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# A simplified optimization model to short-term electricity planning

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ABSTRACT

Short-term optimization models, usually applied to traditional problems like UC (unit commitment) and economic dispatch problem, are essential tools for the planning and operation of power systems. However, the large number of variables and restrictions, necessary for a good and more accurate representation of any electricity system, require high computational resources, frequently resulting in high computation times. This study proposes a simplified approach of a model for the electricity planning of power plants allocation based on the available resources. The model resources to quadratic penalty functions and avoid on/off binary variables. The approach is then supported on a non-linear optimization model able to solve this electricity planning problem in shorter computation times, with solutions close to the ones obtained with more complex models. The model is fully described and tested under different scenarios of an electricity system comprising thermal, wind, and hydropower plants. The results were compared to the ones obtained with a more complex model, analysing the main differences obtained for cost, $CO_2$ emissions and of wind power impacts on this electricity system. The most remarkable advantage of the simplified model comes from the significant reduction on computational time needed for state-of-the-art optimization solvers to provide an optimal solution, comparatively to mixed integer models.



## 1. Introduction

The increasing of electricity production from renewable energy utilities is frequently seen as a fundamental measure to mitigate greenhouse gas emissions. Over the last years, this growth was reached in large extension by the wind power sector. Public awareness about emissions, climate change and environmental issues, oil and gas reserves depletion along with the improvements in wind turbine technologies were some of the main reasons for this increase [1]. However, problems in the operation of the electricity system and even environmental and climatic impacts of renewable utilities were also reported [2]. The unpredictability and variability of RES (renewable energy sources), became a challenge to grid operators as large RES share can give rise to periods of surplus of production, increase the need for thermal power plants operate at low load factor and increase also the their start-up and shutdown requirements [3–5]. These technical issues related to the impacts of high wind penetration on thermal power plants performance were debated for example in Troy et al. [6] or De Jonghe et al. [7]. Despite these concerns, works such as Gutiérrez-Martín et al. [8] concluded that RES potential for $CO_2$ reductions is relevant even at high wind penetration levels.

Electricity power generation systems are now characterized by a high level of complexity, usually combining a high set of thermal power plants with RES power plants, giving rise to a large number of technical constraints. Short-term optimization models, usually applied to traditional problems like UC (unit commitment) and economic dispatch problem, are then essential tools for the planning and operation of power systems. According to Hobbs [9]; traditional UC and economic dispatch problems usually require short-term periods of time. Time periods ranging from one to ten minutes or eight hours to one week for economic dispatch and UC problem respectively are example of time periods addressed in short term optimization models. The basic goal of the UC problem is to properly schedule the on/off states of all power plants in the system. Further on, the optimal UC should meet the predicted load demand, plus the spinning reserve requirement at every time interval minimizing the total cost of production [10]; [11].

Short-term optimization models can also have an important role on supporting strategic energy decision making, allowing to test the expected outcomes of different electricity scenarios. However,

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**Nomenclature**

*Sets*

| | |
|---|---|
| $T$ | set of the time period (hours) |
| $C$ | set of all coal power plants |
| $J$ | set of all thermal power groups |
| $G$ | set of all gas power plants |

*Parameters*

| | |
|---|---|
| $CVOM_{h_d}$ | variable O&M cost of hydropower plants (€/MWh) |
| $CVOM_p$ | variable O&M cost of pumping power plants (€/MWh) |
| $CVOM_j$ | variable O&M cost of thermal power group $j$ (€/MWh) |
| $F_j$ | fuel cost of thermal power group j (€/MWh) |
| $CO_{2_j}$ | $CO_2$ emissions factor of thermal power group $j$ (ton/MWh) |
| $ColdS_j$ | cost of cold startup of thermal power group $j$ (€) |
| $N_j$ | time necessary for a cold startup of thermal power group j in hours |
| $CVOM_{h_r}$ | variable O&M cost of run–of–river power plants (€/MWh) |
| $CVOM_w$ | variable O&M cost of wind power plants (€/MWh) |
| $C_{p_p}$ | pumping cost (€/MWh) |
| $EC$ | $CO_2$ emissions allowance costs (€/ton) |
| $CSd_j$ | shutdown cost of thermal power group $j$ (€) |
| $HotS_j$ | cost of hot startup of thermal power group $j$ (€) |

