Automated direct marketing of small amounts of renewable energies (As of 2022)

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Abstract

With the expiry of the EEG funding, the question of (continued) economical operation arises for smaller PV systems with increasing urgency. The direct marketing of the PV yields, which is common in larger systems, requires too much material and personnel effort in order to be economically viable for small PV systems. We therefore developed standardized interfaces for fully automated trading in small quantities of renewable energies and implemented them as prototypes. An offer for the sale of the expected PV surpluses is made on the supplier side at the beginning of the day and automatically transmitted to an energy broker. Time-flexible buyers of such amounts of energy, such as charging stations / electric vehicles or households with heat pumps, send purchase requests to the energy broker. The energy broker carries out a matching, establishes a virtual connection between seller and buyer, coordinates the proof of simultaneous feed and draw, if necessary, observes conditions regarding the maximum distance between the trading partners (4.5 km limit), and regulates the billing including taxes and grid fees. Standardization of the interfaces ensures competition between energy brokers. After one-time registration with the selected energy broker and configuration of, e.g. targeted minimum and maximum prices, all components involved work fully automatically. This means that transaction costs are so low that trading with just a few kWh per transaction is economically viable.

1 Motivation

Germany so far covers only about 19.7% [7] (as of 03/2021) of its primary energy demand from renewable sources. A rapid expansion of these sources, especially wind and PV energy, is therefore urgently needed to meet the climate protection targets. In particular, the potential of millions of private rooftops should be harnessed to generate PV energy, even beyond self consumption. In fact, the expansion of PV energy generation for small systems beyond self consumption is hindered, e.g. through regulation obligation [1, §9] (70% limit), EEG levy on self-generated PV electricity [1, §61], and requirements for direct marketing of PV surpluses that are not economical for small systems. Currently, operators of older photovoltaic systems, for example, face the challenge of finding a suitable way to market the electricity they generate at the end of the EEG subsidy period. Guaranteed purchase by the grid operator is likely to be possible only until 2027, and the remuneration of subsidized PV systems is very low, which quickly makes the continued operation of the system unprofitable. Anyone seeking higher remuneration and wanting security beyond 2027 will have to market the surplus directly, which as things stand requires the installation of expensive metering technology. Even though simplifications are currently being worked on at the political level [2] - regulations for the economically viable development of the entire PV potential beyond self consumption are not in sight. In parallel, a shift of more and more primary energy from the heat and transport sectors to the power sector is taking place through the proliferation of heat pumps and electric vehicles. Both types of consumers - which are very welcome for energy efficiency reasons - mean new loads for the power grid, but they also bring a valuable characteristic: Time flexibility. This makes them able to consume the midday peak yield of PV electricity from the grid in a decentralized manner and thus without grid expansion - if only these new types of consumers can be motivated to behave in a way that serves the grid.

2 Concept

Our energy broker (Energie-Broker) shows a technically viable alternative how PV surpluses even of small but very numerous PV plants can be marketed in an economically acceptable way through consistent digitalization and automation. The new, flexible consumers/customers are motivated to participate by favorable prices, the providers by the prospect of more attractive returns. The energy broker implements an extreme form of time-variable electricity tariffs without a major technical effort, in a purely decentralized and thus data-protection-friendly manner, and by means of proven market-based mechanisms.

The required software on the supplier side generates a daily yield and consumption forecast, Figure 6. From the difference, it forms the surplus forecast for the starting day and uses it to generate an offer, optionally with a minimum price per kWh, for the expected surplus energy quantity available for sale in a specified time window and with a specified maximum wattage. This requires regular reading of the relevant electricity meters. For electronic meters, the optical SML interface is already sufficient. A smart meter gateway can be helpful, but is not a requirement. The software can be operated inexpensively, e.g. as part of an already existing HEMS (home energy management system) or on existing hardware (such as DSL routers) or dedicated simple hardware, such as a Raspberry Pi.

