

Frequency markets and the problem of predictability

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Large synchronous generators, generally running on non-renewable energy resources have been the main source of stability in traditional power systems. In modern power grids, with such power plants being replaced with renewable energy sources (RES), ancillary service markets (ASMs) are becoming more critical. The main role ASMs is to procure services that are important to maintain power system stability, and reliability. Some of these services are frequency regulation services, voltage control services, and system restart services. The participation of new technologies such as battery energy storage systems (BESSs) in such markets is vital due to their fast response capabilities in providing these services. It has been recognized that a higher input from financiers and business investors can help boost grid integration of BESSs. However, since ASMs are relatively new as compared to the energy markets, the question of the relative predictability of the two markets has so far not been investigated. This is important for BESS owners as submitting bids for a less predictable product despite it showing higher hourly prices can entail less certain revenues leading to higher business risks.

In this paper, we develop revenue forecast models of the energy and ancillary services markets of the Nordic countries to quantify the difference in their predictability. We also compare the revenues a BESS owner can earn in frequency markets of these countries based on the proposed forecast models. Frequency containment normal reserves (FCR-N) are considered as a case of the Nordic ancillary service product. Our analysis shows FCR-N markets of the Nordic countries are in most cases less predictable than their respective spot markets. Finland's and Norway's being 22.7% and 84.6% less predictable. The results also show that despite the similar market requirements for FCR-N provision, the curves used to fit the forecast models of each Nordic country are dissimilar. This contrasts with the Nordic spot markets where the similar curves can be applied. Our findings thus signify a need for BESS owners to account for the difference in market predictability in their business decisions in addition to the hourly market prices. Our calculations show that if the discrepancies due the country size are ignored the FCR-N markets of the Nordic countries show similar total market revenues. However, the

BESS units bidding in Denmark can earn higher yearly payments as compared to the ones in Norway due to the higher availability payments and better predictability of the former.

The analysis presented in this paper is vital for the investors, financiers, policy makers, energy economists, and researchers in the electricity markets and energy storage community as it helps to unveil several important results regarding the differences in ASMs and energy markets of the Nordic region.

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