*Variables*

| | |
|---|---|
| $C_{t,j}$ | total cost of thermal power group $j$ in hour $t$ (€) (€) |
| $Sd_{t,j}$ | shutdown cost of thermal power group $j$ in hour $t$ (€) |
| $phr_t$ | power output of run–of–river power plants in hour $t$ (MWh) |
| $pwind_t$ | Power output of wind power plants in hour $t$ (MWh) |
| $v_{t,j}$ | binary variable that is 1 if thermal power group $j$ is on in hour $t$ or 0 if it is off |
| $L_g(t)$ | load factor of gas power groups in hour t ($pt_{t,g}/\overline{P_g}$) |
| $a_g$,$b_g$,$c_g$ | coefficients of gas quadratic curves |
| $Su_{t,j}$ | startup cost of thermal power group $j$ in hour $t$ (€) |
| $phd_t$ | power output of hydropower plants with reservoir in hour $t$ (MWh) |
| $ppump_t$ | power output of pumping power plants in hour $t$ (MWh) |
| $pt_{t,j}$ | power output of thermal power group $j$ in hour $t$ (MWh) |
| $L_c(t)$ | load factor of coal power groups in hour t ($pt_{t,c}/\overline{P_c}$) |
| $a_c$,$b_c$,$c_c$ | coefficients of coal quadratic curves |
| $\overline{P_j}$ | maximum capacity of thermal power group $j$ |

due to the complexity associated to these problems, their translation in a computational language can be a hard task. The large number of variables and restrictions, necessary for a good and accurate representation of any electricity system turns the code complex and highly computational resource consuming.

A diversity of technics have been applied over the time to solve this UC problem. Technics such as, Bender's decomposition [12], differential evolution [13], evolutionary algorithms [14], genetic algorithms [15], Lagrangian Relaxation [16], MILP optimization [17], particle swarm optimization [18], simulated annealing [19] and stochastic optimization [20] are examples of mathematical approaches used to solve the UC problem.

Seems clear that the increasing integration of RES of variable output brings even more challenges to optimization models used to support decision making on electricity systems operation. The result is an ever increasing complexity of these models requiring high computational resources, frequently resulting in high computation time. The UC problem is then difficult to solve efficiently, especially for large-scale instances [25]. However, in high RES system the problem is proved to be essential not only for the short term decision making but also to efficient generation expansion planning [21]. According to Palmintier [22] typical planning and policy models do not consider the technical operating conditions of the system. This author proposed then a new formulation of a model that captures the operational flexibility within capacity planning optimization. This new formulation consists in grouping similar generators into clusters resulting in the reduction of the problem size but still capturing operating reserves and other flexibility drivers. Also Viana and Pedroso [17] presented a simplified method to solve a typical quadratic optimization for the UC problem, proposing a piecewise linear approximation of the quadratic function. The authors showed that their simplification was capable of tackling large problems and reaching optimal solutions in less computational time. A tighter and more compact MILP formulation of start-up and shut-down ramping in unit commitment problems was proposed in Morales-España et al. [23] and in Morales-España et al. [24] in order to reduce the computational burden of other MILP formulations and by this reaching a dramatic reduction on the computation time. Other recent examples in the literature include Yang et al. [25] or Álvarez López et al. [26] presenting different approaches to solve the UC problems and achieve optimal solutions in less execution time.

This papers aims not only to contribute to the debate on the formulation of optimization model to provide solid results for decision makers in reduced time, but also to show how these models can effectively be used on the analysis of RES integration on the operation of electricity systems and by this assess long term planning scenarios. The, objective of this work is then twofold. Firstly, a simplified model for the UC problem is presented with the final goal of reducing the complexity traditionally present in these models and computational tools, resulting in less computation time to get an optimal solution. A simplified(NLP nonlinear problem) resorting to penalty functions to replace the unit on/off binary variables is therefore proposed in this paper. Secondly, a comparison between the presented model and a more complex one, detailed in Pereira et al. [27] is presented. For the comparison, a case study representing an electricity system close to the Portuguese and mainly comprised of thermal, wind, hydropower plants and SRP (Special Regime Producers, representing cogeneration and non-wind renewable non subject to dispatch) was selected. The comparison was made in terms of the obtained costs, $CO_2$ emissions, thermal power plants commitment, total simulation time and the analysis of wind power impacts on this electricity system. Simulations were conducted assuming three different scenarios, each one representing different levels of installed wind power. The seasonality of both hydro and wind power recourses was considered, as the models were compared under four typical weeks, each one representing a season of the year, with hourly time step (0–167 h).

This paper is organized as follows. First, Section 2 will present an overview of the proposed model, detailing the assumed simplifications comparatively to previous Pereira et al. [27] model. In