On the customer side, the required software is located, for example, in a HEMS that controls a heat pump (with heat storage) or in a electric vehicle charging point/wallbox. It creates a request for a certain amount of energy for a given period of time. As an example, consider an electric car that is plugged in at the employer's parking lot in the morning and tells the charging station that it wants to be fully charged by 4 p.m., with a minimum of 10 kWh. The server of the energy broker now arranges offers and requests that match each other in terms of space, time and price. If a deal is struck, the offer and request are binding; until then, they can be changed at any time. Once the bid has been accepted, the supplier reports the feed-in power of the current time slice to the broker. The broker forwards it to the customer, who regulates his withdrawal accordingly. AC charge points for electric vehicles can adjust the charging current in rough steps for this purpose; more precise controls are possible via ISO 15118. The time slices are selectable, but last a maximum of 15 minutes; a much faster cycle is to be aimed for. Each transaction thus forms its own balancing group. The possibility described by Maasmann [4] of using one's own PV electricity remotely to charge one's own vehicle is strongly generalized by the energy broker. "Pacta sunt servanda" also applies here: If the supplier does not deliver the promised amount of electrical energy in the specified time, the difference is contributed by the grid supplier and the additional costs are attributed to the supplier. A buyer who terminates the withdrawal prematurely or unnecessarily cuts off the withdrawal power, will still be charged the full amount of the accepted offer. Since transactions are not anonymous, but occur only between trading partners previously registered with the broker, billing is technically easy to implement, for example, through monthly invoices from the energy broker to the members.

2.1 Actors

Seller

A seller (Fig. 1, (1)) offers surplus renewable energy for sale through an energy broker (6). The surplus is calculated using the models explained in section 3.1. A seller or a HEMS can also be a buyer and thus also post requests on an energy broker [6], although not simultaneously.

Buyer

A buyer (Fig. 1, (2)) sends requests to an energy broker and purchases electricity directly from the generator via the distribution network (7). Buyers are typically time flexible and controllable loads, such as charging stations, heat pumps with heat storage, or other battery storage. There is also the possibility that a buyer is also a seller of electricity [6].

Energy Broker

The Energy Broker (Fig. 1, (6)) provides a platform for automated trading of smaller amounts of renewable energy as well as all necessary functionalities for authentication, transaction processing and billing[6].

Basic supplier

A basic supplier (Fig. 1, (3)) is an energy supply company which is responsible for the basic supply of all households in its catchment area according to the Energy Industry Act §36 [6].

Distribution system operator

The distribution system operator (Fig. 1, (5)) provides the electricity grid and is responsible for its maintenance. In the context of this work, transmission fees are to be paid.

Fiscal Authority

The fiscal authority (fig. 1, (4)) is involved regarding the taxes to be paid on the revenues of the sellers or the possible brokerage fee of the energy broker [6].

The actors involved and their tasks in the context of regional direct marketing are presented below [6].

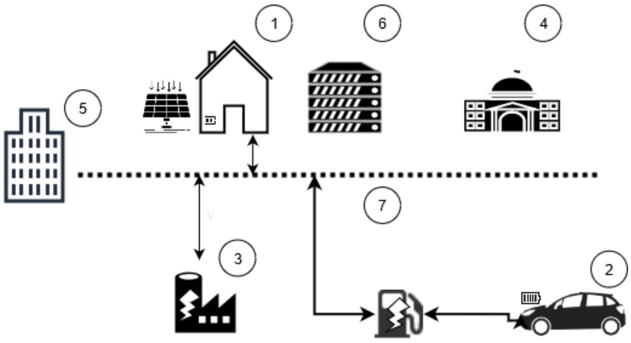

Figure 1 Actors and distribution network [6]

2.2 Principles

Standardized interfaces for fair competition and low-cost devices

To avoid a broker monopoly with excessive transaction fees, the aim is to have a broker market with fair competition. This requires customers to be able to switch easily between different energy brokers. This requires clear standards for software interfaces. Such standards also minimize implementation costs for equipment manufacturers, such as HEMS. Our concept also provides for a central administration unit (master server) as an option. It is intended to serve as a central point of contact for all customers and energy brokers and to ensure compliance with the standards.

