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A RELIABILITY-CONSTRAINED SCENARIO WITH DECREASING SHARE OF NUCLEAR FOR THE FRENCH POWER SECTOR IN 2050

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ABSTRACT

This contribution relies on a prospective study of the French power sector up to 2050 conducted by the TIMES model, combined with a reliability condition for operation. To consider short-term power grid transient conditions, a reliability indicator related to the reserves of kinetic energy has been defined and endogenized in the model to guarantee the power system reliability under the implementation of a high share of variable renewable energy source (VRES). For a declining share of nuclear inducing a high share of VRES, the pace of investments, additional back-up and flexible options to guarantee the grid's stability anytime have been studied.

Keywords: Power generation, Nuclear energy, Power system reliability, TIMES model, France

NONMENCLATURE

VRES	Variable renewable energy source
RES	Renewable energy source
TIMES	The integrated MARKAL-EFFOM System
LTPM	Long-term planning model
DR	Demand response

1. INTRODUCTION

Unlike other sources of energy, renewable energy sources are available at a large geographical scale. Beyond energy efficiency on the demand side, a high share of these sources in the power generation is taken for granted to address the tensions on resource scarcity, energy dependence and environmental concerns by significantly decarbonizing the electrical grids. However, in 2018, renewable energy sources accounted for 19% of final energy consumption in the world, of which more than half comes from biomass and hydraulics. RES account for 24% of electricity production in the world [1].

France, for its part, is lagging far behind in the development of renewable energies despite its hydroelectric potential (about 11% of electricity generation in 2018 [2]). Nevertheless, the French law on energy transition and green growth has set a goal of 40% renewable energy in final power consumption in 2030. For this purpose, a major change in the electrical system must be initiated with mounting renewable energy sectors. Integration of VRES represent a real challenge for the supply-demand balance and call into question the reliability of the electricity grid. In this paper, a prospective analysis based on scenario issued from TIMES optimization model is used to study a decrease of the nuclear capacity combined with a high share of VRES in the electrical mix. The explored scenario consists of the integration of a mounting capacity of renewable energies up to 80% by 2050 and a 50% reduction of the nuclear capacity [3] between 2015 and 2035 compliant with the French multiannual energy programming.

Based on a thermodynamic representation of power systems [3], an indicator related to kinetic energy stored within the power system has been developed in a previous work [4]. It represents the power system's ability to keep stability after a sudden disturbance. This kinetic reserve comes from the rotation of the machines connected to the grid

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(assumed to remain synchronously working in spite of the disturbance) and compensates the unbalanced power exchanges throughout the power grid.

The reference energy system is depicted in Fig. 1: It includes the power exchanges with neighboring countries.

The objective function minimized by the TIMES model represents the total discounted cost of the system over the selected planning horizon. The components of the system's cost are expressed in each year of the study horizon in contrast to the constraints and variables that are related to period. For every specified period, it maximizes the total net surplus (suppliers and consumers) by respecting the defined constraints regarding the availability of resources, capacity transfer, etc. This choice allows a more realistic representation of payments flows performed in the energy system.

1.1 Main assumptions

In this section, the main assumptions of this model are listed below:

- The horizon of study is 2013-2050 divided into 9 time periods of 84 time-slices each. A hypothetic week called Cweek (constrained week) has been added in the model to consider the inter-annual variability of the variable renewable energies. It represents a potential winter week with low solar and wind production and zero imports.

- Three options of flexibility have been integrated in the model: The Demand-response (DR) (sub-hourly DR and hourly DR), the storage technologies and the new interconnections (alternative current (AC) and direct current (DC)).

- The kinetic indicator, which is expressed in seconds, is introduced for quantifying a system's kinetic inertia [5]. This indicator represents the duration during which the stock of kinetic energy runs out completely to help recovering the steady state conditions if the power generation is suddenly disconnected, or, conversely, the final consumption rushes to its peak value P_{peak}:

$$H_{\text{kin}} = \frac{E_{\text{kin}}}{\max\left(S, P_{peak} - S\right) - Q_{\text{stg}}}$$

  H_{kin} quantifies the stored kinetic energy E_{kin} compared to the supplied apparent power S reduced by the dynamic storage compensation Q_{stg}, i.e. operating in less than 15 s. More the indicator is big; more the system can maintain the balance after a perturbation. To ensure a continuum with the primary regulation which typically operates within 15-30 seconds, it is mandatory to enforce H_{kin} to be greater than a certain value $H_{critical}$ (fixed in our study at 30 seconds) to stabilize frequency disruptions:

$$H_{\text{kin}} \geq H_{\text{critical}} = 30s$$

- In this paper, we don't consider the migration of demand towards electricity.

