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To cite this version:

Yacine Alimou, Nadia Maïzi, Jean-Yves Bourmaud, Marion Li. A multi-model approach to address long-term electricity security of supply. International Conference on Applied Energy (ICAE), Aug 2019, Västerås, Sweden. hal-02433398

HAL Id: hal-02433398

https://hal.science/hal-02433398

Submitted on 9 Jan 2020

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International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 1030

A MULTI-MODEL APPROACH TO ADDRESS LONG-TERM ELECTRICITY SECURITY OF SUPPLY

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ABSTRACT

Long-term energy scenario modeling and dispatch simulations are two key stages in a methodology for cost-effective transition to a low-carbon power system. Although these stages are equally important, they are often performed independently. This decoupled approach can lead to future investment trajectories decided by long-term energy models with no guarantee of generation adequacy. In this respect, TIMES-ANTARES is the result of linking a long-term energy model with a stochastic power system model. The aim of this study is to develop a general methodological framework using a multi-model approach to investigate optimal power mixes which meet generation adequacy requirements. The emphasis of this article is on the methodology, but we also include a case study of power generation planning applied to the French system for 2013-2050. The results show that using TIMES alone exposes the power generation mix for 2030 to a risk of insufficient supply. On the other hand, activating the iterative feed-back loops over capacity credit parameters has the potential to ensure both the economic effectiveness of the mix and the security of the electricity supply criterion set by the French public authorities.

Keywords: TIMES, ANTARES, generation adequacy, linking-model approach.

1. INTRODUCTION

The motivation for building this linking model came from the challenges faced by the energy system modeling community due to the changing nature of the 21st-century energy system. In this paper, we look in particular at the power system. Among others, one challenge is that, as Variable Renewable Energy (VRE) deployment increases, concerns have been raised over the methodologies and underlying assumptions employed in standard energy system modeling tools [1], [2]. In fact, these tools were not initially designed to deal with power system planning under a high share of VRE. This difficulty arises for at least two reasons. First, the limited temporal and space granularity that is commonly assumed provides an inadequate basis for capturing the short-term main proprieties of VRE generators [3]. Second, omitting the impact of these technologies' proprieties on system flexibility introduces biases that favor or disadvantage certain investments [4]. As a result, insufficient variability representation either in supply or demand as well as operational details could lead to a sub-optimal, or even inadequate, power generation mix [5]. This could create misunderstanding among policymakers and system operators, who could begin to view power generation portfolios produced by long-term energy modeling tools as at odds with the secure provision of electricity requirements [6]. Therefore, two contrasting methodologies have been developed to overcome this drawback: a direct integration approach and a model-coupling approach [7] [8].

In this challenging context, the main purpose of this study is to contribute to the development of a multi-model framework based on two models with proven track records in techno-economic power system assessment. The energy system model is MARKAL/TIMES, and the ANTARES tool has been selected as the probabilistic unit-commitment and dispatch model. The first objective of this work consists in coupling TIMES with ANTARES as part of a one-directional chain model in order to transfer the power generation mix decided by TIMES for a given year of interest to the ANTARES inputs database. For that

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).
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target year, the second objective is to focus on the ANTARES dispatch results and adequacy metrics to provide consistent feed-back to TIMES to ensure sufficient supply.

2. METHODOLOGY

The framework, as shown in Figure 1, illustrates the linkage of TIMES and ANTARES using a platform that we call the automated soft-linking tool. The link is fully automated and controlled by several packages written using R programming language, but involves running the two models on a stand-alone basis. The link scheme can be split into two independent main steps: a coupling part and a feed-back part. The first part aims to link TIMES and ANTARES as two separate modeling tools and the second part aims to address generation adequacy issues. In such a way, TIMES is used to optimize the investment in new generation capacity over a 2013-2050 time-frame. The resulting power generation mix for a single target year (2030) is then transferred to ANTARES in which the detailed hydro/thermal dispatch will be decided at an hourly resolution for a large number of stochastic scenarios representing weather-dependent and operational uncertainty. Then, based on the ANTARES results, the main function of the feed-back loop is to ensure an adequate generation mix. However, the feed-back with the long-term energy system model is not straightforward and requires an iterative process. In practice, the stopping criterion of the feed-back loop is chosen to be a loss of load expectation limit of 3 hours.

