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An Option-Based Approach for the Fair Pricing of Flexible Electricity Supply

Christiane Rosen and Reinhard Madlener

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Abstract

In this electricity market design paper, we investigate the value of flexibility of conventional power plants in today's electricity markets, and whether the current market conditions suffice for recouping the power plant operator's investments and expenses for enhanced flexibility. We find that traditional option valuation methods are inadequate for sufficient compensation, and argue that a levelized cost of electricity (LCOE) approach for option valuation of flexible and non-flexible electrical energy is preferable. In a case study, we create three different flexibility cost scenarios (optimistic, realistic, pessimistic) in order to determine the LCOE and the option prices of the flexibility options studied. We find that flexibility offered in such a way is affordable and that prices are more reasonable than otherwise incurred balancing costs.

Keywords: flexibility markets, energy options, levelized cost of electricity, capacity markets

JEL Classification: C91, D03, D44, D83

1 Introduction

Ambitious policy goals and support mechanisms for a sustainable energy system transformation have led to an increasing share of fluctuating renewable energy, especially solar and wind power. This is accompanied by an increasing demand for flexible energy generation to keep the system balanced. In principle, this flexibility could be provided by a wide variety of power plant types - including renewably fueled ones -, but often requires technical modifications and investments in the power plant technology to enable timely reactions to supply-demand imbalances. Hence, flexibility is not only valuable, but also costly for those who provide it, and there is no mechanism to remunerate this service.

In this paper, we analyze whether the current market environments offer sufficient possibilities for flexible power plants to earn the revenues needed to recoup their investments, or whether additional mechanisms are necessary. We reflect on existing market ideas before analyzing possible new amendments to the current market framework. The goal hereby is to trade flexibility as an asset. In this context, flexibility can be treated as an option, bought by those who need to balance their portfolio and called when the imbalance occurs. This flexibility option market can take the form of an additional category in the existing reserve energy markets, whose existing product range could be complemented by the "renewable reserve".

We proceed as follows. Section 2 introduces the concept of flexibility and explains why it is costly. Section 3 gives an overview of existing markets and market ideas to determine the exact gap we want to fill. Section 4 presents our market design for flexibility options. Section 5 contains a case study, which puts the resulting prices into perspective. Section 6 concludes.

2 Flexibility in power production

In the context of energy supply, flexibility is related to the capability of a power generating unit or a consumer to adapt the energy output or consumption to external changes. The extent of flexibility is thereby determined by the relative size of the possible adaptation and the time required to perform this adaptation. In more technical terms, this means that start-up or ramp-up times need to be short, and operation at lower loads needs to be enabled. For ecological reasons, the efficiency at different, and especially lower, working points should also be high. This is often not the case because turbines are usually constructed in such a way that they only run optimally, i.e. with maximum energy efficiency, at full load. To reach these targets, there are several measures that can be implemented in existing power plants. In several parts of the plant, the efficiency can be increased with the use of power electronics in pumps or fans. For steam power plants, there exist possibilities to alter processes of the steam generation to increase efficiency, reduce minimum load, and prolong the life expectancy of the power plant (Plewnia, 2014). Also, the fuel, especially coal, can be treated, such that it fires up in an optimal way. While none of these measures can be bought with a price tag readily off the shelf, the approximate installation time can still be estimated (FDBR, 2013). This includes a complete shut-down of the power plant, which leads to accumulated opportunity costs. By doing so, the minimum investment costs can be determined.

