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THE CONCEPT OF AN ENERGY CLUSTER MODEL BASED ON THE PEER-TO-PEER ENERGY TRADING MECHANISM

Damian MROWIEC

PSE Innowacje sp. z o. o.
tel.: 511 374 439 e-mail: damian.mrowiec@pse.pl

Abstract: The idea of forming energy clusters in Poland is one of the initiatives supporting changes taking place on the energy market, which are related, among others, to the development of various municipal energy concepts. Therefore, progress in building local structures of power system is closely tied to the possibility of developing appropriate clearing mechanisms, which would contribute to the fulfilment of expected energy clusters' goals.

The development of information and communication technologies and, among others, the growing penetration of distributed energy resources (DER) in the overall generation structure resulted in the emergence of various concepts based on decentralized or distributed systems of direct purchase and sale of electricity between local producers and consumers.

This article presents a general operational concept of an energy cluster featuring in its clearing model a system of selling electricity on a peer-to-peer basis. Moreover, representative states of work were identified and characterized, along with the basic principles of proposed system's operation.

Keywords: peer-to-peer electricity trading, energy clusters, distributed energy, local energy communities.

1. INTRODUCTION

The gradual increase in the use of renewable energy sources and the growing number of prosumers on the electricity market causes the transformation of energy sector and development of existing solutions in this area, as well as creation of new ones. These concepts are aimed, among other things, at enabling more effective integration of these entities with the power system. Simultaneously, the concept of local energy communities is undergoing its development process, which leads to the emergence of diverse initiatives forming local structures of the power system. One of directions fitting into this trend, from perspective of the Polish national energy sector, is the formation of energy clusters.

Existing legislation and guidelines define these entities at a very general level, which allows a high level of flexibility in defining their detailed forms of activities [1, 2]. The effect of such situation is that the relations occurring between individual entities on the electricity retail market usually have the same form within energy clusters. The clusters' operation concepts, which are currently under development, are not yet implemented on a wider scale and they generally do not differ significantly from standard mechanisms.

The idea presented in this article is to introduce a new electricity trading and clearing system within the operating area of energy cluster, which would be intended for its participants. The fundamental principle of the proposed model is the implementation of mechanisms enabling the purchase and sale of electricity between local power producers, prosumers and consumers on a *peer-to-peer* basis (P2P).

Diverse concepts featuring the use of peer-to-peer energy trading systems have already been presented in the available foreign literature. Also, articles summarizing specific research undertaken in this area of study have been published as well [3, 4, 5]. These ideas are usually based on a very different approaches to the assumptions made and actions taken by particular entities, as well as taking into account different relations between them. Therefore, it seems crucial to explore this research from the perspective of Polish energy clusters, which are now being in their development stadium.

2. PEER-TO-PEER ENERGY TRADING WITHIN ENERGY CLUSTER

The presented concept is based on the idea of distributed energy trading and relies on the flexible possibility to settle the electricity sold directly to other consumers and purchased directly from other local producers or prosumers. In such a system, all participants are treated as peers and operate on an equal and the same rules. This means that any entity can join the system and thus take part in the process of mutual settlement of energy transactions, which is carried out on the basis of strictly defined mechanisms.

The possibility of distributed energy trading carried out automatically in the scope of one energy cluster allows system participants to achieve potential benefits, also on an equal terms. Furthermore, a peer-to-peer network makes it possible to eliminate entities which are responsible only for acting as intermediaries in the process of electricity trading.

From the perspective of energy cluster, an optimal clearing model should provide specific economic effects for individual entities. This outcomes can be characterized by two main dependencies, which have already been identified in the literature as key elements in order to achieve

desired objectives of energy clusters on the level of individual entities [6, 7]. These dependencies can be also applied to the P2P system functioning within the cluster.

First of all, the cost of purchasing a comprehensive service by members of the energy cluster participating in the P2P system, including the purchase of electricity and the cost of energy distribution, should be lower than in the case of customers operating outside the discussed mechanism. Secondly, the selling price of electricity for local power producers participating in the P2P system should be higher than in the case of power producers not participating in the proposed clearing system. Permanent maintenance of both of these dependencies would mean that individual electricity users would be able to achieve greater financial benefits compared to the current approach. The P2P system implemented in the energy cluster is treated as a basic element allowing to maintain the presented dependencies from the perspective of its participants.

