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The Influence of the Energy Spot Market on "On-the-Microgrid-Markets"

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THE INFLUENCE OF THE ENERGY SPOT MARKET ON "ON-THE-MICROGRID-MARKETS"

COMPLETE RESEARCH

Abstract

With the transition towards distributed energy resources (DER) for electricity generation, new applications for information systems arise in enabling the development of innovative business models for grid control and operation. IS enables the merging of DERs and energy consumers into microgrids. Microgrids increase efficiency, e.g. through shorter transmission distances. Cost-savings due to these efficiency gains can be distributed among microgrid-participants via an "on-the-microgrid-market" platform. However, due to differences in the power plant parks and fluctuations in renewable energy generation, energy prices on the "on-the-microgrid-market" (OMM) are likely to differ from energy prices on the spot market. Based on the varying prices in both markets, the supply- or the demand-side of the OMM may from time-to-time, prefer to trade on the spot market, which could cause the OMM to stop functioning. We develop an economic model to analyse the conditions, under which OMMs are a viable concept for energy trading. *Our results indicate that OMMs can indeed function in competitive energy markets.*

1 Motivation

The increasing deployment of intermittent resources, such as sun and wind is burdened with high costs and poses considerable challenges for power system reliability (Annual Energy Outlook, 2013). Applying intelligent information systems (IS) to these challenges appears promising (Depuru, Wang, Devabhaktuni, & Gudi, 2011). Especially since IS enable the merging of loads and distributed energy resources (DER) into local microgrids (Piagi & Lasseter, 2006). A microgrid is a single controllable entity of the main grid that can also disconnect and work in stand-alone mode. Its compact scale allows for various benefits such as better grid management and fewer costs for energy transmission (Bertolini, Giacomini, Grillo, Massucco, & Silvestro, 2010). Large utility consumers already deploy microgrids in practice, e.g. ports (Burns & McDonnell Engineering Company, Inc., 2014) or local energy cooperatives (Ohio University Compass, 2013).

In most microgrids, suppliers only provide energy to consumers. Yet, with adequate IS, generators and loads could also trade automatically with each other on an "on-the-microgrid-market" platform. Considering fewer maintenance costs within microgrids, an "on-the-microgrid-market" (OMM) could allow suppliers to "sell at prices higher than the prices at wholesale level and end consumers could buy at prices lower than the retail level" (Schwaegerl & Tao, 2014, p. 276). As such, the concept of OMM would be economically attractive for both market sides.

Yet, one aspect has been largely neglected so far. The power plant park of a microgrid is typically less diverse and has a higher share of intermittent resources than the power plant park of the energy spot market. Trade on an OMM will only thrive if participants are not trading at a disadvantage. In other words, an OMM's long-term success depends on whether participants are able to trade at least at the same prices and quantities as on the spot market. The rationale behind this assumption is simply that suppliers will stop trading on the OMM if they are able to realize greater profits on the spot market and that consumers will stop trading if they incur lower costs. This would lead to a failure of the OMM.

In our definition, a closed OMM prohibits trade with the spot market and balances residual energy and loads with storage devices. In contrast, an open OMM exchanges residual loads and energy on the spot market and suppliers and consumers are free to choose between trading on the spot market or on the OMM[1].

Given an open OMM, spot market prices are likely to affect OMM prices. The objective of this paper is analyzing whether attractive prices, for both suppliers and consumers, can form on an open OMM under these conditions.

Hence, our research question is: "Under which conditions, if any, are open OMMs a viable concept for energy trading?" To answer our question, we develop an economic model and evaluate the influence of energy exchange between the OMM and the energy spot market on OMM prices. We analyze the full range of scenarios that can occur, i.e. in a closed OMM, prices can be lower than, higher than or equal to spot market prices at any point in time.