3 Background

Despite of the promising presence of the European Power Exchange (EPEX) and the European Energy Exchange (EEX), there is no such thing as a common energy market in Europe. Instead, most countries have their own exchange institutions. In part, this is due to a lack of integration of the existing markets, but it is also due to the grid characteristics, which do not support the free flow of electricity throughout the continent. For the remainder of this paper, we focus on the German energy market. There are two reasons for this. On the one hand, Germany is part of the EPEX/EEX region, which means that it is one of the most integrated markets already. On the other hand, the topic of flexibility is of particular interest in this market. At the moment, a transition from a conventional, centralized system towards a decentralized, renewable energy system is taking place, which is not only exemplary for many other countries, but also represents a unique struggle. The current market scheme in Germany provides three markets with different time horizons. The earliest trading happens on the futures exchange between a few days and up to six years ahead of delivery. The market volume was 1570.4 TWh in 2014 (EEX, 2015). As the name suggests, the day-ahead market supports trading for the upcoming day until 12 a.m. on the day before delivery. In 2014, 262.9 TWh were traded here (EPEX Spot, 2015b). The shortest time to delivery can be found on the intraday market, where trading is possible up to 30 minutes before delivery. The European Power Exchange Spot published a volume of 26.3 TWh for 2014 (EPEX Spot, 2015b). Most traders in these markets work either for utilities or energy trading companies. The second-largest share represents municipal and regional energy companies, whereas a small amount is also traded by commercial (i.e. large) consumers, banks, and transmission system operators (TSOs) (EPEX Spot, 2015a). Products in these markets are highly standardized. They are defined as individual hours or blocks of hours of the day. However, user-specified blocks are also possible, especially in over-the-counter (OTC) bilateral trading, which occurs "on the side" and where details are subject to negotiation of the involved parties. While this form of trading enables more customized products, it also entails higher risks. In the case of a failure in production or bankruptcy of one of the parties, the other party incurs the full costs. In contrast, at the exchange, the clearing house offers insurance mechanisms which cover the economic consequences. While the trading volume at the exchange is relatively small compared to the overall volume in wholesale trading, it has an important signaling effect for prices in OTC trading (BNetzA, 2014). The above-mentioned markets can be summarized as the "energy-only" markets. The name already suggests that only energy, and not capacity (i.e. power), is traded. This is different for the reserve energy market. Here, capacity is reserved, and can later be called whenever it is needed. There are three different qualities, all as negative and positive reserves, which differ in response time. The fastest is primary reserve, followed by secondary and tertiary reserve. These reserves are needed for balancing fluctuations in the grid, which result from imprecise forecasts of demand or supply (e.g. from intermittent renewables, such as solar and wind energy) as well as other unforeseen events such as outages or distortions.

While the reserve energy market is well established and prices have decreased over the years, participation is still not easy and requires a tedious prequalification process. At the same time, many technologies, especially renewably-fueled ones, are excluded from the market, because they cannot meet the requirements. Also, the rules laid down by the TSOs systematically favor large providers with a portfolio of power plants. This is due to the minimum runtimes that are necessary and accumulate over several days. Furthermore, an energy company cannot itself trade on this market to satisfy its balancing needs, but has to rely on the services provided by the TSO.

In addition to these established markets, concerns about security of supply and sufficient capacity to buffer the fluctuations from renewable generation have increased and fueled discussions about alternative markets. In particular, the question has been raised whether a radical, or at least significant, change should be enforced in the energy market. Specifically, the diminishing marginal returns on conventional power plants and the accompanying fear of a loss of necessary capacity led to the idea of capacity markets. Thereby, several different ways of implementation have been proposed. A major distinction can be made with respect to price- and capacity-based mechanisms (e.g. Elberg et al., 2012). Concepts already in use in the first category are administered capacity payments, strategic reserves, and operative reserve.

Chile and the United Kingdom have already experimented with capacity markets, with the United Kingdom re-introducing them in the context of its Electricity Market Reform (EMR, part of the Energy Act, assented in 2013). Currently, they are also in use in Spain and Ireland. They chose administered capacity payments, which are based on the amount of capacity needed for a secure level of supply. Hereby, new power plants receive capacity-based payments in case the secure amount of capacity is low in comparison to the observed peak load or in comparison to a predefined capacity demand. Payments are highest when the situation is most severe, and are reduced gradually until a secure state is achieved. Once the size of the payment is determined, it is fixed for a certain period of time (e.g. for 10 years in Spain, and one year in

Ireland). Thereafter, the administered capacity of the power plants is used for trading on the power exchange (Süßenbacher et al., 2011).

Strategic reserves are power plants that do not participate in the free trade at the exchange or in OTC contracts, but can be used by a coordinating party in the case of scarcity. Hereby, scarcity is defined as a lack of supply that leads to an extremely high spot market price. In such a situation, the coordinator can use the strategic reserves to buffer the exorbitant price. The downside of this mechanism is the lack of high spot market prices, which otherwise incentivize investments in new capacity. While, in principle, the tendering for strategic reserves with an appropriate set-up can also be used for incentivizing new investments, it remains a delicate and non-trivial intervention in the energy-only market. This is not only due to the underlying quantity decisions, but also due to the enforced price cap. It influences, but can also be used to influence, the technology mix in the energy-only market. Still, it remains questionable how well-tuned the mechanism can be implemented in order to control the effects on the overall energy landscape. (Elberg et al., 2012)

