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Expanding renewable energy by implementing dynamic support through storage technologies

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Abstract

In order to address significant share of intermittency in the generation mix, a dynamic reliability constraint on kinetic energy was endogenized in the technical optimum TIMES model. Dedicated to La Réunion island: (i) The potential contribution of electrochemical storage technology, especially NaS, to the power dynamics and the reliability has been demonstrated; and (ii) A high share of variable renewable plants (around 50%) can be considered without jeopardize power transmission, provided appropriate investments in storage are made.

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Keywords: Energy planning; Intermittent energy sources; Storage technologies; Power system reliability; La Réunion island.

1. Introduction

Besides energy efficiency on the demand side, high share of renewable energies is often considered on the supply side to significantly decarbonize the electrical power grid. In order to balance variable renewable energies (*e.g.* wind, solar photovoltaic, wave…), operational management of the electrical power system should take into account flexibility options such as storage, demand response, or interconnection in continental grids.

However, various issues including ageing, cost, and impact on reliability or on sustainability are not fully evaluated especially in a long-term horizon (typically 2050), as traditional methods which rely on a partial description of the electrical workflow are difficult to apply to the long-term prospective planning. To overcome this drawback, an aggregated description of the power system was adopted to derive energy-based dynamic constraints on generation and transmission (section 2). The impact of storage

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facilities on power system's reliability was assessed on the "Ile de La Réunion" case, thanks to the MARKAL/TIMES optimal model (section 3).

2. Power system reliability issues

For a local focus on design or power management, the electrical power P_{elec} is expressed from the power deviation in the domain Ω to [1]:

- locally enforce the integral form of the Poynting's conservation equation:

$$P_{mech}(\Omega) + P_{elec}(\Omega) = P_{Joule}(\Omega) + \frac{dF}{dt}(\Omega) + \frac{dE_{kin}}{dt}(\Omega)$$

- globally satisfy:

$$\sum_{\Omega} P_{elec}(\Omega) = 0$$

where:

- P_{mech} denotes the net mechanical power received externally by the actuators; and
- P_{Joule} the Joule losses;
- F is the electromagnetic (Helmoltz free-) energy; and
- E_{kin} the kinetic energy.

In actual power grids, magnetic energy is processed from generators to be time-harmonic, at the frequency $f = \omega/2\pi$, so that all the grid checks synchronism (set around 50Hz in Europe). As a result, the kinetic energy embedded in the whole power system acts as a global and huge inertia against frequency deviation which therefore may only occur on several periods. Denoting long-time averaged values with ~, the power dynamics experienced by the whole power grid follows:

$$P_{mech}(t) = \tilde{P}_{Joule}(t) + \tilde{Q}(t) + \frac{dE_{kin}}{dt}(t)$$

where $\tilde{Q} = \frac{d\tilde{F}}{dt} = \frac{d}{dt}\left(\frac{Q}{2\omega}\right)$ is the so-called reactive power, *i.e.* exchanged with the electromagnetic field. For electrical couplings, rotating machines and transformers connected to the power system, electrostatic contribution to the electromagnetic energy is negligible. Thus, the reactive power reads:

$$\tilde{Q}(t) = \tilde{Q}_m(t) + \sum_s \tilde{Q}_s \mathbf{1}_{t>\tau_s}$$

where:

- $\tilde{Q}_m$ is the magnetic part of the reactive power available in "real time" to allow electromagnetic conversion, and subsequently enforce transmission and synchronism on the whole grid;
- the subscript *s* denotes the "on-grid" storage technologies available to dynamically sustain the frequency under a delayed time τ_s (typically lower than 15s).

If all the generation means are suddenly disconnected or, conversely, the final consumption rushes to its peak $\tilde{P}_{peak}$, the time to recover steady-state conditions thanks to a relevant management of the reserves before the collapse of the transmission may be roughly assessed by the kinetic reserve indicator [2]:

$$H_{kin} = \frac{E_{kin}}{\max\left(\sum_k \tilde{S}_k - \sum_s \tilde{Q}_s, \tilde{P}_{peak} - \sum_s \tilde{Q}_s - \sum_k \tilde{S}_k\right)}$$

where $\sum_k \tilde{S}_k$ is the apparent power supplied by the generators just before the disturbance. By enforcing H_{kin} to be higher than a minimal value – typically derived from the present conditions of operation –, it is conversely possible to provide a reliability condition on the operation of the system and then reconciling time-scale of power grid management with long-term planning issues.

In the following, the kinetic reserve indicator H_{kin} is endogenized into the "TIMES-Réunion" model in order to prescribe a reliable system under high share of intermittency.

3. Results

Island territories are often blessed with abundant renewable resources [3], but tend to depend mainly on imported fossil products for power generation. In this context, local authorities of La Réunion have set an ambitious goal of achieving energy independence for electricity production by 2030, which results a rapid deployment of renewable energy. This energy policy target is analyzed with the long-term energy planning model “TIMES-Réunion” which evaluates the power sector investments options and activity levels against a multiplicity of load growth and resource supply scenarios. This model, fully described in [4], is of great interest for our study for following reasons:

- Besides the biomass resource, the insular electricity system should promote a broad range of renewable energy sources with ambitious targets for the development of photovoltaics (PV: 700 MW) and ocean energy (OCE: 150 MW), therefore conducive to a high level of intermittency penetration;
- In an insular electricity system, there is no interconnection with other power system. The lack of secondary frequency regulation reinforces the role of storage technologies (ST) to sustain the power dynamics and the system’s reliability (FIA).