2. RESULTS AND DISCUSSIONS

In accordance with the French multiannual energy planning, we enforce the nuclear capacity to decline from 2025 to drop to 50 % of 2013's level in 2035. A

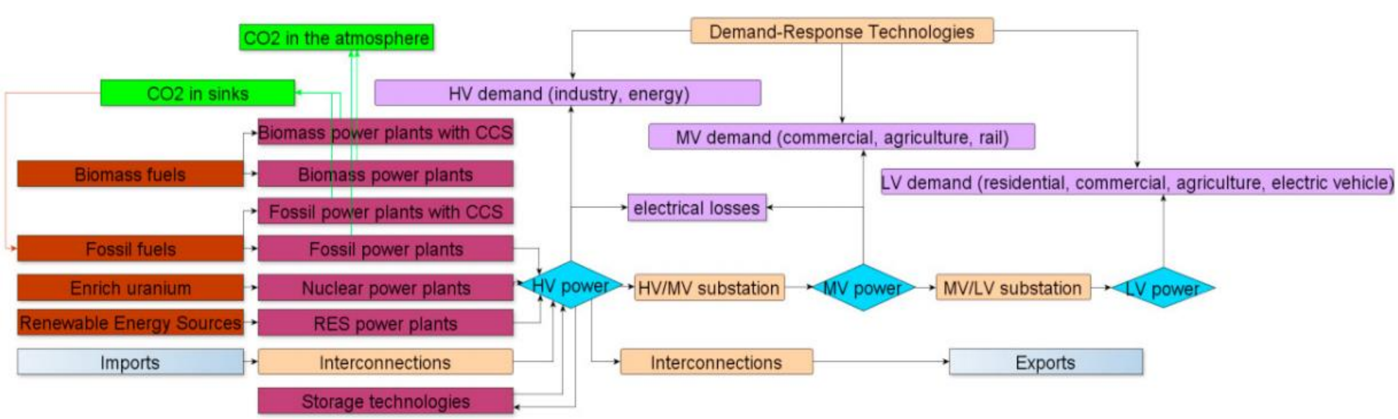

Fig. 1: Schematic description of the reference energy system

second constraint is added to promote RES penetration and reach a capacity up to 80% by 2050.

An increase in installed capacity is observed in Fig. 2. The total installed capacity for each technology over a period is equal to sum of investments made by the model over past and current periods, and for technologies for which the life cycle has not yet ended. The increase in capacity is due to the short life span of intermittent renewable energies (20 years for wind energy and 25 years for solar photovoltaic) and their load factors (23% for onshore wind, 40% for offshore wind and 14% for solar photovoltaic). These load factors are very low compared to those of conventional capacities they replaced (between 70 and 80% for nuclear power plants).

Investments in biomass and in coal plants are made starting from 2025, these plants are necessary to meet the demand and keep reliability constraint on kinetic reserve when the consumption rushes to its peak. The reduction in installed nuclear capacity is replaced by the implementation of solar and photovoltaic power plants. Imports multiply by two between 2013 and 2050 leading to a shift in power exchanges.

