System adequacy assessment for Switzerland: How flow-based market coupling affects a non-FBMC neighbor

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Overview

Ensuring the security of supply in power systems has long been one of the main concerns of policymakers and consumers with regard to energy policy. Energy and power systems are transitioning towards a sustainable and low-carbon system. As a result, power systems worldwide face several fundamental changes in their structure; for instance, some dispatchable assets are planned to be phased out due to their CO2 emission (e.g., coal power plants) or public safety concerns (e.g., nuclear power plants in Switzerland and Germany). As substitutes, weather-dependent generation assets (e.g., PV and wind turbines) will play a more crucial role in the supply side. Even though solutions such as increased energy storage capacities (e.g., pump storage hydro and batteries) or flexibility of the demand side are expected to help increase the adequacy of the systems, there remain concerns about unwanted load shedding. As a result, updated adequacy assessments should be carried out to monitor and ensure that the desired supply security accompanies a transition towards a sustainable system.

Even though Switzerland enjoys high security of supply at the moment, the conditions may change in the coming years. The Swiss power system does not face a capacity problem. In 2020, the installed dispatchable capacity was around 18 GW (15 and 3 GW of hydro and nuclear capacity, respectively), which is considerably higher than its peak demand of 10 GW. Moreover, the Swiss transmission network is also well-connected to its neighbors, with a total nominal capacity of 14 GW. Therefore, the generation and import capacity could satisfy the demand from a pure power perspective (as opposed to an energy perspective). This will hold even in the future despite the expected increase in peak demand and phaseout of nuclear plants after their lifetime is over. However, the security of supply may be at risk in Switzerland because the supply side is limited in its available annual energy, and the import/export capacities may not be fully utilized at certain times. Switzerland has a hydro-dominated generation side with an annual generation of around 35 TWh (compared to an annual demand of 56 TWh) and a limited nominal hydro storage capacity of 9 TWh. As a result, not all potential hydro energy may be shifted to winter, the peak demand season. The winter demand issue may be worsened as the dispatchable nuclear plants phase out, and the planned replacement PV plants may not be producing enough in winters. Moreover, Switzerland is not a member of the EU and is not fully integrated into the European electricity markets and regulations. Notably, the European Clean Energy Package indicates that by 2025 EU member states should reserve at least 70% of the capacity of their grid elements for trade between EU member states (the 70 % rule). Depending on how this regulation is interpreted regarding non-member states, e.g., Switzerland, there are concerns that Switzerland may not optimally use import capacities to cover its demand at peak hours despite its nominally high import/export capacity.

In this paper, we analyze the system adequacy in the Swiss power system up to the year 2040 by developing a scenario-based numerical analysis. Given that Switzerland is well-connected to the European system, the analysis includes developments in most European power systems. Furthermore, the developed model considers that Switzerland is not a part of the European market: we assume that neighboring countries are part of a flow-based market coupling (FBMC); in contrast, Switzerland's trades with the neighboring countries remain based on a net-transfer capacity (NTC) approach. The NTCs are determined based on different possible strictness levels in implementing the 70 % rule. We also analyze if the exclusion of internal Swiss congestions in the electricity markets (which may be caused due to NTC trade) may lead to system adequacy issues in Switzerland. The analyzed scenarios are defined based on several different climate realizations (affecting infeed from PV and wind turbines and hydro inflow) and policy development scenarios in Switzerland and Europe (affecting system demand and installed technologies and capacities). The main quantitative result of the paper is system adequacy indices such as energy-not-supplied and loss of load hours, particularly for Switzerland.

Our paper has significant policy implications. First, we show quantitatively how close collaboration in the electricity markets and interpretation of the 70% rule may affect import/export capacities for Switzerland. Secondly, our results help policymakers decide between the currently discussed system adequacy improving policies such as strategic reserve gas power plants, strategic reserve hydro, and increased hydro energy storage. The resulting adequacy indices demonstrate if strategic gas units are likely to be needed. Moreover, we directly model the effects of implementing strategic reserve hydro and increased hydro energy storage.