The possibility to sell energy directly to located nearby local entities can be particularly important from the viewpoint of small power producers and prosumers. For example, owners of photovoltaic panels are very often unable to consume all of the electricity generated by these installations. In such a case, the optimal solution would be to sell the produced surplus energy to other consumers or prosumers who are not able to cover their needs with their own generation sources, during the same period. Similarly, consumers without any distributed energy resources could freely buy electricity from producers in the same energy cluster.

3. LAYER ARCHITECTURE OF PEER-TO-PEER ENERGY TRADING SYSTEM

Architecture of such model can be divided into two essential layers, on which particular activities are carried out. The first one is characterized by the virtual area and thus the clearing system, while the second one is related to the grid infrastructure and actual power flows taking place between specific entities.

On the virtual level, the first thing that takes place is the transfer of data describing the specific P2P system participants' level of demand and generation. This information is then processed by the clearing platform, on which all transactions and energy cluster balance are carried out. The basic operation principles of virtual platform were described in the next section.

In order to implement such solutions, it is necessary to use appropriate technologies enabling free flow of information and communication, and above all, it is necessary to equip individual entities with smart electricity meters. An important challenge in this area is to ensure complete protection of data from unauthorized access and ensuring appropriately fast data transfer.

The individual participant of the distributed electricity trading system should have access to the information related to operations taking place on the virtual platform. Such access can be granted to any physical entity in many ways. The simplest solutions include the use of a dedicated application or web portal, on which, among other things, verification of user's account and authorization of a specific entity would be carried out. This tool would contain all the necessary information, such as database of system participants with their generation potential, the level of demand and generation balance of the individual entity and the energy cluster in general, history of concluded energy transactions and the financial results of specific settlements.

The physical layer, on the other hand, is mainly shaped by the distribution grid owned by the local Distribution System Operator (DSO). Despite the fact that both calculations and clearing of electricity purchase and sale transactions are carried out in the virtual layer, the actual power flows between individual entities take place in the distribution network. The better the physical layer is represented in the model implemented on the virtual platform, the more accurate can be the operations carried out automatically and their effects, which result from the adopted clearing mechanisms.

It is important to emphasize that the energy transactions carried out between local power producers, prosumers and end users do not affect in any way the authentic supply of energy and the actual power flows in the grid, which are the consequences of known physics laws. Therefore, both layers are completely independent and separated from each other, but both virtual and physical layers are essential and needed elements of a peer-to-peer system.

4. BASIC FUNCTIONALITY OF PEER-TO-PEER ENERGY TRADING SYSTEM IN ENERGY CLUSTER

In order for a distributed energy trading system to operate correctly within the energy cluster, it is necessary to define the appropriate rules according to which the peer-to-peer system will be managed. Such a model requires, in the first step, automation of the process of carrying out individual operations. This paper presents a concept based on the management of the virtual peer-to-peer network through a dedicated clearing platform, functioning as a type of an IT system. The virtual platform can be treated as the core element of distributed electricity trading system. That is because all required operations are carried out and all necessary data flow takes place on this tool. The basic task of such system is to provide appropriate balance, in the clearing and settlement area, between the amount of electricity generated and the demand level of a given participants, in a given period.

An individual entity located in the area of operation of a specific energy cluster may make an optional decision to join the P2P system and to settle his consumed energy and injected into the electricity grid through the mechanisms on which the virtual clearing platform is designed. The choice of such electricity clearing method would be an alternative to the current mechanisms for members of the energy cluster. Therefore, this would account for a completely optional solution. The optimal case from the perspective of possible benefits of the whole cluster might be the participation of all of his members members in the P2P system. However, realistically, there would be a division of individual entities into users which are part of the proposed alternative solution and users which would remain within the current, standard mechanisms.

