Coordination of community electricity markets and distribution network operation

COORDINATION OF COMMUNITY ELECTRICITY MARKETS AND DISTRIBUTION NETWORK OPERATION

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ABSTRACT

Community electricity markets are dedicated markets in which small electricity prosumers can directly trade electricity among themselves. The interest in such markets is growing in recent years as indicated by the increasing number of research studies, pilot projects and commercial implementations of community markets. The large-scale deployment of community markets may contribute to problems in the distribution grid, in combination with the increased electrification of the energy demand. Therefore, a coordinated approach with the DSO's operational activities is preferred in order to avoid network problems. This paper proposes a method for such coordination that is straightforward, effective and considers the electricity deregulation. The results of the case study demonstrate how flexibility from prosumers can be utilized by the DSO to solve network problems. The coordinated approach has a small negative effect on the community market which can be overcome with adequate remuneration policy.

INTRODUCTION

The increasing number of prosumers in the energy system opens the possibility for the development of new, user-centric market models. Community markets in which a group of prosumers can trade electricity among themselves are one type of such markets [1]. Especially for residential prosumers that enable the direct participation of prosumers in dedicated electricity markets. To facilitate the energy exchanges, participants use energy management systems that offer decision support and have control capabilities over a number of household devices, such as electric vehicles. This controllability and market clearing signals will have an impact on the behavior of the residential market participants and their corresponding power injections and withdrawals. Due to the separation of the market and network operation activities, the community market operates unaware of the conditions in the distribution network. This can cause problems in the low voltage (LV) network to which the market participants are connected, such as voltage deviations and line overloading.

It would be beneficial if there is some coordination between the market actions and the operation of the distribution network. First, such coordination will benefit the distribution system operator (DSO) as it will ensure that the distribution network is operated within the technical limits. Second, through this coordination, DSOs can tap into the flexibility of users in the LV network. Third, it will benefit the market operation which will not be compromised by grid outages or result in user complaints for causing network problems. Finally, the business case of community markets will not suffer from failure to deliver its commitments.

In the existing literature, the role of the DSO has been considered in different ways. A DSO is checking whether the trades do not surpass the technical limits of the network continuously in a continuous market in [2]. A DSO can more easily directly influence the outcomes of a community market if its role is combined with the role of a retailer, in an electricity utility as in [3]. In parallel to the research in community markets, flexibility markets are also an active area of research [4]. Therefore, methods that enable coordinated participation of prosumers in both markets are proposed recently [5].

This paper proposes a method for the coordination of the operation of community electricity markets and the operation of the distribution network. In order to perform this coordination in a realistic and practical manner, the division of activities by different stakeholders is taken into account. The method does not require multiple iterations and the communication of information between stakeholders is limited. The applicability of the method is demonstrated in a case study using measurements and other data from residential prosumers as well as low voltage (LV) distribution network from the Netherlands.

METHODOLOGY

Overview

This paper proposes coordination of the operation of the community market and the distribution network while considering the separation of the non-regulated market-based activities and the regulated operation of the DSO. This is achieved by establishing communication between the DSO and the market operator. The overview of the process is shown in Figure *1*. A detailed description of the different steps and the coordination process is provided in the subsequent subsections.

Prosumers optimization

The community electricity market is comprised of a

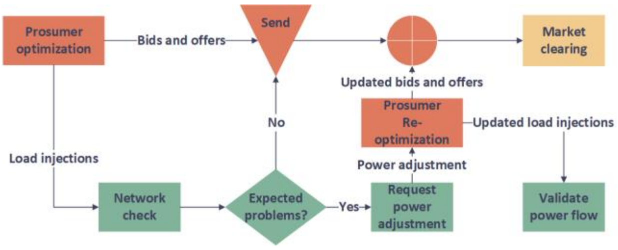

Figure 1 Overview of the proposed methodology

number of residential prosumers who trade among themselves. Prosumers can be both buyers and sellers of electricity at different moments in time. Moreover, prosumers can always choose to buy or sell electricity to their respective energy retailers, in addition to or instead of offering it to the community market. The participating prosumers engage in a decision-making process and determine their bids and offer which they submit to the community market. The residential prosumers may have PV panels and electric vehicles in addition to the household's inflexible load. The EV support vehicle-to-x and their (dis)charging rate can be controlled. The prosumers consider multiple objectives for their participation in the market, as well as the uncertainty related to their forecasted consumption and PV generation. The decision-making problem is cast as a multi-objective stochastic mixed-integer linear optimization. As an output, the quantities that are offered or requested to the community market or to the retailer are generated.