2 Model

For a start, we developed a base model of the OMM, consisting of the following six assumptions:

A1 *The supply-function of the OMM is continuous, twice differentiable, strictly increasing and convex*

A2 *Aggregate demand in the OMM is given*

A3 *We assume perfect competition between suppliers in the OMM, so that the aggregate- supply-function is determined by the generators marginal production costs (merit-order function)*

A4 *We assume that suppliers are generally capable of generating at least enough energy to supply aggregate demand in the OMM.*

A5 *For simplicity, we abstract from grid bottlenecks and other physical constraints, which influence market prices and trade between the microgrid and the spot market*

A6 *For simplicity, we assume that there are only two alternatives for trade, either the spot market or the OMM. Trading on the spot market causes transaction costs to the customer* $c > 0$

[1] Current regulations in many countries ban consumers and small suppliers from trading directly on the spot market. Instead, they contract with utilities via the retail market. Our work is based on the view that regulatory frameworks are subject to change; indeed, current debates about the utility status of microgrids in many countries make it appear probable that fundamental changes are imminent (Costa, Matos, & Lopes, 2008). We therefore abstracted from current regulatory frameworks. This arguably reduces the direct applicability of our model to specific real-world energy markets, but we feel that this is outweighed by its generalizability and flexibility in modelling.

We define the following prices and costs (prices and costs are per unit, e.g. €/kWh):

P_{OMM}	Market price in a fictively closed OMM
P^*	Market price, which forms on an open OMM through interaction between the OMM and the spot market
P_S	Spot market price / price OMM-suppliers get, if they sell on the spot market
$(P_S + c)$	Spot market purchasing price / price OMM-consumer have to pay, if they purchase energy on the spot market

Figure 1 shows our base model.

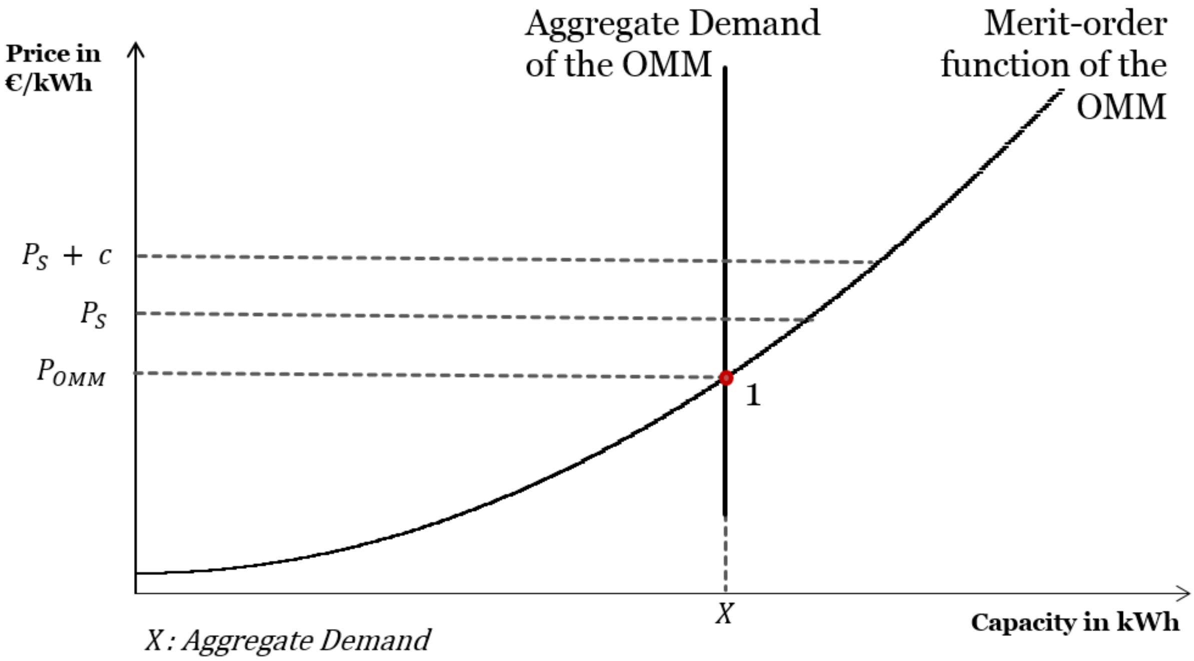

Figure 1: The base model of the OMM

In line with common practice in modelling energy markets, we model suppliers in the OMM to be uniformly paid, according to the price-setting unit in the OMM (1). Our analysis adopts a cost-based perspective, abstracting the model from current regulatory frameworks and market distortions such as negative prices.

3 Model Application

In our analysis, we assess which market price P^* would form, given P_{OMM} and P_S.