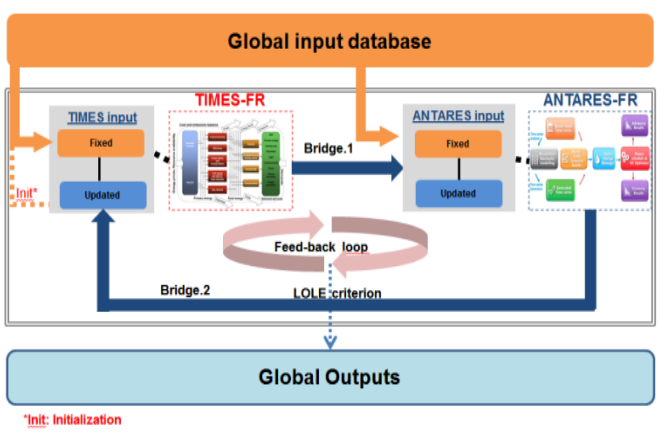

Figure 1 Schematic overview of TIMES-ANTARES linking model. The uninterrupted line describes the information flow interactions, the dashed line indicates the initialization step which is considered as the beginning of the linking process. The first step of the iteration is a TIMES solution. ANTARES is then run with a TIMES solution for a target year, and operates a Monte Carlo dispatch. The iteration ends as soon as the LOLE criterion is achieved. The global outputs are the power generation mix obtained and the insights offers by the linking model.

Coupling part: the two following steps are built to align ANTARES inputs with TIMES outputs:

Global Input database and TIMES initialization: For consistency, before carrying out the linking exercise between TIMES and ANTARES, a necessary first step is to identify the overlapping area between the two models. ANTARES being probabilistic, the electricity demand and renewables capacity factors in input are described by numerous time-series to simulate multiple years. As TIMES is deterministic, only one year is represented. It was thus decided to use the median scenario of ANTARES as the TIMES input.

Bridge.1: This step is the core of the linking model. The generation mix as decided by TIMES for a specific year of interest is used as input for ANTRES, which simulates the supply/demand balance of this power system under several operational and climatic conditions (Monte Carlo years).

Feed-back part: This part aims to use the linking model to address the power system generation adequacy issue.

Bridge.2 and feed-back loops: For a controllable linking, the common power system representation needs to provide common, unambiguous measuring points where the two models should yield identical results [9], e.g. power operation and dispatch. To achieve this, after running ANTARES, the outputs are analyzed in terms of the difference between expected power generation, dispatch decisions, and finally the reliability metrics.

Two things may happen:

i. if the outputs show that the legal adequacy criterion is not met (LOLE>3h), then some parameters will need to be updated in the long-term optimization model for that year;
ii. If the outputs show that the legal adequacy criterion is met, then the process ends.

The feed-back loop algorithm between ANTARES and TIMES is based on the capacity credit value, which is used to measure the contribution to demand peak. In the TIMES model, capacity credit is incorporated as an exogenous parameter within the peaking reserve constraint. In our study we propose a methodology based on the IEA approach to estimate the capacity credit value following equation 1 [10].

$$\mathrm{cc_i} = \mathrm{median}_{s \in \mathrm{Scenario}} \left(\frac{\mathrm{LDC}^s(t'=1) - \mathrm{RLDC}_i^s(t'=1)}{\mathrm{Capacity_i}} \right) \quad (1)$$

where LDC is the load duration curve, RLDC is the residual load duration curve, $\mathrm{Capacity_i}$ is the installed

capacity of a technology i and Scenario is the set of ANTARES scenarios (called Monte Carlo years).

The proposed and developed framework was applied to France on a "copper plate" (i.e. neglecting grid congestions on the French grid) and stand-alone basis (i.e. without taking into account interconnections with other countries). The long-term scenario assumes a mix featuring 60% renewable technology uptake by 2050. 2030 was chosen as the link target year. To explore the sensitivity of the power generation mix decided by TIMES to a subset of relevant variables in the power system operation, two variant cases were developed:

- Sensitivity to climatic events: This involves simulating 200 future climatic years representing 2030, without taking into account either thermal plant technical constraints or hydro energy conditions.
- Sensitivity to climatic and operational impacts: This involves combining the climatic impact with thermal power fleet operation constraints (technical detail and unavailability) and different hydro conditions (wet, normal or dry), thus simulating 1,000 future states.

3. RESULTS

3.1 Dispatch schedule comparison

A first observation is that, despite an identical power generation mix in both models, differences can be observed in terms of dispatch schedule. Consequently, differences in terms of annual energy generation can be observed for a set of technologies. Figure 2 depicts for each installed technology (for 2030), the annual electric energy generation computed from the dispatch in the TIMES model (red) and the corresponding ANTARES model (blue).

