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ON SOME OPTIMIZATION PROBLEMS IN POWER ENERGY

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In the last decades the power energy systems underwent a complete organizational change. In many countries they were transformed from a monopolistic to a free market regime. This change introduced new actors each one with its particular view to be optimized. Moreover, the introduction of a relevant share of renewable sources (in particular, wind and photovoltaic) augmented the uncertainty in the energy production due to weather conditions. Therefore, the new setting increased the needs for optimization and required new levels of performances. We present some new advances in solving optimization problems in the power energy sector mainly considering exact approaches.

Keywords: *power energy production, power energy distribution, optimization, exact methods*

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1. Introduction

In the last decade of the last century most countries of North America and Europe decided to change the power system management and the energy sector in general passing in each contry/region from monopolitic to free market regimes. Rules and governance may change from country to country but many elements are often common:

- a Day-Ahead Market (DAM) that handles the power energy offer and demand bids and establishes the *price of energy* according to the marginal price to maximize the general welfare of the system;
- Intra-day Markets that enable to modify the schedules defined by the DAM by new offer and demand bids taking into account a more exact behavior of production and consumption rates while approaching real time;
- bilateral agreements between power energy operators and large power energy consumers, such as manufacturing industries;
- Dispaching Services Market that deals with offers/demands of energy needed to keep balanced the electrical system, and correct voltage profiles thus allowing actual transmission from producers to consumers.

The energy markets are usually governed by two entities, one responsible for electricity market clearing/pricing, the Nominated Energy Market Operator (NEMO) and one responsible for the dispatching and balancing markets that take into account the transmission network, the Transmission System Operator (TSO).

2. The main optimization problems

The energy system nowadays sees the participation of many different actors: producers, traders, large consumers, small and residential consumers, small producers (also defined *prosumers*), energy communities [1], independent market operators, and others. Each actor manages its operations trying to maximize its own benefit;

therefore many optimization problems arise. However two issues, that were already present in the old monopolistic regime, are of fundamental importance and constraint many of the following operations: (i) where and when energy is produced, (ii) how energy is routed into the transmission grid. The first issue claims for a class of problems named “Unit Commitment problems” where one has to manage a set of production units and decide when and how much power each unit should produce. The second issue refers to the class of problems named “Optimal Power Flow” where one has to manage how the current flows into the grid to provide energy to the final consumers. Both classes of problems are of operational type, that is, they consider a short time horizon (from one day to a week).

3. The Unit Commitment Problem

The *Unit Commitment* (UC) problem considers a time horizon, a set of production units of different types, forecasted demands at each time period of the time horizon and its objective is to decide which units should produce and at which time periods in order to meet the demands at minimum production cost. Each production unit (thermal, nuclear, hydroelectric, solar, wind, and others) must consider its specific technical constraints. After a lot of simplifications, production units are usually partitioned into programmable units (mainly thermal, including nuclear ones, and hydroelectric units) and non-programmable units (solar, wind units). Programmable units can be managed, up to technical constraints, to enable the increase or decrease of production, thus changing the cost of the production. The technical working constraints need to be mathematically modeled with very interesting issues from an optimization and combinatorial point of view [2]. On the contrary, the energy produced by non-programmable units cannot be modified as one likes and largely depends on external and non-controllable factors (weather conditions in general). Consequently uncertainty issues arise that must be handled by correct optimization models (stochastic optimization, robust optimization) thus increasing the need for more efficient optimization algorithms [3].

4. The Optimal Power Flow Problem

The transmission of the power energy is another challenging optimization problem. The transmission grid is one of the main infrastructure of a country. From an optimization point of view, power must satisfy Ohm and Kirchoff’s Laws, i.e., it cannot be routed in the network as water or other commodities. These laws define the basic transmission problem named *Optimal Power Flow* (OPF). Energy may be distributed according two different technologies: (i) direct current, (ii) alternate current. Alternate current is more suitable for transmission at long distances. According to optimization, direct current may be effectively modeled with linear programming models. On the contrary, alternate current must be modeled with high nonlinear models in complex variables. A recent survey on alternate current OPF models is given in [4]. With both transmission technologies, physical laws may induce phenomena such as the Braess paradox: increasing the number or capacity of transmission branches may not improve the transmission. Therefore one has to decide which transmission branches should be activated/deactivated (*Optimal Transmission Switching* problem [5]).