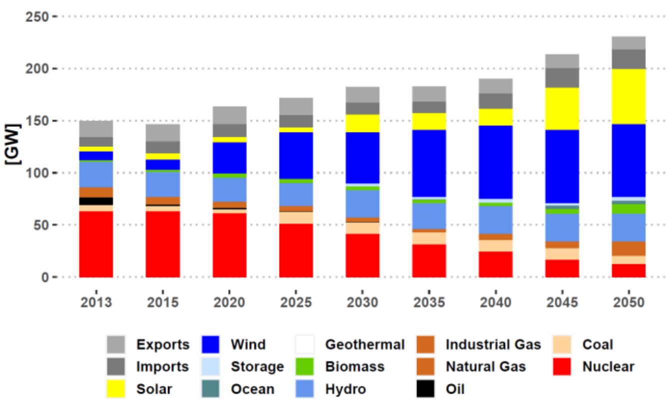

Fig. 2: Evolution of the installed capacity between 2013 and 2050

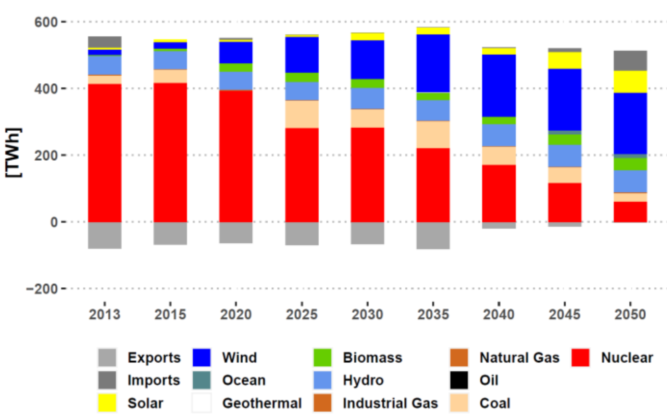

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Fig. 3: Evolution of the power generation between 2013 and 2050

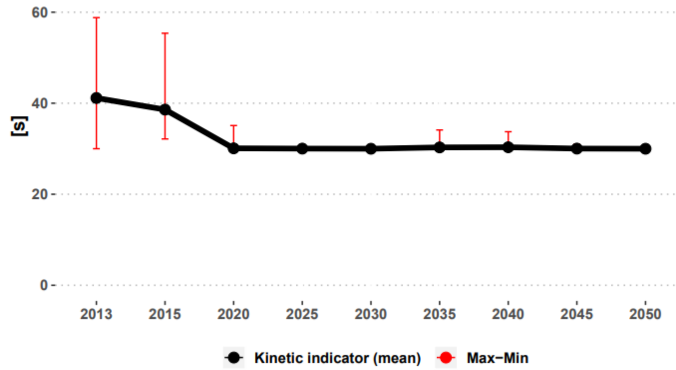

Fig. 4: Evolution of the kinetic reserve between 2013 and 2050, the bars indicate the evolution of the minimum and the maximum values observed during a year

The figure 4 displays the evolution the kinetic reserve H_{kin} between 2015 and 2050. As the VRES share increases over the years, the kinetic reserve decreases to reach its minimum value by 2020. Thus, the integration of intermittent sources of production will have to be anticipated. The question arises particularly in France, because the electrical system is very heat-sensitive (2.4 GW/◦C).

3. CONCLUSION

Using an endogenous kinetic indicator which represents the power system's stability with a long-term planning model, we assessed up to 2050 the impact of reliability-constrained scenarios with a decreasing share of nuclear. The results show that the system could require the installation of additional back-up or storage capacity to get more kinetic reserves, and then to comply the stability requirement even without nuclear power plants. This study could contribute to disentangle the issue of nuclear phase out in France [6].

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REFERENCE

[1] IRENA (2019), Global energy transformation: The REmap transition pathway (Background report to 2019 edition), International Renewable Energy Agency, Abu Dhabi www.irena.org/publications.

[2] « Overview of electrical energy in France, 2018 », *RTE France*. https://www.rte-france.com/en/search/content/renewable%20energy.

[3] X. Li, N. Maïzi, and V. Mazauric, "A lattice-based representation of power systems dedicated to synchronism analysis," International Journal in Applied Electromagnetics and Mechanics, vol. 59, pp. 1049-1056, 2019.

[4] M. Drouineau, N. Maïzi, et V. Mazauric, « Impacts of intermittent sources on the quality of power supply: The key role of reliability indicators », *Appl. Energy*, vol. 116, p. 333-343, mars 2014.

[5] S. Bouckaert, « Contribution des smarts grids dans la transition énergétique : évaluation dans des scénarios long terme. », PhD Thesis, MINES ParisTech, 2013 https://pastel.archives-ouvertes.fr/pastel-00959266/document.

[6] N. Maïzi, E. Assoumou, "Future prospects for nuclear power in France", *Appl. Energy*, vol. 136, pp. 849-859, 2014.