Operative reserves are used in Norway and the US. They are implemented by the TSOs within the framework of the reserve energy market. As for other types of reserve energy, the amount of capacity is determined in advance. The weekly tender and a comparatively simple prequalification process make this market easily accessible, also for more innovative concepts such as demand side measures. While it can be adapted over time, it only supports existing power plants. (Süßenbacher et al., 2011)

Cramton and Stoft (2008) developed a concept which discriminates between existing and newly-built power plants. Although the implementation is quite complex and requires an analysis of the entire generation portfolio as well as load forecasts for the coming years, it offers the benefit of individual risk premia for the two segments. After a successful tender in the capacity market, the regulator obtains capacity options, which can be called in the case of scarcity. Comprehensive capacity markets directly target and remunerate generation capacities. They can co-exist with energy-only markets, but have a more long-term perspective.

(Elberg et al., 2012) Examples of such markets can be found both in research and in practice. Depending on the actual design, aims and incentives can differ. Some argue for a focus on renewables (Kopp et al., 2013), others have suggested to prevent closures of power plants (Consentec, 2012), while still others favor to support the construction of new power plants.

First ideas on flexibility markets have already been formulated. Similar to the operative reserve discussed above, Buchholz et al. (2012) propose to add a fourth segment to the existing reserve energy market. The purpose hereby is, however, to better integrate renewables into the energy market. Rautkivi and Kruisdijk (2013) also introduce a flexibility market as a day-ahead option market. They regard this market as a complement to the existing energy market and also consider capacity markets as an additional measure in the market environment.

Wärtsilä (2014) note that the current German electricity and reserve market design does not set any incentives for flexible energy provision. They propose several measures for linking the balancing mechanisms to market forces. More specifically, they ask for more transparency in the balancing mechanism to support trading on the intraday market, which might buffer some of the balancing needs. This, of course, also requires a decrease in the gap between procurement and delivery of reserves. However, the recent reduction in gate closure times from 45 minutes to 30 minutes in the intraday market seems already a step in the right direction (EPEX, 2015).

It should be noted that some of the above-mentioned mechanisms are already option-based and offer a good foundation for including the flexibility dimension. To achieve this, it is necessary to shift the focus from security of supply to technically motivated issues.

4 Market design

There are two ways to approach flexibility, either one regards flexibility as something to be planned for the system ahead of time, or one regards it as something that happens constantly in an evolutionary manner. The first approach is linked to an option market, where those in need of flexibility can buy options in advance and execute them when a situation of unforeseen fluctuations occurs. It thereby complements an otherwise static system and does not impact the system itself. The second approach aims at marketing flexibility as a system-inherent feature, possibly leading to a real-time market. While both can serve the same purpose, also in the long run, the first approach is easier to implement. It can be added to the existing system, while the second approach requires to rethink and remodel all the established mechanisms.

We therefore focus on the first approach and model the pricing mechanism. Formulas for stock option pricing have been developed by Black and Scholes (1973) and Cox et al. (1979), among others. They involve the price of the stock, which can be stochastic, and the strike price of the option, which is fixed and allows the owner of the option to buy the stock at this predetermined price, independent of the actual development of the stock value. In addition, there are some variables to model the expected price movements over the envisioned time horizon and the risk-free interest rate. The value of the option is then calculated as the difference between the strike price and the stock price.

For an electricity option, however, this formula cannot be applied. There are several reasons for this. Firstly, the primary goal is to incentivize and remunerate operational flexibility, and not to hedge a financial risk (although it might, of course, be inherent). Secondly, and as a result of it, the value of the option cannot be determined from a stock and a strike price, even though the electricity price could in principle be used as a replacement for the stock price. The problem hereby is again the operational perspective. The price of electricity is highly dependent on the time of the day, the weekday, the season, and additional weather conditions. This means that either the contract for the option very neatly defines the time slots during which it can be exercised, or the electricity price is useless for defining its value. Moreover, the electricity price at the EEX results from fierce trading of a myriad of different technologies, some of which might have low marginal costs and therefore are able to make offers at low prices. Since flexibility is costly, both from the perspective of the investments required to provide it and the increased costs of operation, including increased maintenance and early wear-out, calculating its value using the market price of electricity from non-flexible power plants leads to underestimating of the true value.

