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COMPARISON OF OPTIMIZED OPERATION OF ENERGY COMMUNITY'S FLEXIBILITY CONSIDERING DIFFERENT REGULATIONS AND TRADING STRUCTURES

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Abstract

This paper provides a comparison of an energy community energy trading under different regulations and trading structures. In this regard, it considers three cases. In the first case, the community is imposed a fixed price for consuming energy and the community manager aims to maximize the comfort level of its members. In the second case, the community pays for its consumption according to the market prices. The goal of the community manager is to minimize the total costs of the whole community. Finally, regarding the third case, the community trades power based on the negotiated prices with the same goal as the second case. The proposed models are implemented on a hypothetical community with 20 households as a member and the flexibilities of community's flexible energy resources are calculated for each case.

1 Introduction

The high penetration of intermittent renewable-based generation at different levels of the power system has increased flexibility needs of distribution and transmission system operators (DSOs and TSOs). Additionally, it increases the need for increased utilization of services provided by different flexible energy resources (FERs) [1], [2]. FERs can be located in distribution networks as well as transmission networks [3]. New technological advances related to different monitoring and management systems (e.g. smart meters and home energy management systems) is facilitating the control of distribution-network-connected FERs [4].

Distribution-network-located consumers and prosumers (pro-active consumers) in a neighboring area can voluntarily join together and establish a local energy community [5]. In this way, the members can benefit from synergy and monetary outcomes of joining the community and share the costs of assets and facilities together. In the future, the number of energy communities may increase due to their advantages. Subsequently, exploiting the maximum flexibility potential of these resources connected to distribution networks can considerably bring benefits for the DSOs and TSOs [6].

In this paper, three different pricing pricing/trading regulation schemes for distribution network-connected electricity customers (buyers and sellers) are analyzed:

1- Electricity buyers pay fixed tariffs and electricity sellers are paid based on spot market prices (in compliance with current Finnish DSOs pricing scheme/regulation),

2- Electricity buyers and electricity sellers pay and are paid based on spot market prices plus a fixed value (in compliance with current Finnish DSOs pricing scheme/regulation) or

3- Electricity buyers and electricity sellers can directly trade with each other based on the agreement reached bilaterally.

Considering the above-mentioned structure and regulation frameworks, the operation of an energy community is analyzed. The energy community is assumed to have a battery energy storage system (BESS), some electric vehicles (EVs) and heating, ventilation, and air conditioning appliances (HVAC) as FERs. Regarding its production and consumption, the energy community can play either the role of a seller or a buyer. The objective of the community is determined based on the pricing/trading schemes chosen by the community. In this regard, we estimate the flexibility of these communities considering the mentioned pricing regulation schemes and the community's objectives.

The paper introduces first the energy communities in Section 1. In Section 2, the pricing regulation schemes considered in the paper are discussed. Section 4 defines the objective of the energy community according to the pricing regulation schemes. Then, Section 5 provides a methodology to estimate the total cost and flexibility of the community's FERs. Section 6 implements different cases for a hypothetical community and discusses the results. Finally, the conclusions are presented in Section 7.

2 Energy Communities

An energy community consists of a number of prosumers or/and consumers as members of the community. The members voluntarily join together to follow a specific objective. The objective of an energy community can be, for example, minimizing the energy costs of members or other environmental goals. For instance, a number of prosumers and consumers may join together to produce and consume renewable energy. An energy community can have some shared assets such as a battery storage system (BESS), PV panels, or/and wind turbine(s). The capital and operational costs of the common assets are shared between the members so that they can also share the benefits of these resources [7]. In addition to the shared assets, the members may let the energy community manager to control their controllable devices to reach the community's goal.

There should be a manager responsible for energy trading of the members with each other and with the retailer to achieve the objective of the community. In this regard, a community manager is considered in this paper who is in charge of coordinating members, find the optimal energy trading, and controlling the shared assets. The manager can also control some controllable devices with the permission of the members. For example, the manager may schedule charging of EVs within the community, based on the preference and the comfort level of the owners. In this paper it is assumed that the energy community has a PV system and a BESS as common assets. Besides, the community manager is responsible to schedule the EVs and HVACs of the members based on the owners' preferences. EV owners will provide the time span in which their vehicles can be charged to the community manager. In terms of controlling the HVAC, also the preferred range for the temperature of the house needs to be considered by the manager.