Minimal transaction costs through consistent automation

Full automation capability shall be ensured for all processes. Once set up, providers and/or customers should only occasionally check their data after setting up their end devices (HEMS, BEV, etc.) once, and energy brokers should not have to intervene in operations – personnel costs would unnecessarily increase transaction costs.

Emergent grid-serving behavior through market-based trading mechanisms

Customers are motivated to purchase electric energy when it is abundant, such as PV surpluses at midday, through low prices and ease of operation. There is no need for central coordination or regulation by government agencies or grid operators.

Decentralized approach incl. data protection

Energy brokers do not collect any consumption data from provider households that could be used to draw conclusions about lifestyle habits. Energy brokers are potential “data collectors”, but they are in competition and have a high incentive to protect their customer data and earn trust.

Regional marketing

Energy brokers know the locations of their customers and can therefore very easily ensure that PV energy is indeed traded regionally. Matching rules are quickly adaptable to changing regulatory requirements, such as a new interpretation of the “spatial context” of trading partners.

3 Technical implementation

To implement the standardized interfaces of an energy broker, a research setup was realized at RheinMain University. Here, a PV system assumes the role of a seller and a wallbox the role of a buyer. The energy broker is operated on the university’s infrastructure. The remaining actors are simulated in this research setup.

The following technologies are used for the standardization designs.

REST

Communication between all actors is implemented using REST APIs. During an active trade, notifications are exchanged, e.g. via WebSocket connections between the seller and the energy broker, and between the buyer and the energy broker.

XML

In order to simplify the exchange of data between all involved actors and to be able to check the formats accordingly, the interfaces were defined using XML schemas. On the one hand, this enables fast machine processing, and on the other hand, the XML documents generated from the implemented interfaces can be formally validated using the XML schemas.
So far, 11 interfaces between the actors have been identified and defined. The definitions of the interfaces have been made separately according to actors and so far map a

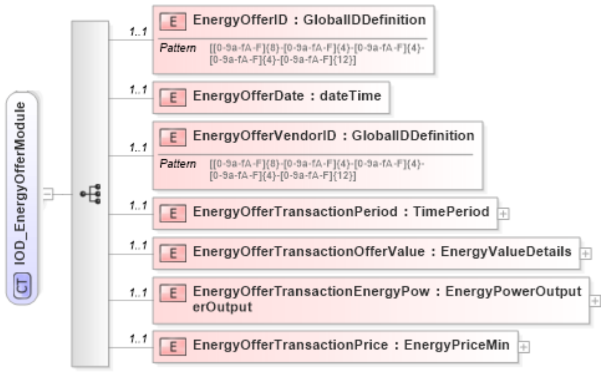

Figure 2 XML data type of a sales quotation

total of 90 use cases. The transferred data resp. data types are defined via corresponding XML schemas, see figure 2.

Machine Learning (ML)

Household consumption forecasting is implemented using Machine Learning. Currently, the K-Nearest Neighbors model is used for this purpose. If the availability of large amounts of datasets to train the ML models improves, we will re-evaluate which ML model is most appropriate. In the future, the yield prediction will be supported by machine learning to take into account influences such as shading, etc.

3.1 Forecasts

The forecasts are composed of three parts: The yield forecast, the consumption forecast and the yield surplus forecast resulting from these two.

$$YieldSurplus = Yield - Consumption$$

The consumption forecast is done by a KNN ML model, which gives good results. For the yield forecast, a simple physical model, taking into account weather forecasts, has been relied on so far. [3]

date	yield forecast	yield measured	consum. forecast	consum. measured
23.08.	12,1 kWh	11,3 kWh	4,2 kWh	5,2 kWh
24.08.	9,7 kWh	8,9 kWh	2,3 kWh	3,3 kWh
25.08.	11,0 kWh	7,7 kWh	2,2 kWh	2,2 kWh
26.08.	12,6 kWh	7,0 kWh	2,0 kWh	2,0 kWh
27.08.	11,7 kWh	12,6 kWh	3,9 kWh	4,8 kWh

Table 1 Forecasts and actual values [3]

Fig. 3 and 4 show initial results of the implemented procedures. The discrepancies between the predicted and actual values are largely due to the yield prediction. A more sophisticated model with better weather data, among others in cooperation with the DWD and with [5], will provide better results and is in preparation.

