Challenges of the representation of near term electricity system flexibility in energy system models

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Keywords: renewable energy, variability, uncertainty, power system reliability, adequacy, flexibility, energy systems optimization, planning.

Introduction

Most analyses of the future European energy system conclude that in order to achieve energy and climate change policy goals, a significant increase in renewable energy in the mix is required. As part of this the proportion of electricity generation from renewable energy is expected to increase from 20% in 2010 to 36% in 2020, 44% in 2030 and 52% in 2050 (1). Hydro generation is the largest contributor to renewable electricity in Europe but its potential is for the most part already exploited. This means that a significant part of the development of renewable electricity in the future will be based on variable generation such as wind and PV. These energies, however, like electricity demand, have a variable nature that is not perfectly predictable. As a consequence, short- and long-term variability and uncertainty in the electricity load-generation balancing is likely to increase in the future.

To cope with this increasing variability and uncertainty the electricity system will need to have sufficient flexibility to maintain the demand-generation balancing at all time. Therefore, energy and power system planning will need to address both the problem of capacity adequacy and flexibility.

The electricity system has always needed flexibility in order to handle demand and run of the river hydro generation variability and uncertainty as well as generation unplanned outages. The additional variability and uncertainty driven by wind and PV, however, will increase the needs and the solicitation of power system flexibility.

In spite of the fact that flexibility is mostly required at the operational time scales from minutes to day-ahead it needs to be considered from the planning stage. A system that has sufficient capacity to meet peak load is adequate but if this capacity is composed mostly by low flexible plants the system can experience problems for handling demand and generation variability. As a consequence, the representation of flexibility at the energy and power systems planning stage will help to deliver a system that can handle this variability in a cost effective fashion.

Electricity system model integration to energy systems models

Nowadays, electricity systems planning tools include a detailed representation of the power system often including the simulation of hourly (or lower) load generation balancing. The stochastic nature of demand and generation availability is commonly incorporated by performing simulations over a large number of climate and generation availability scenarios.

Assessing the flexibility needs and adequacy will probably emerge as a new task in power and energy systems planning and different approaches and metrics to support this have been published over the last years. An example with the overall structure of the energy and electricity system planning process including production cost simulation and flexibility assessment is presented in the figure below.

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1 Flexibility is the ability of a system to adapt its operation to both predictable and unpredictable fluctuating conditions, either on the demand or generation side, at different time scales, within economical boundaries.

2 Adequacy is connected with the issues of investment decisions and is used as a measure of long term ability of a system to match demand and supply with an accepted level of risk. This is a measure that internalizes the stochastic fluctuations of the aggregate demand and supply.
Currently, the electricity system planning does not take into account the interaction with the remaining of the energy system. Furthermore, electricity planning tools that include more detailed simulations of system operation do not provide a multi-year vision of system development as the energy systems planning models do.

Energy system planning models are commonly TIMES type models and have a simplified representation of the power system. In order to obtain a more detailed picture of the energy system development and its interaction with the electricity system, two alternatives can be considered:

1. Solving the energy system optimization with a granularity that permits capturing the electricity system flexibility needs (ex; hourly resolution) and including a more detailed representation of the electricity system constraints.

2. Coupling of energy system models with power system simulation tools as part of a chain of tools in order to test the performance of the electricity system given the generation mix and network solution obtained from the energy systems model.

Preliminary studies at EDF R&D have shown that pursuing alternative 1) by adding additional simulation time steps to a TIMES model (MADONE3), adding a peaking constraint and performing a multi-scenario optimization does not permit to obtain optimal investment strategies for the electricity system4. Indeed when compared to the solutions for the generation mix obtained using an electricity planning tool, CONTINENTAL model with an investment loop (2), (3), our preliminary results show that peak capacity is overestimated and mid merit generation capacity in underestimated. Moreover, adding additional time-steps and further detail of the electricity system leads to an excessive computational burden.

Alternative 2, for example based on coupling TIMES type models with electricity systems models seems the more widely used approach. For example in a recent study published by DG Energy a PRIMES model is coupled with PLEXOS to obtain a multi-annual vision of electricity generation investments. PLEXOS is in turn coupled with a power system simulation model DSIM in order to include a more detailed vision of the electricity system hourly dispatch and adjust transmission and generation to obtain the final electricity system expansion solution (3).

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3 MADONE is a model developed by EDF R&D for internal use. It’s a TIMES model of the EU27+NO+CH interconnected energy system over the 2005-2050 horizon with, in particular, a detailed representation of the economic potential of wind and solar technologies.