3 Community Pricing Schemes – Cases 1-3

Finnish electricity retail companies currently present different pricing options for their customers. They can also buy the surplus production/generation of these customers based on the spot market prices. In this paper, the community's electricity production/generation surplus is considered to be sold with the spot market prices and its consumption is done in three different ways (Cases 1-3).

Case 1: Electricity buying with fixed price
The community pays a fixed price for electricity throughout the contract period. It can choose either to pay a fixed price for consuming 1 kW of electricity or a fixed price for the whole month regardless of its consumption. This pricing regulation is suitable for non-active and risk-averse customers who prefer not to be imposed by different prices. The surplus production/generation of the energy community is sold to the retailer, according to the spot market prices.

Case 2: Electricity buying with spot market price
The community pays for its required electricity according to the spot market price plus a fixed value. This fixed value is determined by the retailer which is mainly in range of (0.1-0.5) Cent/kWh regarding Finnish retailers. This pricing regulation is profitable for customers who are active, have some FERs, and are able to regulate their consumption based on the market prices. The surplus production/generation of the energy community is considered to be sold to the retailer, according to the spot market prices.

Case 3: Bilaterally negotiated electricity prices
In this case, the energy community is proposed to bilaterally negotiate with other communities or producers to partly or fully supply its demand. Moreover, the community sells its production surplus according to the negotiated prices. However, the prices of buying and selling electricity should be profitable for both buyers and sellers since they have the option to trade electricity with the retailer as well.

4 Energy Community's Objectives

The objective of the energy community and the pricing scheme (Section 3) are closely linked. Therefore, this paper defines three different objectives for the introduced pricing schemes (Cases 1-3) as follows:

Case 1) Since the community pays a fixed price, rescheduling the consumption during the day does not affect the electricity costs of members. In other words, it would not matter whether the customers charge their EVs in the morning or in the evening. As a result, in this case, the community manager tries to maximize the comfort level of its members. In addition, the manager aims to minimize the production costs of shared resources including the BESS and the PV system.

Case 2) The energy community manager aims to minimize the total costs of the community. Hence, the shared assets and controllable appliances are scheduled in order to minimize the total costs. However, the comfort level of members needs to maintain within the predefined threshold. The preference of EV owners in charging their vehicles should be also considered when the manager is scheduling the EVs.

Case 3) The objective of the energy community is similar to Case 2. In this case, the community can trade electricity with both retailer and directly with other communities, producers and consumers. In this regard, the bilateral trading needs to be beneficial for both parties.

5 Flexibility and Total Costs Calculation

5.1 Flexibility estimation of community's FERs

In general, flexibility of an FER can be defined as the ability of the resource to change its operating point. Here, EVs, HVACs, the shared BESS are the FERs of the community. The community manager is able to change the operation of these resources to follow the objective of the community. However, each FER has its own constraints. These constraints restrict the available flexibility of the resource. Regarding EVs, the availability of the EVs limit the flexibility potential of these vehicles. The owner can pass the community manager the time span in which the EV is available for charging. On the other hand, the flexibility potential of HVACs is highly dependent on the comfortable temperature requirement of the household customer. The community manager needs to control the HVAC, in a way not to exceed the comfortable temperature level of the members. In addition to these constraints, the operational limits of the FERs are other constraints restricting the objective function. For the BESS and EVs, the maximum and minimum state-of-charge (SOC) and the maximum charging/discharging power of the battery should be defined as constraints [8].

