[Sensitivity Analysis of Load Profiles: Implications for Resource Adequacy in Future Power System]

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Overview

In the context of the energy transition, accurately modeling electricity system is essential to understanding the stakes of this transition and ensuring the reliability of future power grids. For France, one key benchmark in ensuring system reliability is maintaining a loss of load duration (LOLD) lower than 3 hours per year, in average, which validate the security of the production and consumption. Resource Adequacy (RA) assessment are used to calculate the "3-hour metric". Traditional RA uses Monte Carlo method, simulations of multiple climatic years and planned/unplanned outages. These methods effectively capture inter-annual variability by taking numerous loads and climatic values such as capacity factor for variable renewable energy sources.
However, such variations are contingent upon the underlying assumptions that shape the electricity demand profile – factors like the penetration of heat pumps or the rate of building renovations. Forecasting these profiles accurately poses significant challenges. Often, historical data is used as a proxy for future load shapes, but this approach may not fully account for the structural changes that electrification technologies introduce. A slight adjustment can significantly alter the hourly demand profile, often resulting in greater deviations than those typically observed through inter-annual variation alone. Thus, it becomes crucial to investigate how these structural shifts in demand might influence overall system adequacy, potentially in ways that are more disruptive than climatic variability.

Methods

In this study, we investigate the impact of small variations in the electricity load profile on resource adequacy criteria. To do so, a European electricity model is developed based on the French Transmission System Operator projection for 2050, utilizing the hourly dispatch simulation model AntaresSimulator. The model is designed to meet the probabilistic criterion of a maximum of 3 hours annual loss of loads. While the power system is not optimized, it is constructed to be sufficiently representative for conducting sensitivity analysis. A particular focus is made on the French power system.
Four distinct scenarios are modeled: each of them featuring different hourly electricity demand profile – yet still with the same annual amount as the main goal is to understand the role of demand profile. These curves have been manually adjusted to reflect changes in hourly demand profiles, such as a small modification in the adoption of electrification technologies, which influence specific hours or period of time of the load profile. The 'reference scenario' is based using historical load data: deformation of the profile in the future by new electrification is not taken into account. In the 'winter scenario', the consumption during winter is progressively increased in 2% increments, ranging from a 2% to 10% of increase – modeling for instance changes in the share of electrification of heat or building renovation. The 'peakload scenario' models a 5% from 20% increase in peak demand – reflecting a greater penetration of heat pump or less intelligent electric vehicles charging. Finally, the 'summer scenario' explores the effect of rising air conditioning usage by applying similar increments to summer consumption.
The analysis aims to demonstrate that even a resource-adequate system, as seen in the reference scenario, can experience significant degradation in adequacy when slight shifts in the load profile appear.

Results

The results of this study reveal that even minor modification in the load profile can have a significant impact on system adequacy. For instance, an increase of 2% for the winter demand doubles the number of hours of LOLD, while a 10% increase leads in a tenfold rise in unsupplied energy compared to the reference scenario.
This study also underscores the importance of incorporating multiple climatic year into resource adequacy assessments. Out of the 33 climatic years studied in the modeling, only 10% of them were responsible for violating the "3-hour metric" in the reference scenario. This finding highlights the risks of relying on a limited number of climatic years, which could either overestimate or underestimate system adequacy by focusing on either challenging or overly favorable years. Furthermore, the system's sensitivity to load variations differs across years: some are only sensible to a change of the load during the peak hours, while some LOLD increase only with winter

demand increase. Nevertheless, given the significant correlation between low wind capacity factors and unsupplied energy in this study, the system is more sensitive to small increases in winter demand spread across all hours than to larger increases concentrated solely during peak load hours.
While the use of multiple climatic years is essential, the study reveals that critical, stress inducing years are rare, occurring in only a small subset of the dataset. These rare difficult years contribute to nearly 80% of the new unsupplied energy in most scenarios, exposing the fragility of using average metrics like LOLD. This raises a key challenge: identifying and modeling these critical climatic years to improve system robustness.
For France, summer load variations had minimal impact on the system adequacy. Yet, in southern regions, such as Italy, Spain or even the state of California, a focus during the summer period might be crucial to ensuring resource adequacy for the system.

Conclusions

This study highlights the critical role of electricity load shapes in resource adequacy assessment. A slight change in the load profile might have significant impact on the adequacy of the system.
The results of this study could be used by anyone using a power system modeling. While this approach is particularly useful for long-term forecasting models, it may have less immediate application in current system models, where the technological shares of electrification are relatively stable. The use of multiple climatic years is generally sufficient to address inter-annual variability in these cases.
In forecasting model, questions about the electricity load are primordial and structural changes might change patterns in the consumption. While this study used historical load data – largely because such data is easily available for numerous climatic years, the ideal scenario would involve using already modified load shapes to better reflect anticipated future shifts. Even in these ideal cases, small additional changes to the load profile would still need to be analyzed to fully understand their impact on system adequacy.
Moreover, while total annual electricity consumption is often the primary focus, the shape of the load profile – determined by assumptions about technology penetration, such as heat pumps or electric vehicles, can be just as influential. These findings emphasize the need for deeper integration of load profile studies for specific analysis of resource adequacy assessments, but also in general forecasting model. Understanding how these variations affect system performance is essential for ensuring the security of supply.

References

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