In case of individual participant joining the P2P system, all flow of information and particular settlements would be carried out between this entity and the platform. At the same time, this entity must be provided with an electricity supply service. For this purpose, the existing grid infrastructure owned by the local Distribution System Operator (DSO) shall be used. Therefore, in the fee collected from entities being participants of the P2P network,

it is necessary to take into account the relevant rates related to the use of electricity grid.

DSO, on the other hand, in the proposed solution may operate in a similar way as it already does, as well as participate in the P2P system. In the fist case, settlements between the distribution company and the P2P network would be carried out through the coordinator of energy cluster. In the second case, this process would be executed directly by means of the virtual platform, with which the DSO would communicate in the same way as other participants of the peer-to-peer system.

An important role in the presented concept is assigned to the coordinator of energy cluster. This entity can be treated as an independent operator of the virtual clearing platform. Therefore, the coordinator of energy cluster would be responsible for managing the platform operation and maintaining the energy balance of cluster in the settlement area, between its total demand and generation level. Activities of the coordinator of energy cluster in such system would mainly involve acting as an intermediary between all entities that are members of the cluster and external entities, as well as representing the P2P system participants on the external electricity market. From the perspective of balancing the energy demand of the cluster, the coordinator, in turn, would be responsible for purchasing the missing amount of energy from external sellers in case of its shortage or sale of energy in case of its surplus. Another task of the coordinator would be to conclude agreements with individual electricity users inside the cluster, who would like to participate in the peer-to-peer system. Thus, the coordinator would also operate as an aggregator of capacity of distributed energy resources, located in the energy cluster area.

As for the virtual platform, its main activity is to carry out calculations for a given time interval in an automated way, as well as matching sides of electricity purchase and sale transactions and balancing the demand of the entire cluster from the settlement perspective in the same time. Matching transactions should be carried out in the most optimal way from the perspective of the objective function, which in the analysed case is to minimize the total operating costs of the energy cluster. The optimal time interval for carrying out the full process of calculation and recording data should enable basic peer-to-peer system expectations to be met. First of all, this length of time should allow for sufficient reflection on the dynamics of changes in generation and demand level of individual entities. Secondly, registration of these values and their transfer, with the use of appropriate measurement infrastructure, should be possible as well. For example, reasonable and adequate time interval for the calculation cycle can be assumed to be equal of 15 minutes. Therefore, the virtual platform, based on information describing the total level of generation and energy consumption in the given 15-minute period, would carry out the operation process automatically after this period's finish.

In the context of method the energy sell and purchase transactions in the peer-to-peer system are conducted, the presented solution is based on the automated matching of particular transaction sides and their electricity volumes. The advantage of such solution is its simplicity from the perspective of responsibilities of a typical electricity user participating in the P2P system, because transactions are carried out automatically without its direct participation. Although this situation doesn't take into account the possibility of actual decision making by individual entities, it is necessary to achieve benefit on the community level. It means that prosumers or local producers would not be able to set the price at which they want to sell energy and end users would not indicate directly from whom they want to buy energy. However, the adoption of such model is necessary to work out the best economic situation from the perspective of the whole energy cluster, as well as P2P system and not for specific participants at the expense of others.

5. CHARACTERISTIC STATES OF OPERATION

Considering the basis operation of an energy cluster based on the model of energy trade in a peer-to-peer system, several characteristic states of operation can be identified. From the perspective of the whole cluster, it may have a surplus or shortage of produced energy in a given period of time. The first case means that all generation sources of the cluster generate more electricity, in a given period of time, than equals the total demand of end users located in its area. In such a situation, the excess of generated power is exported outside the cluster by means of a distribution network, while particular calculations are carried out by means of a clearing platform. The total amount of surplus energy in the whole clearing period is settled in the form of its sale on the external energy market with the use of standard known and already being in use methods. This activity is carried out by the coordinator of energy cluster, which in this case would operate as an independent electricity trading company.

The opposite situation occurs when the cluster has an electricity shortage, which would result from lower production of energy by cluster's generation sources in a given period than the total level of demand of its end users. The outcome of this situation would be the power import from beyond the cluster area by distribution network and estimating the level of cluster's energy demand, resulting from the produced energy shortage magnitude, by the virtual clearing platform. Thereafter, in a similar way as previously, the coordinator of the energy cluster settles electricity with external entities in the clearing period, by purchasing energy in the amount resulting from the determined shortage level.