Scenario I: $P_{OMM} \leq P_S < (P_S + c)$

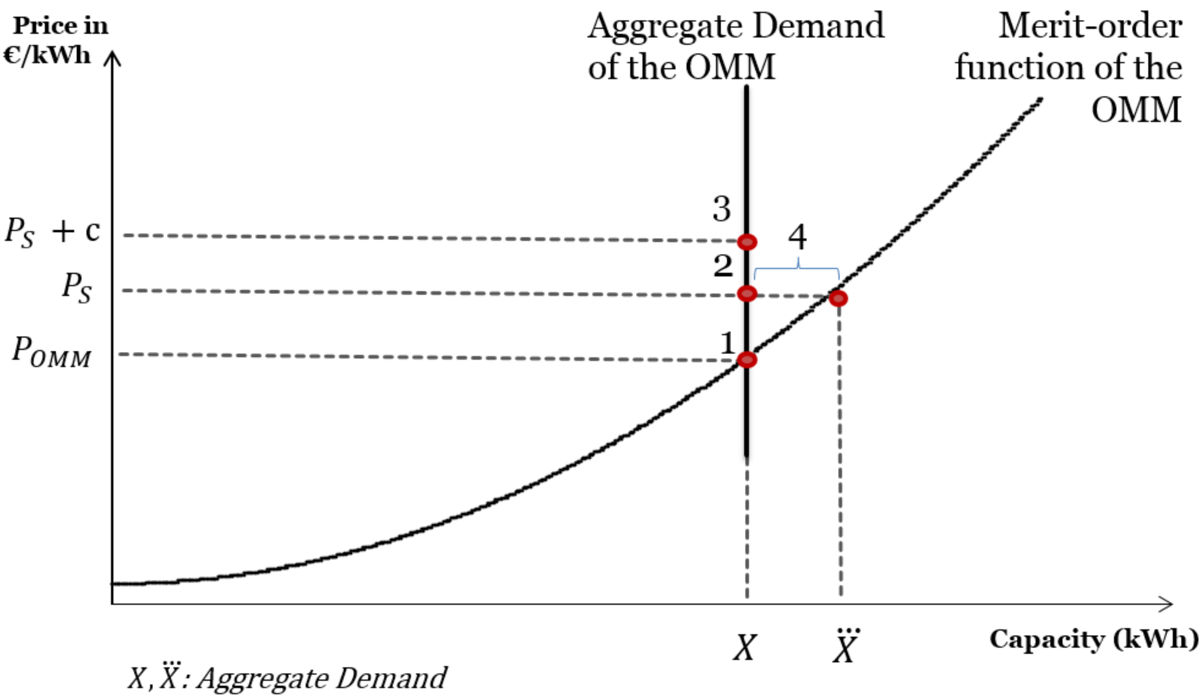

Figure 2: The market price in the closed OMM is below the spot market price for energy

Figure 2 illustrates scenario I. If OMM-suppliers (1) can serve demand at a lower price than the spot market (2), trading on the spot market would be more profitable for them. Hence, in open OMMs, suppliers' willingness to trade on the OMM starts at $P^* \geq P_S$.

In turn, if there was no OMM, consumers (3) would have to purchase energy at price $(P_S + c)$. Considering this as their maximal willingness to pay, $P^* \leq (P_S + c)$. Consequently, $P_S \leq P^* \leq (P_S + c)$.

The perfect competition among suppliers prevents them from exploiting consumers' maximum willingness to pay. $P^* = P_S$ will form in the open OMM.

When trading on the OMM, consumers benefit by more attractive prices, compared to the spot market. Suppliers have no disadvantage when trading on the OMM as they can sell as much energy at the same price as before. Excess supply (4), which can be produced by suppliers at P^*, is traded on the spot market.

