Optimizing wellfield operation in a variable power price regime

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Optimizing wellfield operation in a variable power price regime

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Energy cost optimization of wellfields: Motivation

• Water pumping and conveyance consumes significant amounts of electric energy
• Energy footprint (MJ/m³) of water supply has become an important objective in wellfield management (e.g. previous presentation)
• There is a trade-off between energy footprint and more traditional management objectives (safety, reliability, water quality etc.)
• In view of increased penetration of wind power, pumping & conveyance cost (PCC in DKK/m³), may be a more suitable performance indicator than energy footprint
• Wellfield management can contribute to balancing the power market (adaptive demand, smart grid)
Minimize Energy Cost? Why??

Hourly wholesale electricity price on the Danish Market (DK-East segment). This is a stochastic variable but strongly auto-correlated.
Power demand is satisfied using available technologies in the order of their marginal cost ("merit order"). When power is cheap, it is also clean!
• Power system: Delivers power at a variable price, which is stochastic but strongly auto-correlated
• Wellfield: Supplies water with a given relationship between energy footprint and pumping rate
• Storage: Represents the available storage capacity in the system (water towers, reservoirs)
• Demand: Specified deterministic water demand to be met at all times
The optimization problem

- Given a deterministic water demand
- Given storage capacity and stored volume now
- Given present power price
- Given statistical information about the power price on the market

- What is the optimal pumping strategy and how much can we save by pumping flexibly?
Water demand variation

Miljøstyrelsen (2005). *Vandforbrug og forbrugsvariationer*, Miljøministeriet, [Online], Available: http://www2.mst.dk/common/Udgivramme/Frame.asp?http://www2.mst.dk/Udgiv/publikationer/2005/87-7614-592-1/html/sum.htm
Example Wellfield: Søndersø

Lake Søndersø

Annette K. Hansen et al., Hydrology Research, 2012
Annette K. Hansen et al., Journal of Water Resources Planning and Management, 2013
EFP–Q relationship

- Analytical drawdown model (Thiem)
- Well screen efficiency
- Pump characteristic curves
- Variable-frequency pumps
- Head losses in the pipe network
Stochastic Dynamic Programming (SDP)

Immediate cost  Expected future cost

\[
\min (q \cdot EFP(q) \cdot p) + EFC(s_{t+1}, p)
\]

\begin{align*}
  s_{t+1} & = s_t + q - d_t \\
  s_t & \leq K
\end{align*}

- The future cost is a stochastic variable, because future power price is unknown.
- The future cost depends only on the end storage (water availability for the future) and the present power price (because of the autocorrelation of the price time series).
- Price variability is modelled as a Markov chain with a number of price classes and given transition probabilities between price classes.
- The scheme is solved recursively from the end until steady–state decision rules are obtained.
- Steady–state rules are then used to simulate actual management.
Steady-state decision rules

- Gives the value of water pumped into storage
- Water value depends on price class, hour of the day and stored volume
- Enables a rational trade-off between present and future
- In optimal management, one would always pump to the point where the immediate cost of pumping equals the value of water
Results—Baseline

- Present wellfield setup
- Present maximum pumping rate
- Present EFP–Q relationship

Savings are expressed relative to costs in a constant pumping scenario
Results—Larger Wellfield

- Present wellfield setup scaled by factor 1.5
- Present maximum pumping rate scaled by factor 1.5
- Present EFP–Q relationship scaled by factor 1.5

Savings are expressed relative to costs in a constant pumping scenario. Grey lines show the baseline performance.
Results—Stronger pumps

- Present wellfield setup, extrapolated to 1.5 times max rate
- Present maximum pumping rate times 1.5
- Present EFP–Q relationship extrapolated to 1.5 times max rate max rate

Savings are expressed relative to costs in a constant pumping scenario. Grey lines show the baseline performance.
Results–Ideal World

- Hypothetical wellfield
- No maximum pumping rate, can deliver any rate
- Constant EFP, independent of pumping rate

Savings are expressed relative to costs in a constant pumping scenario. Grey lines show the baseline performance.
Discussion

• A number of simplifying assumptions in the EFP–Q relationship (most important: Thiem solution)
• Additional constraints may be relevant in practice, e.g. mixing ratios, maximum drawdown etc.
• How could this be put into practice? Either wellfield operators start buying power on the market or the power utility gets some control over wellfield operation in return for lower power prices.
• How much information on the future power price is available when decision is taken? We assume only present power price is known. Price forecasts?
• Here we deal with one single storage. If more than 2–3 coupled storages are considered, we run into the ”curse of dimensionality”. A possible solution is SDDP.
• Flexible wellfield pumping saves costs for wellfield operators but also has a stabilizing effect on the power system by making power demand elastic (smart grid). Although power demands may be relatively small, operation is centralized and relatively easy to control (as compared to individual fridges in people’s homes for instance)
Conclusions

• An approach for flexible wellfield management under variable power prices has been presented.
• With present infrastructure, costs can be reduced by about 7% (=1.6 MDKK/yr for all of DK).
• In a hypothetical ideal world scenario, up to 35% cost savings are possible.
• These are the factors controlling cost savings:
  – Shape of the EFP–Q relationship
  – Maximum wellfield pumping rate
  – Storage capacity
• Flexible wellfield pumping can save costs and contribute to the penetration of renewable energy sources.