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Consumption management in the Nord Pool region: A stability analysis

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HIGHLIGHTS

- We extend the Independent Spike Model used to model the electricity price.
- We find that consumption can be used predict extreme events on the Nord Pool market.
- The model is used then to evaluate the effects of consumption management strategies.
- The probability for extreme events can be substantially influences by our strategies.
- Our results indicate that spikes and drops are virtually independent of each other.

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ABSTRACT

Integration of fluctuating renewables like wind and solar power is nowadays a hot topic, but this comes at a cost of decreased stability of the power system. The deterioration often translates into so-called spikes and drops in the electricity spot price, very large (even extreme) deviations from the regular spot price, followed by a reversion to roughly the original level a few days later. We use the spikes and drops as an strong indication that there is an imbalance in the physical power system in this paper.

Independent Spike Models (ISM) is a popular class of models for the electricity spot price that uses regime switching, typically having three regimes (base regime, spikes and drops). We fit a such model to Nord Pool spot data to characterize the size and intensity of these deviations, and proceed by augmenting the standard second generation, three factor Independent Spike Model by relating the spike and drop intensity to several factors and find strong statistical support for relating the consumption to the spike and drop intensity.

The model is then used to quantitatively evaluate the effects when modifying the consumption in order to mimic how additional renewables are integrated into the power system or conversely the effects when smoothing consumption using strategies that can be implemented in smart grids. We use this tool to obtain a direct measure of how much the spike and drop intensity can be reduced by smoothing the consumption and see that even a small increase in the variability of the consumption translates into decreased stability (more spikes and/or drops) of the power system.

1. Introduction

Large scale integration of renewable energy, such as wind or solar energy, is increasing the complexity of the power system. Efficient production planning is difficult as the actual amount of power being generated is uncertain. This is reflected in the electricity spot price that is known to be very volatile and sometimes spike (extreme upward movement) or drop (extreme downward movement), see Escribano et al. [1] for an overview of stylized facts. There have even been instance with negative prices in the German (EEX), see Nicolosi [2], and Danish (Nord Pool) markets, see Nielsen et al. [3]. This trend can be expected to continue as the amount of renewable energy keeps increasing throughout Europe. The extreme spot electricity prices such sudden and very large jumps to extreme levels, are usually attributed to unexpected increases in demand, unexpected shortfalls in production, failures of transmission infrastructure, cf. Geman and Roncoroni [4], and/or the inelastic market structure, see Corradi et al. [5]. We utilize the information carried by the spikes and drops to characterize the stability of the power system, cf. Lindström and Regland [6], the intuition being that the number of spikes and drops experienced would decrease if additional capacity was available.

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Our paper contributes to the current literature in two dimensions. We extend the class of Independent Spike Models (ISMs) by combining external information, see Mount et al. [7], Huisman [8] with the class of second generation ISM models, cf. Janczura and Weron [9], Lindström and Regland [10]. The model in this paper is shown to provide a better fit to data than any of the models in those papers, as all parameters in the augmented model is statistically significant.

We then proceed by using the model to evaluate the effect of managing the electricity consumption in four different scenarios. The scenarios are constructed by (artificially) modifying the historical consumption, either by shaving peaks and/or troughs or by adding variability. The unconditional probability of experiencing spikes or drops are then computed using Monte Carlo simulations. Technical solutions for implementing smoothing strategies in our first three scenarios for the consumption are discussed in a Danish context in Meibom et al. [11], see Siano [12] for a more general overview. The simulations are primarily intended as a demonstration – more advanced strategies can easily be implemented and evaluated. This means that the tool provided in this paper can be used to test and design smart grid strategies without having to solve some complicated stochastic optimization problem.

The remainder of the paper is organized as follows. Section 2 reviews Independent Spike Models, including extensions introduced in this paper. Section 3 fits the models to Nord Pool data while Section 4 explores the unconditional probability of experiencing spikes and/or drops. Finally, Section 5 concludes the paper.

2. Modeling the electricity spot price

The electricity spot price is ultimately determined by equilibrium between supply and demand. The electricity spot market is currently characterized by being inelastic demand (but varies on a yearly, weekly and daily scale) while the supply curve that resembles a hockey stick, see Fig. 1. Consequently, a small change in demand can lead to a small or potentially very large change in the spot price, depending on the available capacity.