5. The Energy markets problems

The energy markets introduce two main types of problems: (i) market clearing problems to be solved by NEMOs, (ii) strategic bidding problems to be solved by production companies, traders and others involved actors. The former are used to find the offers and demands that maximize the social welfare according to the rules defined by market regulators; While in their simplest forms these market clearing problems are simple LPs (if the network constraints are suitably simplified), regulatory rules often make them more complex, e.g., due to the definition of zonal markets (i.e., aggregations of portions of the grid) and of possible “nonlinear” interactions among zones such as the unique purchase price in the Italian market, or “complex offers” in other European ones. Thus such market clearing problems often become more complex including integer variables. A recent need, due to the natural gas prices crisis, is related to the issue of (partly) decoupling the price of energy rewarded to producers with significant fuel costs (thereby subject to the large fluctuations in the hydrocarbon markets) from those relying on sources (mainly, but not exclusively, renewables) that do not suffer from the issue. A proposal in this sense [6] turns the market clearing problem into a bilevel / MPEC one, which is solvable with off-the-shelf tools for small-size instances but that may require specialised algorithmic developments for real-world deployments.

The strategic bidding problems are used by each single operator (produces, traders, large consumers) to define the bids to be presented at the different markets in order to optimize its own results (optimize profits or costs). This class of problems may be defined as bilevel programming problems [7].

6. The Generation and Transmission Expansion Planning Problem

Well known growing policy targets is prompting the development of effective strategies for a decarbonized energy system. Increasing the share of renewable generation requires also increasing the system flexibility (electrical storage of various kind) and integrating the electricity and gas systems (electricity-to-gas conversion by PtX and gas-to-electricity conversion by thermal power plants).

Generation and Transmission Expansion Planning (GTEP) problem determines the evolution of the eletric energy system over a long-term horizon, taking into account policy targets. While *decentralized models* consider multiple decision-makers with different objectives, in *centralized models* a single decision-maker (e.g., the authority or a suitable Ministry) determines the expansion plan that minimizes investment and operating costs: on the basis of this solution, policies and incentives can be identified to lead generation companies to invest in a socially efficient manner (*anticipative planning*). The variability of non-programmable generation can lead to higher operating costs for thermal units, which can be accurately estimated by considering a high level of temporal and technical detail. Long-term uncertainties, such as fuel costs and CO_2 costs, can also be considered. Recent GTEP approaches aim to determine the expansion plan in which generation units are guaranteed to recover all their costs, e.g. [8].

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REFERENCES

1. Fioriti, D., Frangioni, A. and Poli, D. Optimal sizing of energy communities with fair revenue sharing and exit clauses: Value, role and business model of aggregators and users, *Applied Energy*, **299**, 117328, (2021).
2. Bacci, T., Frangioni, A., Gentile, C. and Tavlaridis-Gyparakis, K. New minlp formulations for the unit commitment problem with ramping constraints, *Operations Research*, **to appear**, (2023).
3. van Ackooij, W., Lopez, I. D., Frangioni, A., Lacalandra, F. and Tahanan, M. Large-scale unit commitment under uncertainty: an updated literature survey, *Annals of Operations Research*, **271** (1), 11–85, (2018).
4. Bienstock, D., Escobar, M., Gentile, C. and Liberti, L. Mathematical programming formulations for the alternating current optimal power flow problem, *Annals of Operations Research*, **314**, 227–315, (2022).
5. Kocuk, B., Jeon, H., Dey, S. S., Linderoth, J., Luedtke, J. and Sun, X. A. A cycle-based formulation and valid inequalities for dc power transmission problems with switching, *Operations Research*, **64** (4), 922–938, (2016).
6. Frangioni, A. and Lacalandra, F. Dipartimento di Informatica, Università di Pisa, A bilevel programming approach to price decoupling in pay-as-clear markets, with application to day-ahead electricity market, (2022).
7. Kalashnikov, V., Dempe, S., Pérez-Valdés, G. A., Kalashnykova, N. and Camacho-Vallejo, J.-F. Bilevel programming and applications, *Mathematical Problems in Engineering*, **2015**, Article ID 310301, 16 pages, (2015).
8. Guo, C., Bodur, M. and Papageorgiou, D. J. Generation expansion planning with revenue adequacy constraints, *Computers & Operations Research*, **142**, 105736, (2022).