Whereas the transition to achieve a fully renewable generation mix is highlighted in Fig. 1, the investment planning is given in Fig. 2. Compared with Business-as-Usual (BAU, left), the level of generation capacities to implement is twice in highly renewable case (PVOCE-FIASTG, right). Political involvement, capital raising and incentive policies seem therefore mandatory to achieve the energy transition.

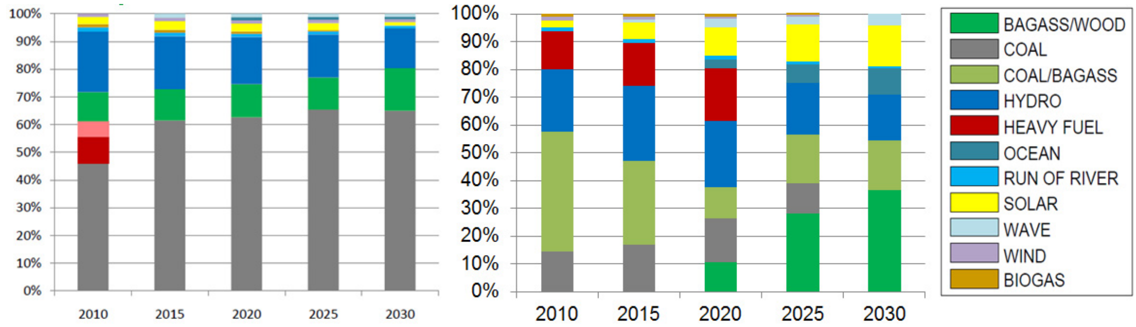

Fig. 1 Annual generation mix scenario BAU (left) vs. PVOCE-FIASTG (right).
Notice the coal and heavy fuel fire plant phase-out under the 2030 horizon.

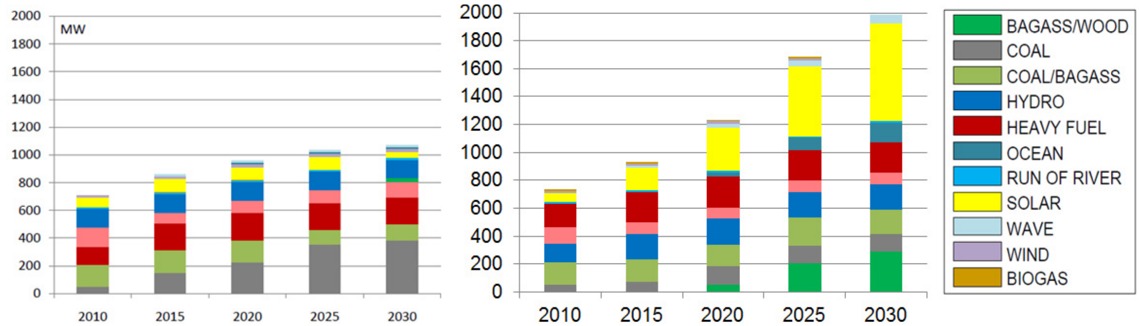

Fig. 2 Installed power (MW) scenario BAU (left) vs. PVOCE-FIASTG (right)

According to the reliability constraint expressed on H_{kin}, the system operation is found to turn to NaS electrochemical storage technologies to balance PV intermittency in the morning operations (Fig. 3).

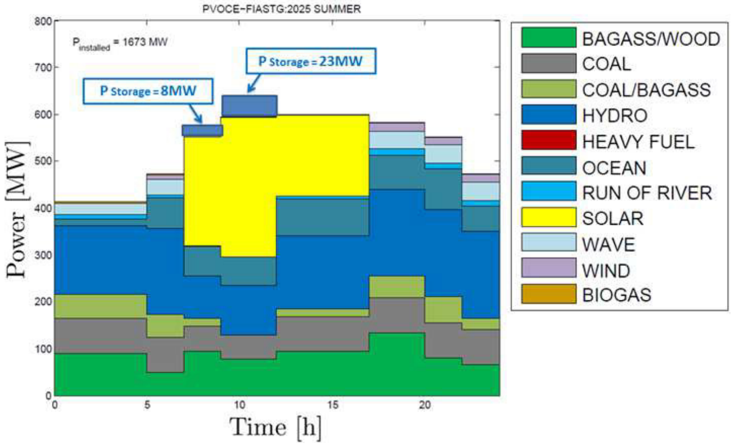

Fig. 3 Electricity generation mix by source with the reliability constrained scenario for a typical summer day in 2025: Notice the dynamic support provided by storage to balance PV intermittency.

4. Conclusion

Provided appropriate investments in storage are made, endogenization of the kinetic reserve indicator set as a constraint in the long-term planning exercise shows that a generation mix relying on 100% of renewable sources with a high share of variable intermittent plants (above 50%) can be considered without jeopardize power management. This result, significantly above the current legal limit (30%), should foster electrochemical storage technology, especially NaS, to sustain power dynamic operation under high renewable penetration.

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