Scenario II: $P_S < P_{OMM} \leq (P_S + c)$

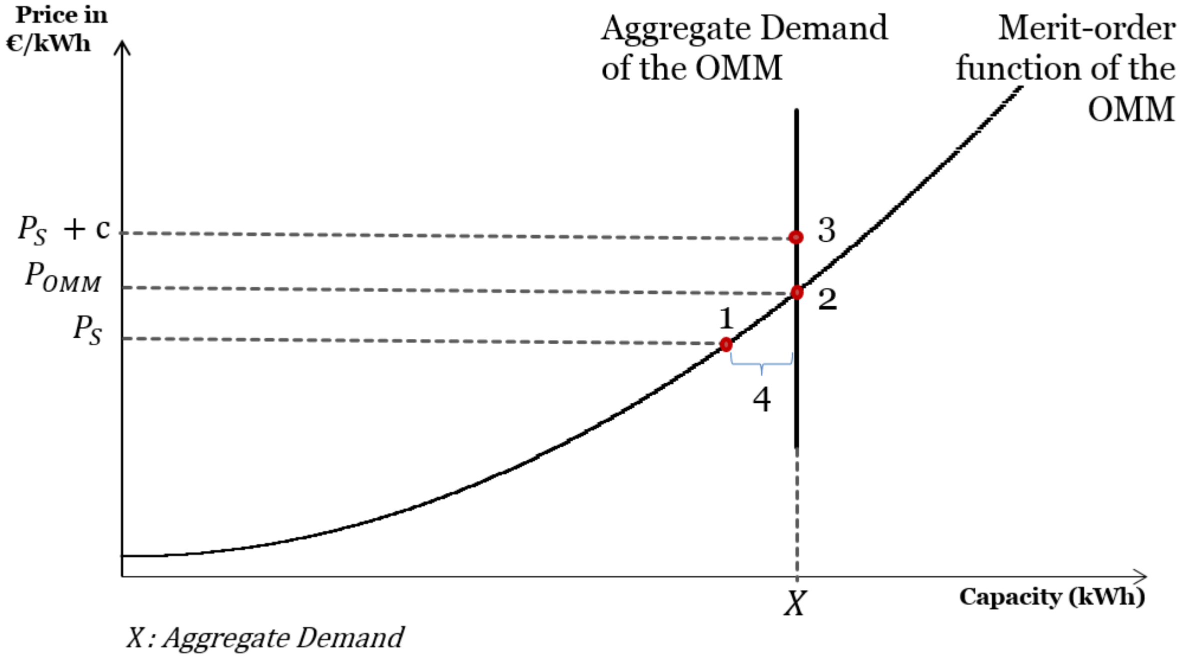

Figure 3: The market price in the closed OMM is in between of the spot market prices for energy

Figure 3 illustrates scenario II: the spot market (1) provides demand at a lower price than the OMM (2). Yet, based on the transaction costs, purchasing supply on the spot market would be more expensive (3) than purchasing it on the OMM (2). Consequently, neither consumers nor suppliers have an incentive to trade on the spot market, which is why $P^* = P_{OMM}$.

When trading on the OMM, consumers benefit by more attractive prices, compared to the spot market. Suppliers (4) also benefit from trading on the OMM instead of trading on the spot market since they can sell more energy at a higher price on the OMM.