From the perspective of an individual electricity user who is a participant of the peer-to-peer system as well, the general scheme of operation is similar. This entity may be a local electricity producer, a prosumer or an electricity end user. If the user, in a given calculation interval, generates more electricity than is his demand, the excess power would be injected into the distribution grid. Then, the corresponding amount of energy would be sold directly to another participants of the P2P system automatically through the virtual clearing platform. Local producer and the prosumer, who is not able to use for his own needs all of generated by his sources energy in a given period of time, are both treated in the same way by the virtual platform. Finally, when specific period of time finishes, costs and receivables are distributed among particular participants of transactions that were carried out.

On the other hand, a different state is when an electricity user who is also a participant of the P2P system has an electricity shortfall. In that situation, the user generates less energy than is his demand. From the view of peer-to-peer system, this case applies to both prosumers with energy shortages and typical electricity end-users.

The lack of power is being imported from the distribution network, whilst the process of carrying out particular operations is exactly the same as in the previous case. The virtual platform determines the total level of a given entity's demand for the last finished specified period of time. That demand level is equal to the magnitude of energy production shortage in case of a prosumer, whilst for an ordinary energy consumer it corresponds to his total electricity demand during this period of time. Thereafter, these entities buy electricity directly from other participants of the peer-to-peer system automatically through a clearing platform. As in the case of having surplus energy, the distribution of costs and receivables between individual entities is then carried out in the specified clearing period.

6. CONCLUSIONS

This paper outlines the general operation principles of energy cluster based on peer-to-peer energy trading system. However, no detailed aspects of carrying out these processes have been presented. This is mainly due to the fact that the content would be too large and it would exceed the bounds of a single article. In particular, it is necessary to specify and clarify actions to be taken by the virtual platform in given cases, as well as the calculations and clearing mechanism itself.

Another very important issue is the characteristic of technologies enabling presented solutions to be implemented. This refers mainly to the appropriate advanced metering infrastructure (AMI) and specific information and communication technologies (ICT). The potential in this area is placed especially in the distributed ledger technologies (DLT), such as blockchain. However, these are not yet fully developed and their possible future use on a wider scale is currently a certain unknown [8, 9].

These aspects mentioned above, as well as others that were not covered in this paper, are treated as a basis for future research in this area.

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KONCEPCJA MODELU KLASTRA ENERGII OPARTEGO NA MECHANIZMIE SPRZEDAŻY ENERGII W SYSTEMIE PEER-TO-PEER

Idea tworzenia klastrów energii w Polsce jest jedną z inicjatyw wspierających zachodzące na rynku energii zmiany, związane między innymi z rozwojem energetyki obywatelskiej. Postęp w zakresie kształtowania się lokalnych struktur systemu elektroenergetycznego jest więc silnie powiązany z możliwością wypracowania odpowiednich mechanizmów rozliczeniowych, których zastosowanie umożliwiłoby zrealizowanie zakładanych celów klasteryzacji.

Rozwój technologii informacyjno-komunikacyjnych oraz między innymi wzrastający udział generacji rozproszonej w strukturze wytwórczej skutkowały natomiast pojawieniem się koncepcji zdecentralizowanych lub rozproszonych systemów bezpośredniego przeprowadzania transakcji kupna i sprzedaży energii elektrycznej pomiędzy jej lokalnymi wytwórcami oraz odbiorcami.

W niniejszym artykule przedstawiono ogólną koncepcję funkcjonowania modelu klastra energii wykorzystującego w swoim mechanizmie rozliczeniowym system sprzedaży energii elektrycznej na zasadzie peer-to-peer. Ponadto, zidentyfikowano i scharakteryzowano reprezentatywne stany pracy przedstawianego systemu wraz z podstawowymi zasadami jego działania.

Słowa kluczowe: transakcje energii elektrycznej w formule peer-to-peer, klastry energii, obywatelska energetyka rozproszona, lokalne społeczności energetyczne.