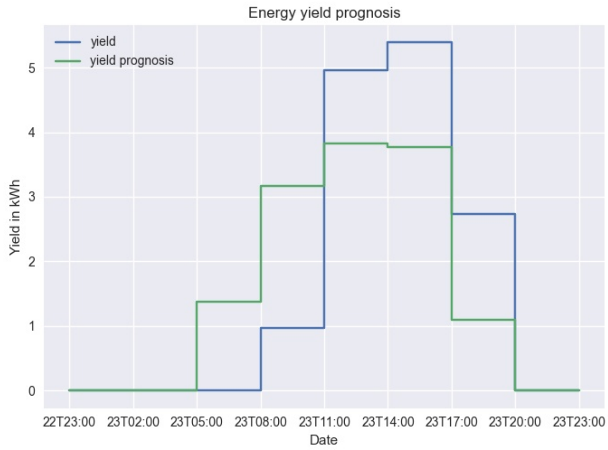

Figure 3 Yield forecast 23.08. [3]

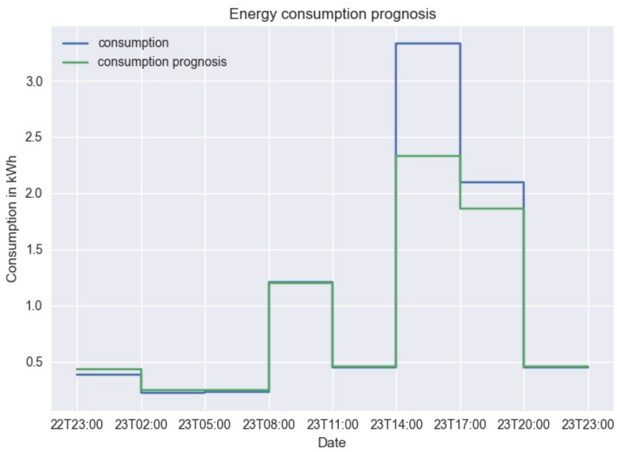

Figure 4 Consumption forecast 23.08. [3]

3.2 Procedure

To produce the most accurate forecasts possible, several ML models are pre-trained to cover the most common household types. The HEMS then obtains the appropriate ML model from an external server based on its collected data and then runs it locally. At the current time, ML-based forecasting is limited to consumption forecasting.

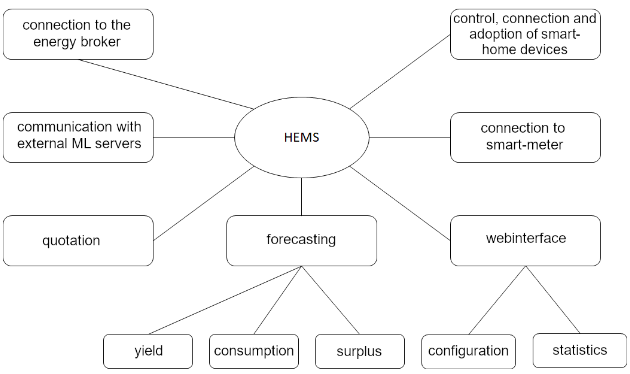

Figure 5 Overview of HEMS functionalities [3]

With the locally generated forecasts, offers are formed for the energy broker and kept up to date until they have been brokered or revoked. If an offer is brokered, the energy broker notifies the trading partners in a binding manner that a transaction has been concluded. For the duration of this transaction, the partners inform the broker in fixed time slices what quantities of energy they have fed in or withdrawn, see section 3.2.2 and Fig. 6.

