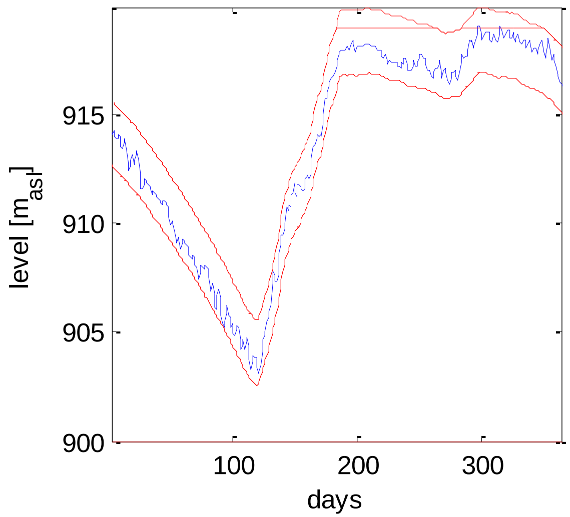
- perfect forecast approach

- upper estimation

- development of M-Day



Rjukan	E_{br}	E_{be}		E_{ue}	
	(GWh)	*(GWh)*	*(%)*	*(GWh)*	*(%)*
M-Year	9381	6504	69	2878	31
M-Day	9381	6223	66	3158	34



Results from M-Day

daily optimization model

Results:

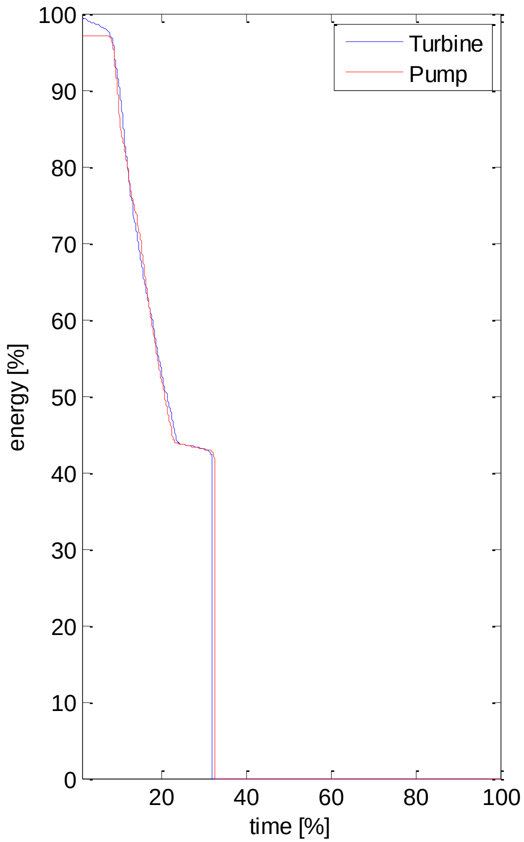
- similar trends for the management strategy of the plants
- Rjukan is limited by the system constraints interaction
- the balanced energy can reach the 66% of the overall balancing request

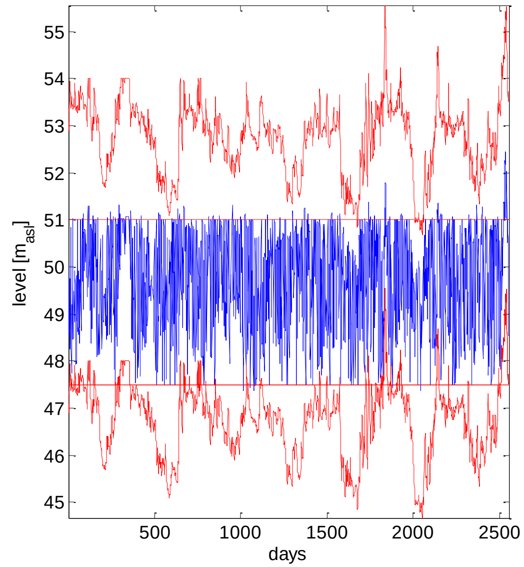
PHSP	WB *(m)*	E_{br} *(GWh)*	E_{be} *(GWh)*	*(%)*	E_{ue} *(GWh)*	*(%)*	$\lvert E_{uel} \rvert$ *(GWh)*	*(%)*	$\lvert E_{uee} \rvert$ *(GWh)*	*(%)*
Holen	±0.5	58359	0	0	58359	100	58359	100	0	0
Holen	±1.5	58359	18052	31	40306	69	39310	98	997	2
Holen	±3.0	58359	34282	59	24076	41	22495	93	1581	7
Rjukan	±0.5	65999	39314	60	26685	40	20967	79	5718	21
Rjukan	±1.5	65999	45245	69	20753	31	14384	69	6370	31
Rjukan	±3.0	65999	45210	69	20789	31	14277	69	6512	31
Tonstad	±0.5	56866	2422	4	54443	96	54307	100	136	0
Tonstad	±1.5	56866	31985	56	24881	44	23386	94	1495	6
Tonstad	±3.0	56866	39599	70	17266	30	15338	89	1928	11