In Case 1, the community does not utilize the flexibility of the FERs since it has a fixed electricity buying price. The community manager tries to maximize the comfort level of its members. Thus, the operating points of FERs are determined based on the preference and the comfort of their owners. We consider this as a reference case. In other words, the operating points of FERs in other cases are compared to the reference case, in which no external signals are used to change their operating points. Regarding HVAC, the flexibility of this appliance in Case 2 for each time slot is estimated as follows:

$$Flex_t^{HVAC,C2} = P_t^{HVAC,C2} - P_t^{HVAC,C1} \quad (1)$$

Where, $Flex_t^{HVAC}$ denotes the flexibility of the HVAC at t in Case 2, $P_t^{HVAC,C2}$ is the scheduled power of this appliance in Case 2 at t while $P_t^{HVAC,C1}$ is the power of the HVAC at the same time slot considering that the appliance is not flexible. Therefore, the flexibility power of an appliance in Case 2 is defined as the difference between the operating power of the appliance in that case minus its operating point in the reference case (Case 1).

The same equations can be defined for other FERs and other cases as well. For example, the flexibilities of the BESS and the EV in Case 3, are defined as follows:

$$Flex_t^{BESS,C3} = P_t^{BESS,ch,C3} - P_t^{BESS,ch,C1} + P_t^{BESS,dis,C1} - P_t^{BESS,dis,C3} \quad (2)$$

$$Flex_t^{EV,C3} = P_t^{EV,C3} - P_t^{EV,C1} \quad (3)$$

Where, in (2), $Flex_t^{BESS,C3}$ refers to the flexibility of the BESS in Case 3 at t, which is obtained from the difference between the third-case operating power of the device at t, minus its first-case operating power at t. The operating power of the BESS is defined as its charging power minus the discharging power. Similarly, the difference between the charging power of the EV's battery in Case 3 and Case 1 determines the flexibility of the EV in Case 3, as indicated by (3).

If the flexibility of an FER at the specific time slot has a positive value, it means that the resource's flexibility has a downward direction at that time slot. It means that the resource is increasing its consumption due to the result of the external signal (such as prices). Otherwise, if the flexibility of the device equals to a negative value, it means that the FER's flexibility has an upward direction. In this case, the device decreases its consumption or increases its consumption as a result of the external signal. The flexibility power of each FER can be divided by its maximum power. The obtained value can represent the flexibility ratio of that FER.

5.2 Total costs calculation of the energy community

Since the community is assumed to be rational, its flexibility should lead to the benefit for the whole members of the community. This benefit can be either economic-based or not. However, this paper aims to calculate the economic benefit of the community providing that the community is flexible. Thus, in each case, we calculate the total costs of the whole community and assess whether the flexibility of the community leads to the economic profits or not. For each case, the total cost of the community is calculated using (4):

$$NC = \Sigma_t (OC_t^{FER} + C_t^{buy} - R_t^{sell}) \quad (4)$$

Where, NC denotes the total cost of the community, OC_t^{FER} is the operating cost of the FERs at t and C_t^{buy} indicates the cost of buying power from the retailer or/and from the other producers (regarding Case 3) at time slot t. Moreover, R_t^{sell} is the revenue of the community from selling power to the retailer or/and other consumers.

6 Case Study and Simulation Results

This paper considers a hypothetical energy community with 20 household members. The community manager is in charge of controlling the HVAC of each consumer, taking into consideration the comfortable range of temperature within the house. This desired range is assumed to be between 21-26°C degrees. The HVAC is considered to be controllable in terms of its operating power, meaning that its power can be controlled within the range of 0-2 kW. Moreover, we consider 10 EVs which should be charged during 1:00 AM-7:00 AM. After 7:00 AM, the EVs are not available for charging. The charging power of each EV can be controlled in the range of 0-3 kW. The shared assets of the community are a 100-kW PV system and a BESS with a 100 kWh capacity and the 25 kW maximum charging and discharging power. The hourly consumption and PV production of the community as well as the hourly market prices are illustrated in Fig. 1. The hourly market prices are extracted from Nordic Pool day-ahead prices on 3.9.2020.