Scenario III: $P_S < (P_S + c) < P_{OMM}$

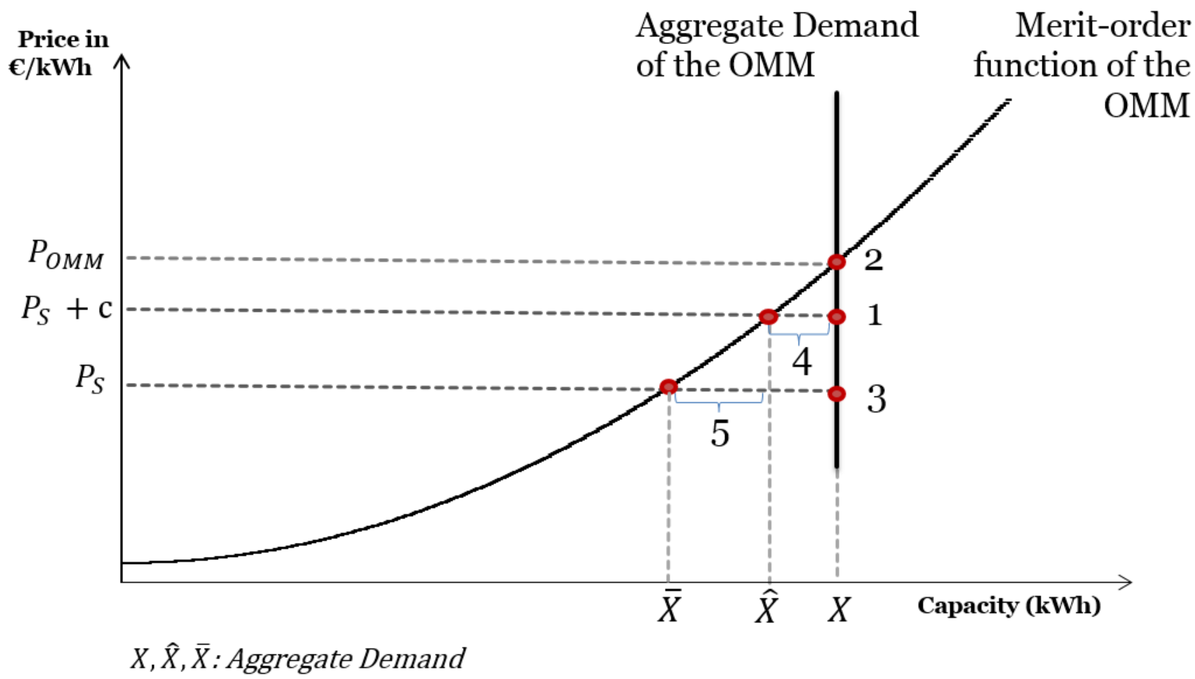

Figure 4: The market price in the closed OMM is above the spot market price for energy

Figure 4 illustrates scenario III. If the spot market (1) can serve demand at a lower price than the OMM (2), trading on the spot market would be more beneficial for consumers. Considering this as their maximal willingness to pay, consumers stop trading on the OMM if $P^* \geq (P_S + c)$. Suppliers (3) would get P_S, if there would be no OMM. Hence, suppliers prefer trading on the OMM as soon as $P^* \geq P_S$. Consequently, neither consumer nor suppliers have an incentive to trade on the spot market, if $P^* = (P_S + c)$.

Compared to the spot market, consumers have no disadvantage since residual demand (4) can be bought on the spot market at the price as before. Suppliers benefit from trading on the OMM due to a higher price and a larger capacity utilization (5).

4 Conclusion, state of research and future outlook

Our results indicate that open OMMs are a viable concept for energy trading. We find that consumers and suppliers do not necessarily trade at a disadvantage in open OMMs. Depending on the respective scenario, they can even benefit from attractive prices and higher capacity utilization. Since prices vary on both markets, the distribution of benefits among the participants is likely to fluctuate too, so that everyone profits from time to time. A quantitative assessment of the probability of occurrence is of further interest for our research.

In order to increase the applicability of our base model to real-world energy markets, we will relax its inherent assumptions step by step. Specifically, we have already developed models that relax assumptions 2-4.

First, we relaxed the assumption of inelastic demand functions. In case of direct trade like in the OMM, where consumer are exposed to price fluctuations, elastic demand is a more realistic assumption (Kirschen, Strbac, Cumperayot, & de Paiva Mendes, 2000). We therefore analyzed this effect on P^* and found our results of the base model confirmed. Nevertheless, consumers generally prefer payment schemes like flat tariffs or usage-dependent tariffs (Dütschke & Paetz, 2013) that shield them from fluctuations on the spot market. Since tariffs usually are a reflection of average costs, our analysis is informative for the development of tariff structures for microgrid operators. In addition, this may be promising for behavioral research, to inform the development of automated bidding routines, which act in accordance with the preferences of individuals and might increase the acceptability of OMMs.

Second, we lifted the assumption of perfect competition. Depending on the size of a microgrid, different market types may emerge. In larger microgrids, for instance villages with many PV modules, wind turbines, or biogas plants, it may be realistic to assume perfect competition on the supply side. In smaller microgrids, for instance ports with but a few PV modules and a diesel generator, monopolistic market structures may be more realistic. The results of our analysis indicate that consumer do not trade at a disadvantage even in case of monopolistic market structures, given an open OMM.

Finally, we adapted our base model to cases in which the closed OMM is not self-sufficient and needs purchasing energy on the spot market. This restriction is unrealistic for cases like microgrids with a large share of RES where generation capacity fluctuates along with the availability of natural fuels. We find that even in such cases neither suppliers nor consumer face a disadvantage while trading on an open OMM.

Subsequently, we will lift the remaining assumptions to further improve the real-world applicability of our model. Moreover, we plan to adapt the model to different real-world applications, e.g. energy cooperatives, where participants might follow a different code of conduct than purely rational agents do.

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