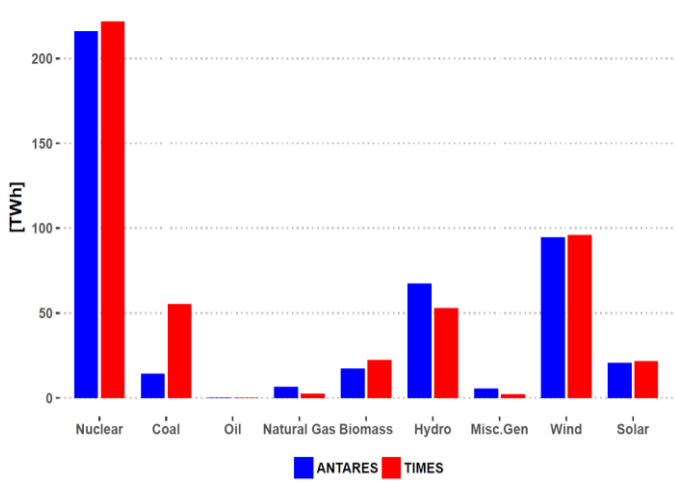

Figure 2 Annual power generation comparison between TIMES (red) and ANTARES median scenario (blue)

We observe negligible differences for both the non-dispatchable generation technologies (especially wind and solar) and nuclear. These depend on a range of factors, such as the economic merit order behind the dispatch decision, which ranks renewables and nuclear first. On the contrary, we observe a significant difference for mid-merit power plants (i.e. coal) and peak technologies (natural gas). The principal cause for the differences in annual dispatchable power generation can be found in the way the TIMES and ANTARES models approximate the residual load (figure not presented here). More precisely, two main patterns are highlighted:

- Using 84 time-slices within TIMES tends to smooth the high variability of the wind and solar capacity factors. Therefore, the residual load duration curve is overestimated compared to ANTARES.
- Overestimating the thermal power plant flexibility within TIMES (using a minimum capacity of 40% of the total) tends to lead to an over-use of the mid-merit order and peak load

3.2 Adequacy assessment and feed-back loop cost

For the first variant simulation (200 scenarios), ANTARES outputs result in an LOLE equal to 36 h, which is not conform to the three-hour limit. However, when the thermal constraint and hydro power generation variability are added (1,000 scenarios), an increase in the LOLE is observed (from 36 hours to 79 hours). A statistical analysis of loss of load duration shows that close to 10% (i.e. 1 in 10) of the 1,000 climatic future states last more than 300 hours with a maximum value of 950 h. Figure 3 shows the impact of iteratively updating the capacity credit values on the loss of load distribution calculated by ANTARES.

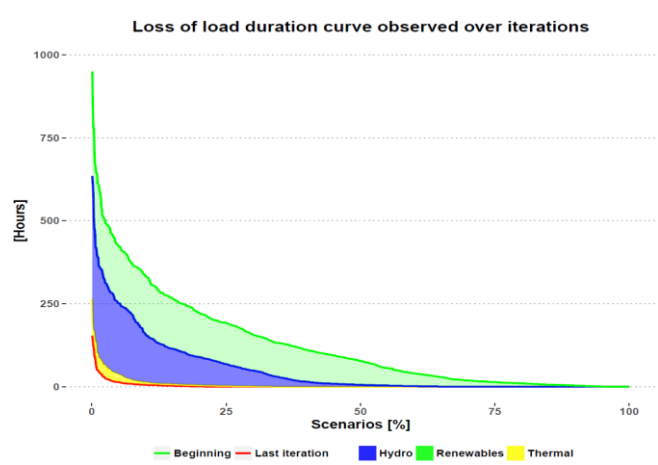

Figure 3 Loss of load duration curve evolution over iterations

Seven iterations were necessary to build a power generation mix with sufficient supplies to meet the adequacy criterion. Two important observations are that: the first iteration (renewables capacity credit) has a significant impact on reducing the LOLE indicator, while the last iteration affecting the thermal power fleet has a limited impact (1-4 hours). Obviously, this gain in reliability is mainly due to the evolution of the power generation mix over iterations. On the other hand, while feed-back loops mainly affect the peaking reserve constraint, mid-merit power plants (biomass) increase their share over iteration. Feed-back loops do not simply add peak generation to the existing mix; iterations substantially change the mix structure by adjusting all power plant capacities.

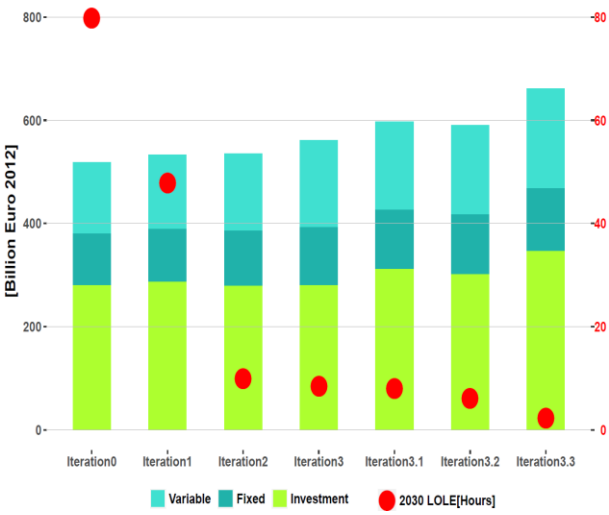

Figure 2: TIMES total discounted cost over iterations.