Community market clearing

The market clearing mechanism is a double-sided action, in which both buyers and sellers submit bids and offers, respectively, The market is cleared for every time interval with a single market clearing price per time interval and per product, i.e. the market clearing mechanism is pay-as-clear. In the case of insufficient liquidity in the market, the retailer of the prosumers acts as a balancing party and supplies or buys the quantity that is not covered by the market. The presented market is implemented in this study as a forward, day-ahead market. However, it can be operated in a near-real-time manner. This depends on the computational speed to perform the different steps in the process and the communication latency.

Network check

After the decision-making process of the prosumers is completed, they send their planned power injections for the next day to the DSO. This can be performed by establishing a direct data exchange between the DSO and the prosumers or indirectly, through the market operation. The net load injections include the both the planned net load for the community market and the retailer. Moreover, the DSO uses forecasts for the net load of other customers in the network that are not participating in the community market and thus do not communicate their planned injections with the DSO.

Then, the DSO performs a power flow analysis to determine whether some problems are expected in the network for the upcoming day. If that is the case, the DSO will request flexibility from the prosumers that participate in the community market to resolve the expected problems. The prosumers will be requested to adjust their net load injections and will be remunerated for providing such service to the DSO. In order to determine the required flexibility adjustments, the DSO solves an optimization problem. The model uses the relaxed branch flow AC optimal power flow formulation [6], i.e. it is cast as a second-order cone program (SOCP), as given in (1)-(9).

$$\min \sum_{t\in T}\sum_{i\in N}\left(c^{+}\Delta p_{i,t}^{+}+c^{-}\Delta p_{i,t}^{-}\right)+\alpha\sum_{t\in T}\sum_{ij\in L}\left(R_{ij}l_{ij,t}^{2}\right) \qquad (1)$$

Subject to:

$$P_{i,t}^{L}=P_{i,t}^{L,ini}+\Delta p_{i,t}^{+}-\Delta p_{i,t}^{-},\forall i\in N^{F},\forall t\in T \qquad (2)$$

$$Q_{i,t}^{L}=P_{i,t}^{L}\sqrt{(1-\cos^{2}\phi)/\cos^{2}\phi},\forall i\in N^{F},\forall t\in T \qquad (3)$$

$$\sum_{i:i\to k}\left(P_{ik,t}-R_{ik}l_{ik,t}\right)-\sum_{j:k\to j}P_{kj,t}-P_{k,t}^{L}=0,\forall k\in N,\forall t\in T \qquad (4)$$

$$\sum_{i:i\to k}\left(Q_{ik,t}-X_{ik}l_{ik,t}\right)-\sum_{j:k\to j}Q_{kj,t}-Q_{k,t}^{L}=0,\ \forall k\in N,\forall t\in T \qquad (5)$$

$$v_{j,t}=v_{i,t}-2\left(R_{ij}P_{ij,t}+X_{ij}Q_{ij,t}\right)+\left(R_{ij}^{2}+X_{ij}^{2}\right)l_{ij,t},\forall ij\in L,\forall t\in T \qquad (6)$$

$$P_{ij,t}^{2}+Q_{ij,t}^{2}\le l_{ij,t}v_{i,t},\forall ij\in L,\forall t\in T \qquad (7)$$

$$P_{ij,t}^{2}+Q_{ij,t}^{2}\le S_{ij}^{max\,2},\forall ij\in L,\forall t\in T \qquad (8)$$

$$v_{i}^{min}\le v_{i,t}\le v_{i}^{max},\forall i\in N,\forall t\in T \qquad (9)$$

The objective function (1) is to minimize the costs for the required increase ($\Delta p_{i,t}^{+}$) and decrease ($\Delta p_{i,t}^{-}$) in net load. The second term in (1) is added and multiplied with a small number to ensure that the SOCP relaxation of (7) is exact without having a large effect on the first term. The flexible prosumers can adjust their active and reactive net load as in (2) and (3) respectively. The relaxed branch flow equations are given in (4)-(7). The constraint in (8) limits the power flow in the lines and constraint (9) limits the voltage magnitude in all busses.