4 Conclusions obtained from tests with 288 time steps (corresponding to representative weeks), a peaking constraint to represent the maximum power and with a multi-scenario optimization with 4 scenarios.
EDF R&D is exploring the possibility of coupling the MADONE model with CONTINENTAL model and its investment loop mostly with the objective of obtaining the renewable energy mix and its geographical distribution across Europe. Moreover, this will provide a multi-year vision of renewable development. The adaptation of the remaining electricity system generation mix and interconnections is obtained by the electricity planning tool as a second step by CONTINENTAL Model and its investment loop.

**EDF R&D Chain of tools to integrate near term flexibility into electricity systems planning**

The assessment of the need for flexibility and its evolution with the increase of wind and PV installed capacity is a key step of the process of integrating flexibility in energy and electricity systems planning.

The need for enhancing system flexibility with the increase of variable generation is system specific since it depends on many parameters such as the flexibility of the existing mix and the demand variability, etc.

Approaches with different levels of complexity have been proposed to analyze power system flexibility. Examples of these are flexibility visualization charts, offline flexibility indexes and probabilistic tools (4). Several publications proposed methods to address this problem within the power system context over the last years (see table below).

<table>
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<th>Single optimization problem</th>
<th>Production cost models with investment loop</th>
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<td>Unit construction and commitment (4)</td>
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In order to address the problem of obtaining power system expansion solutions and respect both system adequacy and flexibility needs, EDF R&D developed a chain of power systems simulation tools. This chain of tools permits coupling a production cost model (CONTINENTAL Model) with an investment loop and a probabilistic tool that performs a detailed ex post flexibility assessment. This chain of tools is presented in the next figure.

In this chain, *Flex Assessment* is used to assess the ability of the investment and dispatch solutions provided by the planning tool to manage the uncertainty of the demand-generation balancing, for
different time-scales (2) and all simulation time-steps (e.g. hourly). This tool assesses whether the electricity system has sufficient flexibility to cope with increasing variability and uncertainty due to the increase of variable generation. With this analysis one can also identify the constraints and lead-times that lead to a flexibility deficit risk. More precisely, the items addressed are:

- Are the generation scheduling provided by these long term tools able to manage the short term unpredictable changes in net load?
- Which generation dynamic constraints (minimal up/down time, ramping up/down rate, etc) should be included in generation planning tools?
- Is it necessary to include additional flexibility constraints, such as upward and downward ramping requirements in order to ensure flexibility adequacy?

The flexibility indicators obtained from Flex Assessment could be fed into the chain in order to guide the investment optimization to obtain a mix that is adequate and also sufficiently flexible.

This hierarchical approach presents some drawbacks since it can lead to suboptimal solutions. This problem has already been shown by other studies and for example a recent DG Energy study about the integration of renewable energy in Europe (3) presents a rather high peaking plant capacity since the electricity systems model adjusts any flexibility/transmission and adequacy gaps from PLEXOS by adding peak plants.

**Conclusions**

The problem of flexibly adequacy is becoming increasingly relevant and tools capable of handling it are important. This problem, however, should not be confused with (2) system adequacy and needs to be treated separately since it addresses different issues.

Significant work has been done in the identification of the impact of VG on different flexibility aspects but there is no unified view of the problem. Methods and tools with different levels of complexity and different simulation and data requirements have been proposed in the literature.

Among these, offline flexibility indicators are seen as very promising but they do not fully solve the problem since flexibility is a time-specific system characteristic.

Coupling of investment and operation models seems to be the state of the art practice for realistic size systems.

This notion of coupling of different models is currently being extended to multi-energy systems in order to make the problem of integrating power system flexibility needs into energy systems planning solution tractable.

Such hierarchical approaches have the advantage of obtaining a good representation of both the energy and the electricity system whilst rendering the problem tractable. The solutions obtained can be suboptimal with an excessive investment in peaking plants. Further work is thus required in order to improve the representation of the electricity system in the energy model in order to obtain a global solution (obtained from the chain of tools) that is closer to the optimum.

Renewable capacities development is based first of all on the geographic distribution of wind and sun resources which involves a necessary adaptation of the existing electrical and energy system (networks constraints) and drive additional costs. Thus further work would also require that the solutions obtained that respect global flexibility and adequacy requirements, also comply with local constraints of both the electricity and the energy system, still in a cost effective fashion.

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5 The tool is able to consider hydro generation uncertainty, generation forced outages and failure to synchronize, demand, wind and PV forecast errors.
References