3.2.1 Example: Sequence of a sale

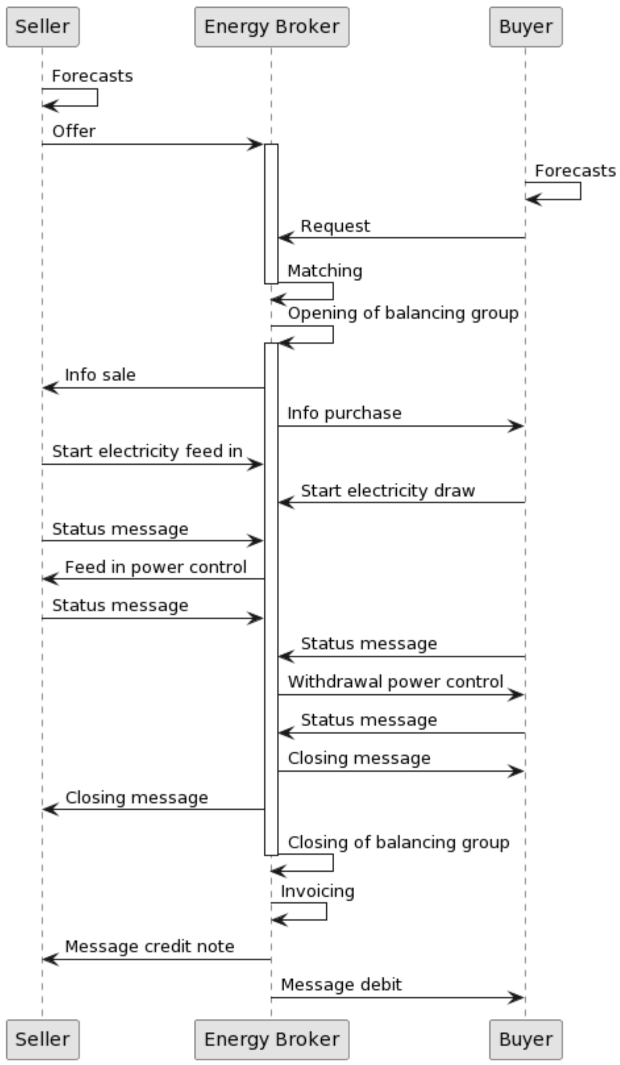

Figure 6 Simplified transaction process

The simplified sequence shown in Figure 6 illustrates the basic structure of a successful trade. Offers and requests are mediated by the energy broker. As long as trading is active, it is managed as an active balancing group. Power feed-in and power draw are regulated in such a way that the feed-in corresponds to the draw (simultaneity proof), see 3.2.2 . If the buyer ends the procurement or the end of the agreed trade is reached, the balancing group is closed and the collected data is used for billing.

3.2.2 Control of withdrawal power

For each time slice (max. 15 minutes), the supplier reports the instantaneous or foreseeable feed-in power as well as the amount of energy fed in during the last time slice to the broker. At the same interval, the buyer reports its planned

next power draw as well as the amount of energy withdrawn during the last time slice. The broker responds with a specification for the withdrawal power of the new time slice. This can deviate from the reported feed-in power. The buyer then regulates his withdrawal power for the new time slice as closely as possible to this specification.
The energy broker updates the reported energy quantities and, if necessary, intervenes to reduce the carryover between time slices as quickly as possible. This is done by notifying the buyer of a deviating withdrawal rate.
If it becomes foreseeable that the committed energy quantity can no longer be withdrawn by the scheduled end of the transaction, the energy broker is authorized and also obligated to increase the withdrawal capacity in a timely manner. Necessary energy differences are purchased from the regular electricity market and charged to the provider.