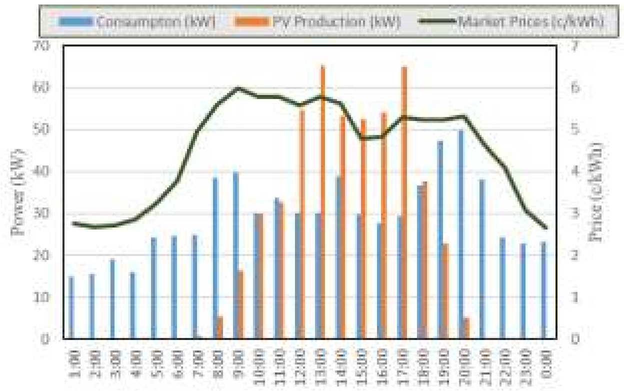

Fig. 1. The hourly consumption, PV production, and market prices on 3.9.2020.

For each case proposed in the paper, the optimization problem is run to obtain the optimal operation of each FER of the community. Considering Case 1, the objective is defined to maximize the comfort level of the HVAC and EV owners. In this regard, the manager maintains the temperature of the houses at the desired temperature which is considered to be 24°C and to maximize the SOC of the EVs at 7:00 AM so that the EV owners can utilize its highly charged vehicle. Note that the surplus production of the community is sold to the retailer based on the market prices. In addition, the community pays a fixed prices equalling 5.39 Cent/kWh. This value is extracted from the fixed tariff of one of the Finnish retailer [9].

Regarding Case 2, the community manager aims to minimize the total costs of the community for 24 hours of the day. Again, the surplus production is sold based on the market prices while the community should pay (market price + 0.24 Cent /kWh) to the retailer to meet its demand [9]. In this case, the temperature of the houses can vary within the range 21-26°C and the EVs can be charged from 1:00-7:00 AM. Note that the operating cost of charging and discharging battery is assumed to be equal to 2 Cent /kWh, obtained from the formulation used in [5].

In Case 3, the community manager tries to minimize the total costs, similar to Case 2. However, the community is assumed to trade with other producers/consumers which can be other communities. However, this energy trading should be beneficial for both parties, comparing this case with the previous cases. In this regard, we propose that the community can trade energy based on the prices equalling market prices + 0.12 Cent/kWh. These prices would be beneficial for both parties as producers receive higher prices and consumers should pay lower prices compared to the previous case. The optimization problems have been developed considering the mentioned cases. The flexibility ratio of each FER in Case 2 and Case 3can be found in Fig. 2, Fig. 3 and Fig. 4, while the hourly total costs of the community are illustrated in Fig. 5. Fig. 5 states that the community plays the role of a seller when its total cost is negative whereas it buys power when the total cost equals a positive value.

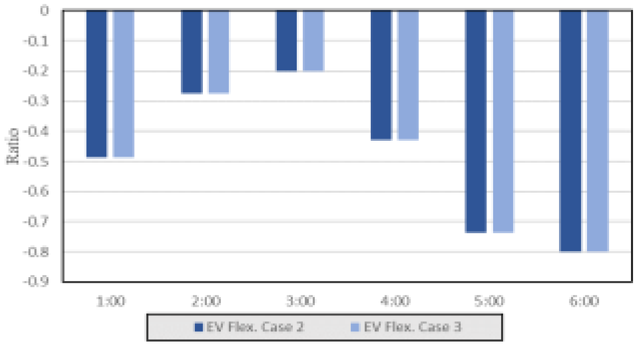

Fig. 2. Flexibility ratio of the EVs of the community.

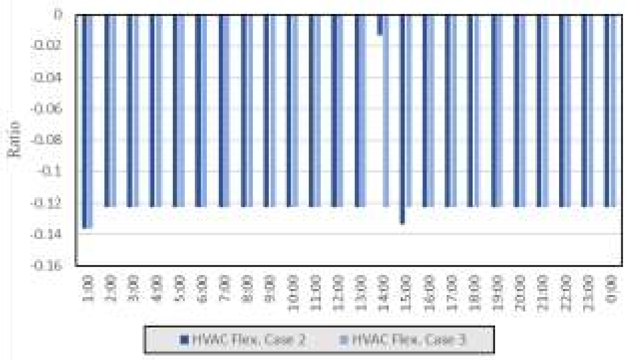

Fig. 3. Flexibility ratio of the HVACs of the community.