The strike price, on the other hand, could be agreed to be the EEX price at strike time. This confirms the non-financial nature of the option, because with a variable strike price equal to the market price, no hedge against unfavorable market conditions is possible. A fair price for a flexibility option should consider the costs it produces. These are captured by the so-called "levelized cost of electricity" (LCOE) and include capital costs, fixed and variable operation costs, fuel costs as well as an interest rate for the entire lifetime, i.e. over all working hours, of a power plant. This full-cost approach provides an amount in Euro per MWh, which can be translated into a minimum average price.

The IEA (2010) suggests the following formula for determining the LCOE:

$$LCOE = \frac{\sum_{t=0}^{T}((Invest_t + O\&M_t + Fuel_t + CO_{2t} + Dec_t) \cdot (1+r)^{-t})}{\sum_{t=0}^{T}(Electricity_t \cdot (1+r)^{-t})}. \tag{1}$$

Costs of flexibility can be categorized accordingly. Hereby, the most important distinction is between a more flexible operation of a power plant, or the flexible operation of a power plant that has been retrofitted with a suitable flexibility measure (which enables an enhanced level of flexibility in a power plant's operation). This determines whether there are additional investment costs to be considered or not. For all other parameters only the size of change is influenced. Under all circumstances, operation and maintenance (O&M) costs increase. This is due to the increased stress that parts experience during more variable generation, which then leads to the need for more timely replacement (increased wear and tear). Fuel costs may also increase for partial loads, which are more frequent in flexible operation, because the efficiency factor decreases. This means that more fuel is needed per MWh of output. At the same time, and for similar reasons, the carbon emissions increase for partial loads. Pickard and Meinecke (2011) even define, as a technical constraint, the minimum load by the maximum allowable level of emissions.

For a flexible power plant, we can thus define the $LCOE_{flex}$ as follows:

$$LCOE_{flex} = \frac{\sum_{t=0}^{T}[(Invest_{t,flex} + O\&M_{t,flex} + Fuel_{t,flex} + CO_{2t,flex} + Dec_{t,flex}) \cdot (1+r)^{-t}]}{\sum_{t=0,flex}^{T}[Electricity_{t,flex} \cdot (1+r)^{-t}]}. \quad (2)$$

Hereby, $Invest_{t,flex}$ equals the investment costs that need to be incurred to implement a flexibility measure. Once a power plant is operated in a more flexible way, O&M costs increase due to earlier wear-out. This is reflected in the term $O\&M_{t,flex}$. Flexible operation often also means that power is produced in less efficient working points, which results in higher expenses for fuel ($Fuel_{t,flex}$) and CO$_2$ emissions ($CO_{2t,flex}$). Another parameter, which is likely to be affected, is decommissioning cost. This is captured by the term $Dec_{t.flex}$. $Electricity_{t,flex}$ is the capacity of the enhanced power plant, multiplied by the number of full-load hours, or, put differently, the yearly energy production of the flexible power plant.

The option price should now be determined from the difference of the $LCOE$ and the $LCOE_{flex}$. Both give costs in Euro per MWh, which can then be used for pricing the option:

$$V_{Opt} = (LCOE_{flex} - LCOE) \cdot P \cdot t, \quad (3)$$

where P is the maximum capacity which can be used when exercising the option, and t determines which time period is covered by the option. The option price V_{Opt} is thus given in €.

5 Case study

Now that we have derived how the value of a flexibility option can be determined, we want to find some plausible values for the actual price. While finding suitable data is always cumbersome, a major obstacle hereby is that flexibility measures currently cannot be bought “off the shelf". This means that there are no price tags that would help to estimate the investment costs. For this reason, Plewnia (2014) took a different approach to determine the lower bounds of the investments costs that can be expected. He analyzed the construction times and calculated the amount of foregone profits, i.e. the opportunity costs for the outage time. This is supplemented by rough estimates from the German Association for Power Plant Engineering (FDBR, 2013). Thereby, costs of between 1.4 - 26.9 million € per year over the lifetime of a power plant have been obtained. Using these findings, we can evaluate the $LCOE_{flex}$. Kumar et al. (2012) analyze the impact of increased cycling on operation and maintenance costs. They find costs of between 38 - 157 US$/MW. These include capital as well as maintenance costs for coal-fired power plants, depending on the power plant's characteristics, its criticality (which relates to the efficient operating points) and the start-up conditions.

