RESOURCE ADEQUACY IN CARBON-NEUTRAL POWER SYSTEMS

Sonja WOGRIN[1*], Robert GAUGL[1], Thomas KLATZER[1]

Motivation

The European Union has established clear long-term goals of achieving a carbon-neutral economy by 2050 [1]. Carbon neutrality by 2050 is now also the US administration's goal [2]. In order to achieve such policy goals there will have to be a deployment of existing clean technologies, such as variable renewable energy (VRE) sources as wind and solar or energy storage systems (ESS), at an unprecedented scale. It is therefore of utmost importance to guarantee resource adequacy in carbon-neutral power systems. In this paper, we compare resource adequacy of current and future power systems by applying the open source "Low-carbon Expansion Generation Optimization" (LEGO) model [3] available on GitHub[2] to a stylized 9-bus network example shown in Figure 1. We analyse the concept of firm capacity in both cases. In renewables-dominated power systems, our results indicate that the competence of a firm capacity constraint to achieve the goal of long-term resource adequacy in a cost-efficient way is questionable. Our findings regarding the usefulness of a firm capacity constraint in a 100% renewable power system, open up the discussion for alternative market-based remuneration schemes that can provide sufficient incentives for efficient investment decisions towards a fully renewable electricity system.

Methodology

We employ the LEGO model, which is an optimization model used for cost-minimal generation and transmission expansion planning, as well as operational decisions such as the unit commitment. Inspired by [4], we have introduced a firm capacity constraint in LEGO:

$$\sum_{g} FCC_g \cdot P_g \cdot x_g \geq FCP \cdot D^{peak}$$

where g is the index for generators, FCC_g is the firm capacity coefficient[3] by technology and FCP is the percentage of firm capacity required by the system – both taken from [4], P_g is the maximum power output per generator, x_g is the discrete investment variable, and finally, D^{peak} is the hourly system peak demand. Essentially this constraint enforces that firm system capacity is at least FCP (e.g. in %) of system peak demand. The dual of this constraint yields a firm capacity price in €/MW of firm capacity, which can be interpreted as firm capacity payments.

Preliminary Results

In the stylized test system, this constraint requires a minimum firm capacity of 110% of hourly system peak demand; however, in the case study for the carbon-neutral power system, this amount is way less than the total capacity required to actually satisfy demand overall. In particular, in a 100% renewable system, during the night hours only battery energy storage systems (BESS) and potentially wind (if there is any) can serve demand. Therefore, a large amount of BESS capacity needs to be installed, to be charged during the day in order to provide sustained energy through the night. The amount of BESS capacity necessary to achieve this, i.e., almost 9 GW, by far exceeds the 110% of peak demand of 4.5 GW. This result raises the question of whether a firm capacity constraint, as it is proposed in the literature, really serves its purpose in 100% VRE power systems, in which this constraint is inactive.

[1] Graz University of Technology, Institute of Electricity Economics and Energy Innovation, Inffeldgasse 18/II, A-8010 Graz
Email: wogrin@tugraz.at, Website: iee.tugraz.at

[2] https://github.com/wogrin/LEGO

[3] This factor describes the percentage of the installed capacity for each technology that is considered firm. In this context, firm means the capacity available for production or transmission which can be (and in many cases must be) guaranteed to be available at a given time. These coefficients are almost 100% for dispatchable technologies, and usually much lower for intermittent VREs.

In fact, capacity markets, akin to the firm capacity constraint that we study here, were conceived for traditional power systems that mainly comprise dispatchable thermal generation and have limited participation of the end-consumers in the wholesale market, e.g., through active demand response programs. In this market environment, capacity payments resulting from the firm capacity constraint can be an efficient measure to compensate generation units for their capital costs, which are not recovered through the energy market, provided that the firm capacity and the contribution of each unit during stressed system conditions can be accurately estimated. Still, capacity markets have been questioned in terms of the link between the revenue received by participating units and the benefits that individual units provide to the system [5].

As opposed to dispatchable thermal generation, the stochastic nature of renewable energy production makes it difficult to perform an unbiased calculation of the firm capacity of those resources, which is typically much lower than their nominal capacity, and it depends on the energy that they can contribute to the system during stressed conditions. Estimating these contributions from, e.g., wind units, is the subject of active discussion [6]. However, this introduces a significant degree of arbitrariness in the parameters of the firm capacity constraint and often renders it redundant, as is shown in this case study, considering that it is the energy and not the capacity shortfall that drives investment decisions in a 100% VRE system. In addition, capacity mechanisms are typically accompanied by price caps in the energy market, which hinder active demand-side participation and decrease short-term wholesale market competitiveness, by removing consumer incentives to respond to price changes according to renewables' production [6]. In future research we want to explore regulatory alternatives that impose firm energy, as opposed to firm capacity, and assess their impact in carbon-neutral power systems.

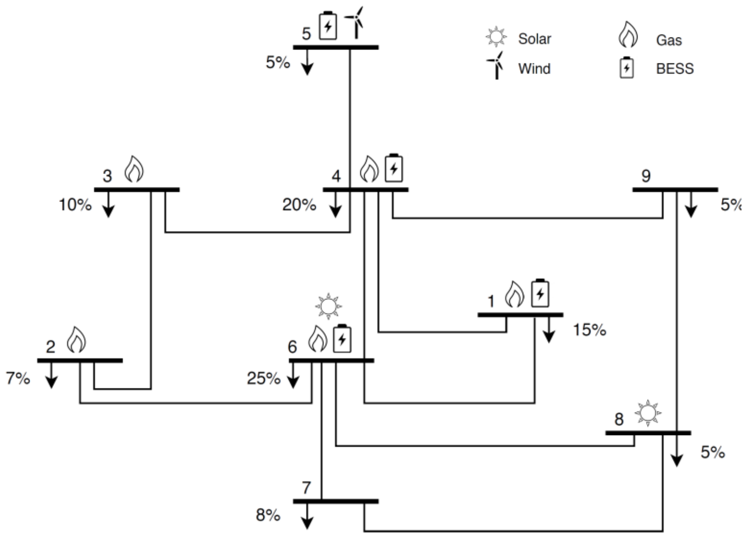

Figure 1: 9-bus stylized test system (demand indicated in %)

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