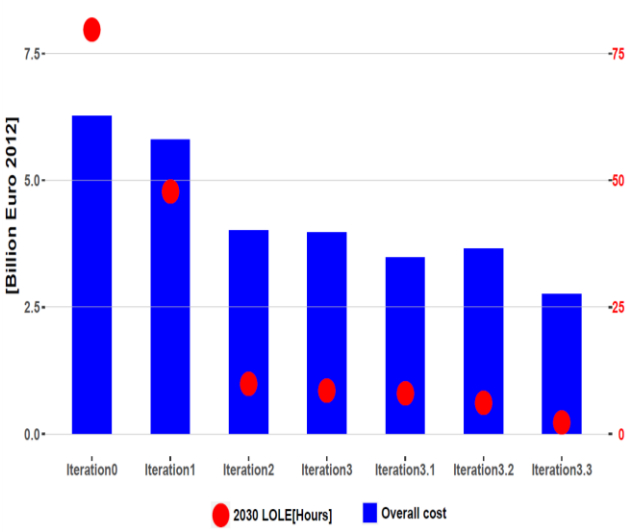

Figure 3 ANTARES overall operational costs (2030) over iterations.

From an economic viewpoint, any improvements in the adequacy of the system involve additional costs. To illustrate this effect, two costs are analyzed here: the discounted total cost calculated by TIMES includes investment costs, variable and fixed costs over a 2013-2050 time-frame. The evolution of this cost over the different iterations is presented in figure 6. The overall cost calculated in ANTARES represents operating costs and fictional costs (associated with unsupplied energy and spilled energy) for 2030 only and is plotted in Figure 7.

Figure 6 shows that French energy system costs will be increased by 28% over iterations to satisfy the 2030 adequacy criterion, driven mainly by the investment share. In addition, focusing on the last iterations, the results suggest that an incremental cost of a few hours (3-4 hours) of adequacy improvement requires approximately half of the total increase. This is due to the inverse correlation which exists between the investment cost of a power system and system reliability (reliability can be improved by increasing the investment cost). This fact is also reflected in the first iterations, which present a significant reduction in the LOLE index (50-75 hours). Figure 7 gives an indication of how the reduction (40%) of the 2030 operation cost is reached over iterations. This result is logical: the unsupplied energy cost associated with shortage decreases as reliability increases.

4. CONCLUSION

This work describes how we linked a long-term energy model with a stochastic power system model. The purpose of the linkage was to build a tool that generates a power generation mix that respects generation adequacy requirements. Technically, we used an approach that leaves the independence of the two constituent models, TIMES and ANTARES, intact. Compared to the direct integration approach (one single model), the main advantage of this soft-linking is its flexibility and practicality. To our knowledge, no similar work has used a similar approach to study long-term power system adequacy. Three key conclusions arise from this study. First, using TIMES alone exposes the 2030 power generation mix to a risk of insufficient supply (Loss of Load > 3h). Second, activating an iterative feed-back loop has the potential to achieve generation adequacy requirements. From a planning point of view, an underestimation of the total discounted cost of 28% (driven mainly by the

investment share) is observed. Our contribution to the model-linking approaches has a limited scope by design. In fact, for tractability reasons, this linking exercise focused only on 2030, thus not benefiting from the overall evolution yielded by TIMES over the full time-frame. A first set of necessary additions to the model is to assess adequacy over the entire period represented by TIMES (here from 2013 to 2050) and to accurately represent cross-border exchanges by taking into account the power mix used by neighboring countries, which is essential to perform adequacy studies. Furthermore, power system reliability is a multi-faceted notion and is fundamentally composed of two distinct and related components: adequacy and security (stability). In our research, we focused only on the adequacy side. Furthermore, Drouineau et al., 2015 [11] developed an approach to stability analysis by introducing TIMES additional constraints based on estimates of instantaneous kinetic and magnetic energies. In a similar way, Daly P. and al [12] performed an external linking with an off-the-shelf optimal dispatch, while Cardoso C., 2016 described an internal linking introducing nonlinear transient stability dynamic effects [13]. The automated soft-linking model could be interestingly extended to add a security assessment component.

ACKNOWLEDGEMENTS

This research was conducted in joint collaboration between RTE, the French power grid operator, and the Modeling for Sustainable Development Chair led by MINES ParisTech, Ecole des Ponts ParisTech, AgroParisTech. It was supported by ADEME, EDF, GRTgaz, Total, RTE, SCHNEIDER ELECTRIC and the French Department for Climate and Energy.

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