The yearly seasonality can be tricky to model, as it is related to factors like temperature, wind speed, the magnitude and arrival of the spring flood etc. – the problem being that the spring flood occurs every year but the actual time of the year is uncertain. This makes models that accounts for seasonality using sums of trigonometric functions or wavelets, see Weron et al. [13], prone to overfitting the data when forecasting. However, trigonometric techniques are still useful for modeling the weekly and daily seasonal patterns, as they are constant over time and they do also work well when removing the seasonal component for a fixed set of data. Another approach, which we follow in this paper is to use futures as these are cointegrated with the spot price, see De Jong and Schneider [14], as their price implicitly depends all the relevant factors listed above. The electricity price is also known to be mean reverting, see Escribano et al. [1], i.e. the price returns to some equilibrium price shortly after some external disturbance caused the price to spike or drop dramatically.

Another statistical problem is the extreme volatility and spikes/drops, see Escribano et al. [1] for an overview. It is well known in the statistical literature that time-varying volatility (heteroscedasticity), if not corrected for, degrade the efficiency of the estimators, see Engle [15]. Spikes can affect several markets simultaneously as markets are connected, see Lindström Regland [6] for a study on inter market extreme dependence. It is well known from robust statistics that removal of removed from the data often leads to better (in the sense that the stochastic variability of predictions generated by the model is decreased), but that general recommendation is not relevant in our context as we are interested in the frequency and magnitude of the extreme events in this paper.

Standard time series tools, see e.g. Madsen [16], does not work very well on heteroscedastic and volatile data. It is well known that the market changes over time, cf. the supply and demand curves presented in Fig. 1. Many non-linear model identification methods, see e.g. Lindström, [17], will also struggle with this type of dependence as many tests for non-linear dependence suffers implicitly from the curse of dimensionality in the parameter space of the non-linear specification.

We are instead focusing on so-called Independent Spike Models (ISM), which are Markov Regime Switching (MRS) models for the electricity spot price, that are being able to capture most stylized facts, see Janczura and Weron [9]. A latent Markov chain governs the dynamics, allowing the model dynamics to adapt to changing market conditions. It has been argued that MRS models are more capable than e.g. jump-diffusion models to describe spikes that lasts several days, see De Jong [18], as the reversion to the pre spike/drop level is part of the MRS model dynamics. An early study that used regime switching models for the electricity price is Davison et al. [19]. Their work was later extended by Mount et al. [7], Huisman [8] and Kanamura and Ōhashi [20] who introduced a simple time in-homogeneous transition probabilities in the latent Markov chain.

Our model in this paper is a second generation Independent Spike Model, essentially based on a combination of De Jong and

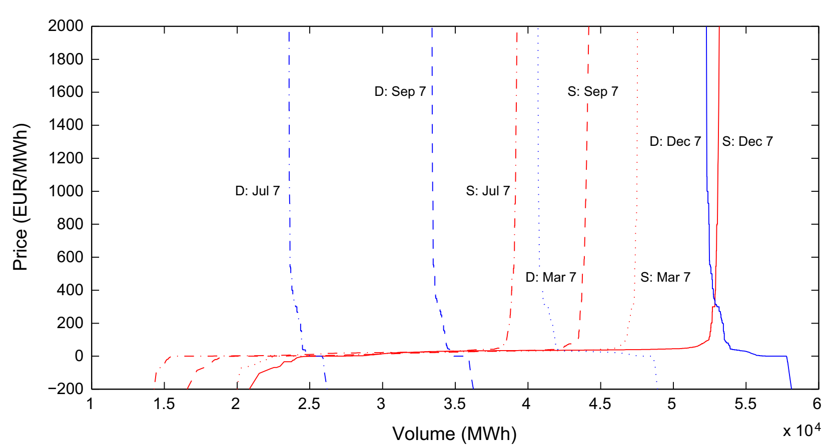

Fig. 1. Supply and demand curves Nord Pool at four different times of the year, March 7th (dotted line), July 7th (dash-dotted line), September 7th (dashed line) and December 7th (solid line).