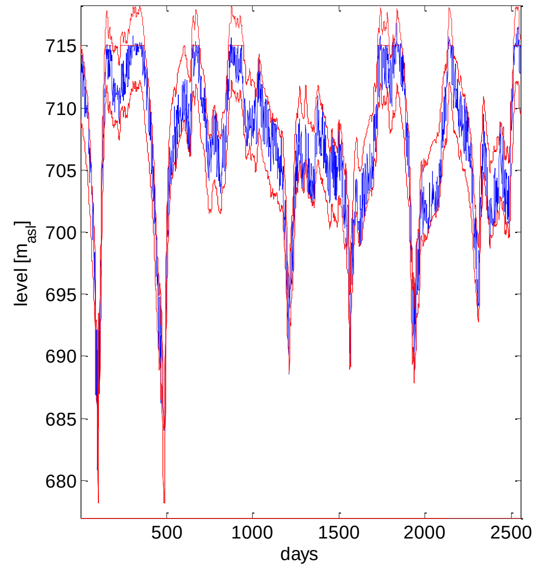
Results from M-Day

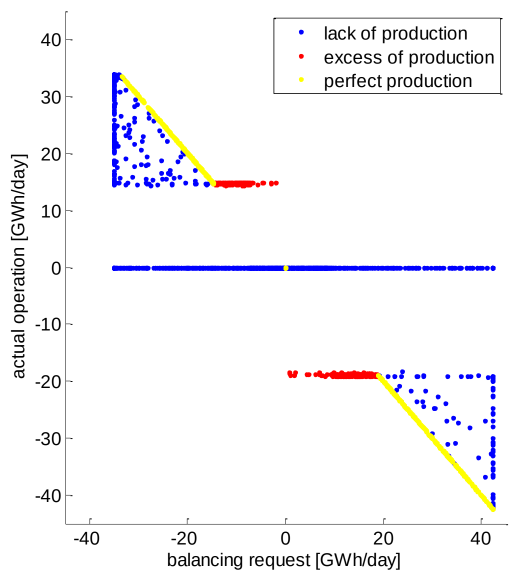
daily optimization model

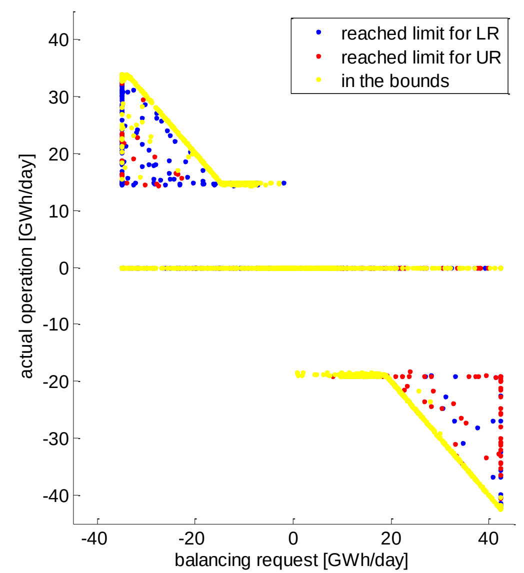
Tonstad hydropower plant











Conclusions

Conclusions

- has been determine the balancing potential considering:

- 7 years of offshore wind power production
- 7 years of reservoirs levels
- 2 optimization models
- 3 Norwegian hydro power plants
- reservoirs levels as trajectory working curves

- future work will be focused on:

- improvement of the details of the models
- assessment of the return of investment of the upgraded plants

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