Coordination with network operation

The coordination between the optimization of the prosumers, the community market and the requests by the DSO is shown in Figure *1*. If the result of the network check is that no problems in the network are expected, then the prosumers proceed to sending their bids and offers to the community market, where they are cleared. However, if the network check determines that adjustments in the net load are necessary in order to avoid network problems, the required adjustments are sent to the respective prosumers. Then the prosumers reoptimize their planned energy usage. As a result, it is possible that their bids and offers to the community market are modified. In that case, the updated offers and bids are sent for market

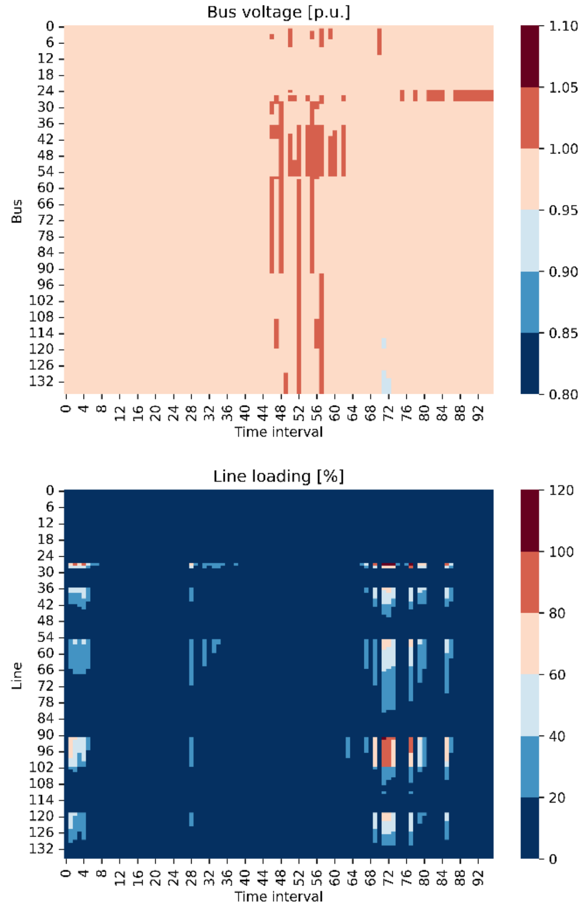

Figure 2 Power flow results before load adjustment

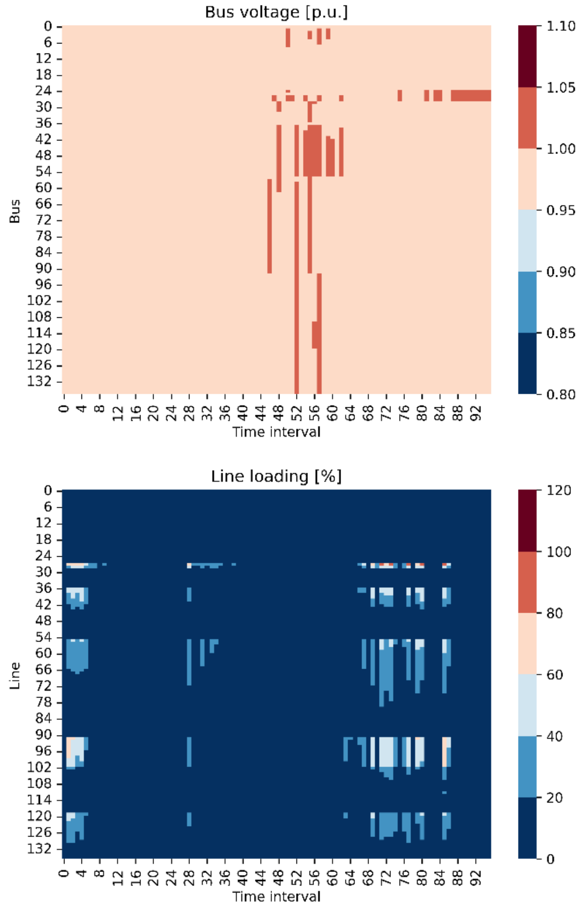

Figure 3 Power flow results after load adjustment

clearing. Moreover, it is possible that the electricity planned to be bought or sold to the retailer is also modified.

In this study, it is assumed that the prosumers will implement the required adjustments by the DSO if possible, without considering whether the financial benefit of the remuneration outweighs their other objectives. In practice, the power adjustments are incorporated as constraints in the re-optimization of the prosumers, with consideration of the limits imposed by the inflexible load and generation. As a final step, the DSO receives the updated planned load injections and performs another power flow to validated whether the requested adjustment are implemented and whether they succeed in preventing the expected problems.

CASE STUDY

Description and input data

The proposed methodology is applied to a case study for which data from the Netherlands is used. To model the prosumers connected to the distribution network, smart meter measurements from the month of August provided by a Dutch DSO are used EV charging profiles are extracted from the open dataset. by ElaadNL [7].The maximum (dis)charging rate of the EVs is 3.7 kW. Average retail electricity prices from the Netherlands are used.

The LV distribution network that is used is a typical Dutch suburban residential network. There are 129 residential customers that are connected to this network. It is assumed that 100 customers participate in the community market, whereas the remaining customers do not. The network is connected to the medium voltage distribution grid via 400 kVA 10kV/0.4 kV distribution transformer. The limits for the voltage magnitude are between 0.95 and 1.05 [p.u.].