Fig. 2-3 show that the EVs and HVACs can contribute to the total costs minimization by injecting upward flexibility into the community. In contrast, the BESS utilizes both its upward and downward flexibility to decrease the costs of Case 2 and Case 3. It should be highlighted the negative value of flexibility ratio indicates the upward flexibility of the device whereas the positive value refers to the downward flexibility of the resource. By comparing Fig. 2, 3 and 4, it can be concluded that the BESS is highly flexible according to its higher flexibility ratio as BESS is categorized as high-flexible FERs [10]. The EVs stand in the second rank while the temperature constraints of the households result in the HVACs being less flexible compared to the storage-based devices.

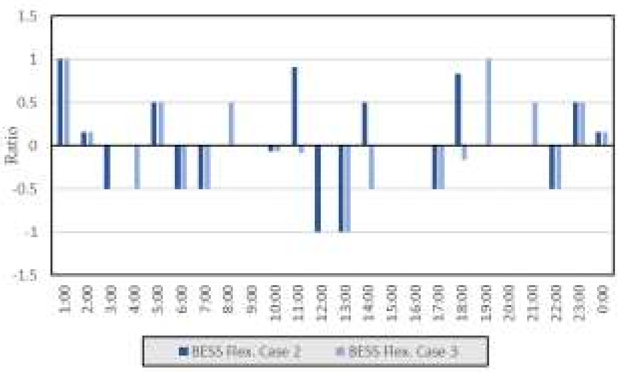

Fig. 4. Flexibility ratio of the BESS of the community.

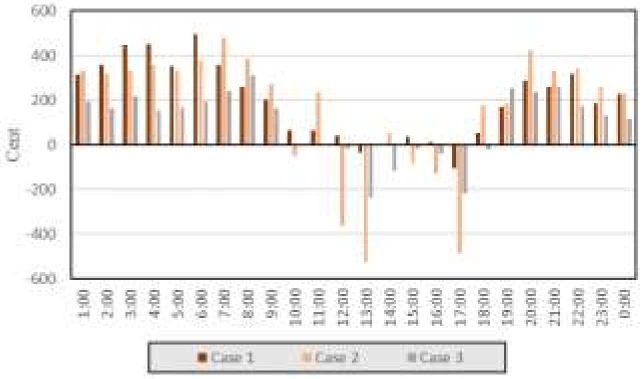

Fig. 5. The total costs of the community considering three different cases.

Finally, Fig. 5 states that the community of Case 3 in which it buys power according to the negotiated prices has less total costs in comparison with Case 1 and 2. In the most of time slots, the costs of Case 2 are also lower than those of the Case 1. This means that it is more beneficial for the community to play more active role in trading energy rather than accepting the fixed prices of the retailer.

7 Conclusion and Future Works

This paper aims to assess the optimized operation of an energy community considering different electricity pricing schemes. In addition, it provides a methodology to calculate the flexibilities of the community's FERs considering different prices for consuming electricity. Three different cases (1-3) with different pricing schemes were considered. In case 1, the community was not flexible whereas the communities in cases 2 and 3 were able to utilize flexibility using their FERs. These flexible resources included EV, BESS, and HVAC.

The proposed cases were implemented for a hypothetical community with 20 households. The flexibilities of community's FERs were calculated in different cases as well as the total costs. The results clearly demonstrated how the BESS of the community provides more flexibility compared to the EVs and HVACs. Besides, the temperature constraints result in HVACs being the least flexible device. Finally, the results prove that the community can decrease its total costs considerably by being more flexible and having active role in trading electricity. The following directions could also be considered in continuation to this paper:

- Sizing of FERs in different types of energy communities
- Analysing the costs, benefits, and possibility of utilizing different types of shared assets in energy communities
- Considering different temporal time spans for energy communities' operation in mid-/long-term horizons as well as their differences

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