Litau (2015) finds that when reacting optimally to the electricity market, a conventional power plant has between 5000 and 6000 hours of full-load operation, and 350 to 450 hours of minimum- load operation. In addition, he finds that flexibility measures can increase or decrease the number of full-load hours by a factor of 1000. In order to determine the $LCOE_{flex}$, we will assume additional yearly full-load hours of 1000. Even if they were indeed a reduction, this establishes a good basis for a fair remuneration. The yearly (additional) output is assumed to be produced for at least 10 years, which is the remaining lifetime of the power plant in this context.

Decommissioning costs are not assumed to be affected by the retrofitting measures. While fuel as well as CO_2 costs will rise due to operation at lower efficiencies, it remains unclear with what magnitude they will change. Since these costs are also relatively small compared to investments and maintenance costs, we will disregard them in the further analysis.

For obtaining a comprehensive picture of possible option prices, we create an optimistic, a realistic, and a pessimistic scenario. The optimistic scenario relates to the lower bounds of the costs given in Table 1, the realistic scenario to the median values, and the pessimistic scenario to the upper bounds. For the discount factor, we adopt the lower proposition of the

Table 1: Cost variables and their specifications

Type of costs	Variable	Optimistic	Realistic	Pessimistic
Investment costs [million €]	$Invest_{t,flex}$	1.4	14.15	26.9
Operation and maintenance costs [€/MW]	$O\&M_{t,flex}$	35	90	145
Fuel costs	$Fuel_{t,flex}$	unknown[a]		
CO_2 costs	$CO_{2t,flex}$	unknown		
Additional operating hours p.a. [h]	$Electricity_{t,flex}$	1,000	1,000	1,000

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[a] The additional fuel and CO_2 costs that arise due to less efficient working points of the power plant are very hard to estimate. Since we only want to determine an option price, and not the strike price, we can disregard them in our analysis. The full cost of providing the energy when exercising the option should, however, be considered in the strike price.

IEA (2010), i.e. 5%, because this currently seems more realistic than the otherwise proposed 10%. These values are subsequently used for determining $LCOE_{flex}$ and V_{Opt}.

Table 2: Option prices by scenario, per unit of capacity

Scenario	V_{Opt} [€/MW]
Optimistic	0.32
Realistic	3.00
Pessimistic	5.67

For verifying the robustness of our results, Tables 3 and 4 contain the results for scenarios with mixed inputs from the optimistic, realistic, and pessimistic branches of investment and O&M costs. Hereby, the initial investment costs have the highest impact and determine the level of the option price. Operation and maintenance costs influence the final price by less then 5%.

When looking at Table 2, one can see that the prices for a flexibility option are fairly low. To put them into perspective, it makes sense to compare them with the prices for balancing energy. For example, in February 2014 the TSOs charged on average 61 €/MW for every quarter of an hour (50Hertz, 2015). Keeping in mind that the above-mentioned option prices

Table 3: Option prices for mixed scenarios I

Scenario	V_{Opt} [€/MW]
Optimistic/pessimistic	0.43
Realistic/optimistic	2.94
Pessimistic/realistic	5.62

Table 4: Option prices for mixed scenarios II

Scenario	V_{Opt} [€/MW]
Optimistic/realistic	0.38
Realistic/pessimistic	3.05
Pessimistic/optimistic	5.56

can be regarded as minimum prices for a fair remuneration of providing flexibility, it becomes apparent that the system costs for achieving more flexibility are manageable. This is especially important since flexibility is one of the cornerstones for the energy turnaround.

6 Conclusion

In this paper, we have looked into possibilities for a fair remuneration of flexible electricity. Although the intra-day market helps the procure electricity on a rather short-term basis, it does not provide full flexibility due to the gate closure times. To fill this gap, a different trading or market scheme is necessary. Options are suitable for this purpose, because they can be traded in advance, and called when an unanticipated situation of energy shortage occurs. We have shown that traditional option theory does not provide a good basis for modeling the costs that emerge and, in turn, for finding an adequate compensation. Therefore, we take a cost-based approach for determining the value of the option. This relies on the "levelized costs of electricity" for producing both flexible and non-flexible energy. The difference thereof is the minimum price a power plant operator should receive. In our case study, we could show that this approach results in reasonable prices compared to prices for balancing energy, which would otherwise have to be paid.

Further research should analyze the underlying risk and uncertainty structure in more detail. Moreover, in this paper, we have argued from the point of view of a power producer. An emphasis on the buyer, or the market structure and forces, might lead to very different results, which should be investigated as well, either in isolation or in an integrated manner. Another avenue for further research is, of course, the data used for the calculations. A broader and from time to time updated database might again lead to additional insights and might be worthwhile examining.

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