Methods

The numerical analysis consists of a market model and a redispatch model. The market model clears the multi-region electricity market of Europe, i.e., the net position of different bidding zones and transactions between zones are calculated, assuming that supply and demand need to be balanced at all hours, except if shortages lead to loss of load. A flow-based market coupling (FBMC) is implemented to account for congestion on the transmission network. The transmission constraints for the trades between Switzerland and its neighbors are modeled in an NTC approach as, in reality, Switzerland is not a part of FBMC in the European market. The NTC approach focuses on the cross-border lines and does not include possible congestions on the internal Swiss lines. The redispatch model aims to see if the Swiss transmission system operator may take care of internal transmission grid congestions using Swiss assets, given that the electricity market outcomes (e.g., net positions of bidding regions) are already fixed.

In both models, Swiss hydropower stations are represented with a high degree of detail; hydrologic interrelations within hydropower cascades are modeled such that the outflow of an upstream power plant ends up as inflow to a downstream power plant. The model captures more than 400 hydro stations in detail, representing around 96% of Swiss hydro production. Both models assume perfect competition; therefore, the social welfare maximization problem of the market operators (in the market model) and transmission system operator (in the redispatch model) may be programmed as a cost minimization problem. Both models are also deterministic, solving for one whole year on an hourly time resolution.

Our analysis is based on combinatory scenarios for Switzerland and the EU to cover several possible policy developments. On the Swiss side, we use three development scenarios from the Federal Office of Energy and a business-as-usual case. On the European side, we take advantage of the European mid-term adequacy forecast (MAF) analysis and the Ten-Year Network Development Plan 2020 (TYNDP 2020). Each scenario, among other things, indicates the development of the supply side (e.g., installed capacities in different technologies) and the demand side (demand time series and available demand-side response options). In addition, we also cover several other customized scenarios such as partial nuclear phaseout in France, earlier coal phaseout in Germany, reduced import capacities due to strict enforcement of the 70% rule, delayed investment in the transmission grid, and implementation of hydro storage reserve in Switzerland.

On the other hand, given that renewable energy infeeds, hydro inflows, and demand profiles are highly weather-dependent, we cover several climate profiles based on historical data. We chose the climate years of 1982, 1984, and 2007 similar to TYNDP. TYNDP uses a clustering algorithm to find three climate years to represent historical load, wind, solar, and hydro inflows for a dataset encompassing 1982 to 2015. In addition, we analyze hourly residual loads and choose climate years 1985, 1997, and 2009 to represent years with the highest daily, bi-weekly (Dunkelflaute), and winter residual loads, respectively. For each climate year, availability factors for solar/wind and hydro inflows are taken from Renewables.ninja and ENTSO-E PECD (European Climate Database), respectively. Table 1 presents selected characteristics of the models and the analyzed scenarios.

Table 1 Model and scenario characteristics

Geog. coverage	AT, BE, CH, CZ, DE, DK, ES, FR, UK, HU, IT, LU, NL, NO, PL, PT, SE, SI, SK, HR
Time coverage	2025, 2030, 2035, 2040
Time resolution	Hourly
EU policy scenarios	Midterm adequacy forecast (National Trends) TYNDP 2020 (National Trends, Distributed Energy, Global Ambition)
CH policy scenarios	Swiss energy perspectives (BAU, Zero base, Zero variance A, Zero variance B)
Climate year scenarios	1982, 1984, 1985, 1997, 2007, 2009

Results

The result section will summarize and analyze the model outcomes from 864 market and redispatch runs. We will report loss of load hours, energy not supplied, remaining capacity margin, and stored hydro energy in Switzerland. Preliminary results suggest that Switzerland will have no system adequacy issues in 2025.

Conclusions

This paper presents a comprehensive system adequacy analysis for Switzerland that may inform the public about future challenges and guide policymakers in designing appropriate system adequacy improving policies.