3.3 Behavior in the event of malfunctions

Sellers, brokers and buyers rely on stable network connections. Network disruptions are treated as rare events. Because of the small trading amounts per transaction, and to keep system costs low, simple fallback rules are agreed upon:

- In case of temporary connection failures, the buyer uses the key data from the offer. In particular, it is bound to the maximum power specified there (averaged over a time slice).
- In case of persistent disconnection during an ongoing transaction, all parties behave according to the contract conclusion, i.e. they feed in over the scheduled time or take out the agreed amount of energy respecting the maximum power.
- If possible, the transaction data is subsequently reported to the broker after the connection is restored.
- If not, the transaction will be billed based on the reported data until the connection is terminated and beyond as if it had been fulfilled according to the contract (if possible).

4 Discussion

4.1 State of development

The required interfaces were designed in detail based on REST and implemented prototypically with open source software. A software demonstrator (Fig. 7) and a simplified hardware model were created to communicate the energy broker principle. A simple model and weather data based yield forecast was developed, and initial machine learning based models for self consumption forecasting are currently being validated.

4.2 Challenges

For trading small amounts of energy via a broker, neither an expensive installation of meters with calibrated time measurement nor a shutdown device for excess supply is

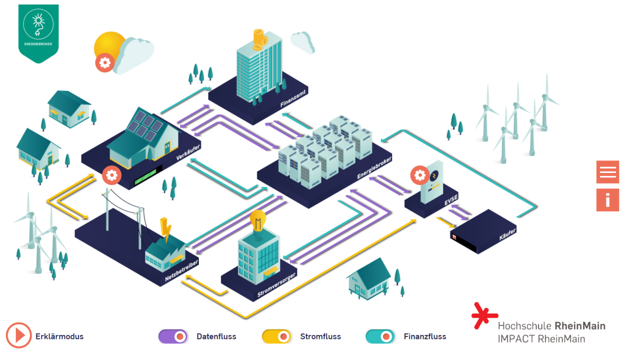

Figure 7 Energy Broker Demo

required, because the broker already takes care of the proof of simultaneity and the balancing of the formed balancing groups. Unfortunately, these cost-driving devices are mandatory in Germany when trading PV surpluses, even for small quantities. Up to now, an EEG levy would also have to be paid for PV surpluses traded in this way. This regulation contradicts the creation of incentives for the rapid expansion of renewable energy sources and also reduces the incentive to use an energy broker. The energy broker concept provides a financial incentive to build PV capacity even beyond the respective own demand. It is surprising that, on the one hand, this expansion is urgently needed for the energy transition, but is still hindered by regulation.
While HEMS or low-cost control units could allow providers to connect to energy brokers relatively easily, ease of use by electric vehicles is more difficult to achieve. For a user-friendly "plug & charge" to emerge, both charging station and vehicle software, and ultimately the ISO 15118 standard, need to be expanded and therefore the automotive industry is needed as a partner.
Yield prediction has proven to be technically challenging. There is still room for improvement in modeling shading effects as well as in the precision of the predicted solar radiation during the course of the day.
Finally, the potential problem of manipulation of exchanged reporting data by uncooperative market participants has not yet been addressed in detail.

4.3 Prospect

In the university's own research setup (section 3), we simplify the integration of electric vehicles as customers of an energy broker using ISO 15118-based dialogs. First field tests ("living labs") are currently prepared. For the operation of the energy brokers we strive for a cooperation with suitable partners from the energy industry. To improve the yield forecasts, a closer connection to data of the weather services is in progress. To improve the data situation for the machine learning algorithms, a data collection involving voluntarily participating households is currently underway.
Due to the climate protection goals of the German government, we expect the reduction of regulatory barriers and the discussion of new possibilities, such as the energy broker, to ensure the continued operation of PV systems

that have been subsidized, as well as to create an incentive for the installation of PV systems beyond the household's own needs. We interpret the great interest of our partners from the field in a virtual field test under real conditions as a strong indicator that energy brokers, such as the one we have developed, could make an effective, inexpensive and technically comparatively easy-to-implement contribution to solving the growing challenges of the energy transition.

5 Literatur

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