RETAIL RATE DESIGN IN A DECARBONIZED POWER SYSTEM: ON THE LIMITS OF TIME-OF-USE PRICING

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Overview

In today's power sector, we see the development of two important trends. On the demand side, opportunities for end-users to better manage their electricity consumption are significantly increasing, enabled by digitalisation and the adoption of electric vehicles, heat pumps, stationary batteries, and other controllable loads. On the supply side, the share of intermittent renewable generation in the power mix is rising in many countries. In this context, system cost savings can be made by having load follow generation, at least to a certain extent, compared to the old paradigm of generation following load. As such, the operational and expansion costs of the future generation fleet and, potentially, investments in distribution networks can be optimised. Currently, only a few, often bigger consumers, are directly active in forward and wholesale markets. For the majority of end users, the interface between the supply and demand-side is the retail rate. Traditionally, electricity retail rates have been mostly flat, i.e., a constant price per kWh of electricity consumed. The flat rate reflects somehow the average cost of electricity supply. In theory, optimally, end users are exposed to changing system conditions by having the retail rate passing-through wholesale prices (Borenstein and Holland, 2005). Such rates are often called real-time pricing (RTP). In practice, even though RTP is technically feasible via the adoption of smart meters, consumers are risk-averse, and many do not want to be exposed to the inherently volatile wholesale prices. Especially the occurrence of scarcity price events creates acceptability issues, this is evidenced by the Texas energy crisis in February 2021 and the EU energy price crisis that has been ongoing since the Summer of 2021.

A popular alternative rate design, acting as a sort of intermediary between flat and real-time prices, are time-of-use rates (TOU). Trabish (2022) reports that there were over 150 rate design policy initiatives in 2021 addressing new time-of-use (TOU) or time-varying rate (TVR) structures in the United States. TOU rates are predefined, e.g., a year ahead, and vary according to fixed time blocks- see e.g., Faruqui and Sergici (2013). Typically, time blocks are differentiated based on seasons, months, type of day (workdays or weekends), and/or time of the day (so-called peak, shoulder, or off-peak hours). The idea behind TOU rates is that consumers are to a certain extent exposed to the time-varying conditions in wholesale electricity markets while keeping rates predictable and protecting consumers from unexpected price shocks. TOU rates are calibrated on historical price data. The more predictable wholesale prices are, the better TOU rates reflect actual system conditions and the more their introduction can lead to overall welfare gains.

In this research, we analyse how well TOU can reflect wholesale electricity prices. A relevant reference in this regard is the paper by Jacobson et al. (2020). In this paper, they compute the in-sample correlation of PJM wholesale prices (year 2012) and seven alternative TOU schemes. The highest in-sample R^2 value they find is 0.428 for their most complicated TOU scheme (Hour of day x day of week x month of year). One of our metrics of interest is as well the degree of correlation between wholesale prices and different TOU rates but we also introduce additional metric such as average rank correlations of the TOU blocks, which we argue to more relevant in a context of high volumes of shiftable load. Further, we conduct an analysis in different contexts and assumptions focussing on out-of-sample performance. Regarding the context, we look at historical data in different power systems (ERCOT and ISO-NE). We also simulate the price series using the capacity expansion model GenX, compare the properties of modelled prices with historical prices, and simulate future price series of (nearly) fully decarbonised power systems. Regarding the assumptions, we test different TOU schemes, how our metrics change when leaving out price peaks in the training data and the test data. The latter approximates the implementation of Critical Peak Pricing (CPP) on top of TOU prices. Under CPP, typically, the system operator announces on a short notice, e.g., day-ahead, a critical peak pricing event when prices in the wholesale market are expected to be very high and often involves automated demand control.

Methods

To determine the TOU rates, we use simple linear regression with the regression coefficients being dummies representing the different fixed time blocks. We evaluate of the performance of the TOU rates (with or without CPP) by calculating our metric of interest using the TOU rates calibrated on historical data (e.g., wholesale prices of Y-1) and unseen test data (e.g., wholesale prices of Y).

To simulate price series, we utilise GenX, an open-source capacity expansion model (MITEI and Princeton University Zero lab, 2022). GenX includes representation of various supply and demand-side resources, including energy storage with independent discharging and charging power capacities and energy storage capacity, demand flexibility, demand response, and use of hydrogen for non-electric end-uses. We calibrate GenX based on the current generation mix and demand in ERCOT and ISO-NE. We also develop several scenarios representing the two power systems in 2050. Such simulations for ERCOT are presented in Mallapragada et al. (2022). Mallapragada et al. (2022) show that the wholesale price distributions in 2050 are significantly different that the price distribution we are witnessing today.

Results (to be confirmed by the runs)

The variability in power prices is driven by many factors. In thermal-dominated systems, the main driver is demand. In addition, discrete events such as maintenance and outages of power generators can cause additional unpredictability. Changes in prices for coal or natural gas change price levels from one year to another but not necessarily the price pattern. As the predefined periods in TOU prices are based on variations in demand patterns (e.g., one season to another, peak vs off-peak hours etc.), the performance of TOU prices, especially when reinforced with CPP, in such thermal-dominated can be expected to be "reasonable" (to be quantified). This is especially the case when TOU prices are calibrated on filtered historical data (i.e., leaving out the unpredictable scarcity events).

As we also show that "synthetic" price series using GenX when calibrated for existing power systems exhibits the same properties as historical data, we feel confident that we can use GenX to project future price series for a (nearly) entirely decarbonised power system. We show that the out-of-sample performance of TOU, even with CPP, deteriorates quite quickly. We illustrate that because of wind, solar, and storage technologies the variability of wholesale prices follows very different (and more unpredictable) patterns than classic variability in electricity demand.

Conclusions (to be confirmed by results)

Increased electrification of heating and transport on the demand-side and increased penetration of intermittent renewable energy resources on the supply-side increase the importance of retail electricity rates. Due to current concerns with the first-best solution, i.e., retail rates passing-through wholesale prices, alternatives are being proposed. An important alternative are TOU tariffs, possibly reinforced by CPP. In this paper, we show that in the power system of yesterday, TOU rates might have served as a reasonable intermediate option between flat and real-time rates. In the power system of tomorrow, due to the increased unpredictability of power price patterns, TOU rates, even with CPP, a high degree of freedom and trained on filtered price series, cannot reflect changing conditions in the wholesale market. We see two avenues of future research. First, so far, we have evaluated the performance of TOU rates by comparing them to out-of-sample wholesale prices. However, the metric we are really interested in is the system cost implications of having imperfect retail rates. Second, as we argue that TOU rates are unfit for eliciting demand-side response in a decarbonised power system, alternatives need to be studies. The alternatives need to find a right balance between better reflecting wholesale prices while limiting electricity bill volatility, such as discussed in e.g., Chao (2011) or Wolak and Hardman (2020).

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