Results

The power flow results from the network check with the planed load injections are shown in . In general, there are very few expected problems in the network. This means that the network is not severely affected by the increasing electricity demand due to EV charging nor it is negatively affected by the activities of the community market, even in the case when the majority of customers are active prosumers. Nevertheless, in the evening hours, there are

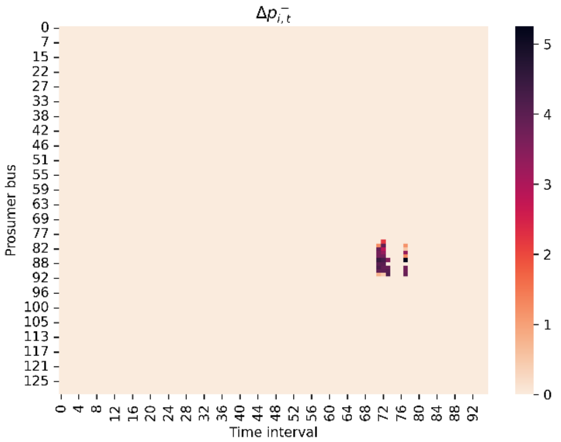

Figure 4 Power reduction requests by DSO

some undervoltage events. Moreover, around the same time intervals, some of the cables are overloaded. These problems can be attributed to the early evening peak and the fact that there is almost no electricity generated by the PVs. Finally, the distribution transformer does not get overloaded at any moment of the simulated day.

As a next step, the required adjustments are calculated using the optimization model in (1)-(9). The DSO only requires decrease in the net load injections to resolve the congestion and undervoltage problems in the early evening hours. The requested power reductions are shown in. Only few customers are requested to adjust their power and for small number of time intervals. This means that the impact of the proposed coordination on the customers is likely to be very limited. These adjustment are forwarded to the respective prosumers connected to those buses. They consequently reoptimize their electricity usage and generate new bids and offers which are forwarded to the community market.

The prosumers further communicate their updated net load injections to the DSO and the DSO performs another power flow to validate whether the undertaken actions prevent the forecasted problems. The results of this analysis are shown in **Error! Reference source not found.**. Both the undervoltage problems and the overloading of the cables are resolved. This means that customers were able to implement the required power adjustments and the flexibility they provided to the DSO was sufficient to resolve the problems.

Next, the influence of the power adjustments due to the requested flexibility on the community market are analyzed. The results of the market clearing using the initial bids and offers as well as the updated bids and offers are shown in Table Table *1*. The total electricity that is traded in the market is reduced after the adjustment. It is probable that some of the network

Table 1 Traded electricity and average market clearing price in the Community market.

	Traded electricity [kWh]	Av. market price [€/kWh]
Before adjustment	118.14	0.185
After adjustment	115.81	0.195

problems are partially due to planned trades in the community market. After the adjustment the bids and offers have been reduced which results in lower quantity that is cleared. The average market clearing price has increased after the flexibility adjustment. Due to the changes in the bids, the demand for electricity has shifted to other time intervals. The increased demand has resulted in higher market clearing price.

The reduction of the traded electricity in combination with an increased average market clearing price is a negative effect of the coordination between the market operation and the DSO operation. Due to the foreseen network problems in the case study, this change is an expected outcome. Nevertheless, the difference between the two situations is not very large. Simulations over longer period of time are required to determine the extent of the impact on the community market. The negative impact can be overcome by adequate pricing of the flexibility service provided by prosumers, which will make the power adjustment an attractive option for residential customer.

CONCLUSION

Coordination between the market activities of a community electricity market and the operational activities of a DSO are the focus of this paper. Uncoordinated functioning of the community market may lead to network problems, such as undervoltage and cable overloading. Therefore a methodology to integrate a network check and a request flexibility service by the DSO to solve expected network problems day-ahead is proposed. The proposed methodology takes into account the division of activities between the different stakeholders. The DSO requires prosumers to adjust their net load injections to prevent network problems. The prosumers implement these requests if possible. The proposed approach does not require multiple iterations. The provided flexibility is sufficient to resolve the network problems as shown in the case study using data and LV network from the Netherlands. Such coordination of activities has somewhat negative effect on the quantity and price that are cleared on the market. However, this can be compensated by an adequate remuneration for the provided service. Future work will consider the uncertainty in the power injections from the perspective of determining the required adjustments. Moreover, alternative ways for implementing the flexibility provision will be considered.

ACKNOWLEDGEMENTS

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