Hydro-thermal power reserve optimization

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Abstract

In last decades, energy markets have faced circumstances with increasing volatility related to global political and environmental events and processes. Such volatility affects all entities acting in the power sector. In this work, we focus on the power plant operator's point of view.

First, the recent context of the European energy sector is discussed. Then power plant scheduling problem and its aspects are introduced backed by a comprehensive literature review.

Central goal of this work lies in formulation and development of a power scheduling tool providing optimal power production schedule taking into consideration uncertainty in the reliability of operated power units. Deterministic power scheduling model with predefined power reserve is introduced, then we introduce model for optimal power reserve based on minimization of lost opportunity cost versus minimization of schedule violation penalty. By fusing these two models, we propose method to handle uncertain scenarios power producer faces in power plant operation practice.

By Monte Carlo scenario simulations, we demonstrate that the method proposes solution exceeding economic performance of deterministic reserve allocation strategies.

Introduction

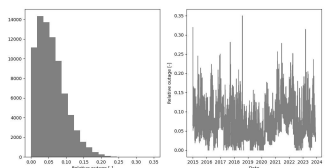
Power grid operators are responsible for reliable and efficient operation and control of the power in the grid. To achieve that, they motivate power producers to fulfill contracted delivery by penalizing the producers for not delivering contracted power into the grid, which is constrained by balance of production and consumption of the energy at every moment of operation.

Power producers, apart from cooperative manners, are motivated to provide reliable power economically by imposed economic sanctions. Since the market in general behaves optimally if every participant behaves economically, the optimal operation of the producing power units contributes to an efficient operation of the whole system The optimality of such behavior lies in minimizing negative economic consequences of inevitable phenomenon og unplanned production shortage.

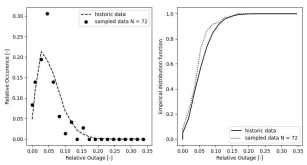
This work proposes methot do optimize power plant portfolio operation with respect to economic and technical aspects of the power units under various market situations with respect to not only economic profit, but also handling the risk of unplanned production unavailiability properly. Optimality is formulated as minimization of mean value negative economic impacts across all feasible scenarios.

Methodology

To efficiently tackle the challenges outlined above, we investigate history of outages and construct statistical model in form of empirical cumumulative distribution fuction, which represents probability of relative outage at each moment of operation time.



Unplanned Power Unit outages in Poland between 2015 and 2024: Histogram and data in time



Relative occurrencesnand empirical distribution function of relative outage magnitudes

To model thechnical and economic parameters of thermal and power plants, mixed integer optimization model was developed, the model takes into consideration unit commitment and dispatch problem of thermal and hydro power units.

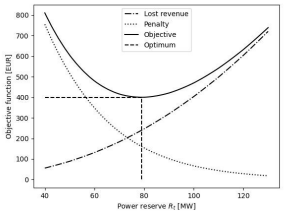
The model respects power ranges, starting ramping sequences, starting costs, operational ramping capacity of the units, cost of production is modelled as quadratic function. Hydro power units are modelled as pump and storage power plants. Market power price is taken as input parameter, the model produces power plant portfolio operation plan maximizing economical profit while respecting the technical and economical parameters of the power plants plus prescribed power reserve (spinning and idle) is respected and optimally distributed among operated power capacities.

The main contribution of this work is a method how to integrate probabilistic nature of the operational reliability into the deterministic decision making tool in form of power plant portfolio operation optimization tool. This challenge is resolved by optimization method that minimizes negative economic consequenes of producer's inability to deliver contracted power supply. The method minimizes probability weighted sum of penalty for not delivering the contracted power (in consequence of holding power reserve lesser than outage occurrence) and lost opportunity (in consequence of holding too large power reserve).

$$minimize\ F([^{tot}p_t, R_t]) = \mathbb{E}\, f([^{tot}p_t, R_t], \delta) \qquad \forall t \in \mathcal{T}$$

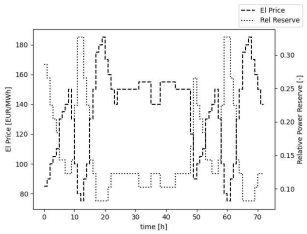
$$F([^{tot}p_t, R_t]) = \sum_{\delta \in \Delta} P(\delta)\{(\delta - R_t)^+[95.92 + 0.2245(\delta - R_t)^+] +$$
$$+(R_t - \delta)^+[ep_t(R_t - \delta)^+ - (C(^{tot}p_t) - C(^{tot}p_t - (R_t - \delta)^+)]\}$$

Optimization problem equation and graphical representation

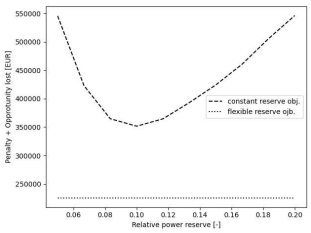


Results

- The statistical model has been validated by Kolmogorov Smirnoff test on significance level α = 0.01.
- For given market price prediction and statistical outage model, optimal power reserve distribution has been found, it is more economical to hold larger power reserve in hours with higher market and price.
- To demonstrate stochastic optimality, 10,000 random outage scenarios respecting statistical model have been generated via Monte Carlo simulation. Proposed method provides lesser mean value of negative consequences of holding power reserve than constant relative power held throughout the modelled time horizon.



Optimal relative power reserve compared to electricity price.



Proposed method provides an optimal solution, which outperforms optimal constant power reserve.

Literature

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