Optimized operation of local energy community with flexible energy resources providing local and system-wide flexibility services for DSO and TSO needs

Author(s): Firoozi, Hooman; Khajeh, Hosna; Laaksonen, Hannu

Title: Optimized operation of local energy community with flexible energy resources providing local and system-wide flexibility services for DSO and TSO needs

Year: 2021

Version: Accepted manuscript

Please cite the original version:

Khajeh, H., Firoozi, H. & Laaksonen, H. (2021). Optimized operation of local energy community with flexible energy resources providing local and system-wide flexibility services for DSO and TSO needs. *CIRED 2021 - The 26th International Conference and Exhibition on Electricity Distribution,* 2028-2032. https://doi.org/10.1049/icp.2021.1516

OPTIMIZED OPERATION OF LOCAL ENERGY COMMUNITY WITH FLEXIBLE ENERGY RESOURCES PROVIDING LOCAL AND SYSTEM-WIDE FLEXIBILITY SERVICES FOR DSO AND TSO NEEDS

Hooman Firoozi[1]*, Hosna Khajeh[1], Hannu Laaksonen[1]

[1]*Flexible Energy Resources, School of Technology and Innovations, University of Vaasa, 65200 Vaasa, Finland*
* *hooman.firoozi@uwasa.fi*

Keywords: LOCAL ENERGY COMMUNITY, FLEXIBILITY SERVICES, FLEXIBILITY NEEDS, OPTIMAL OPERATION, FLEXIBLE ENERGY RESOURCES

Abstract

This paper proposes the participation of a local energy community (LEC) in providing flexibility services to electrical network. In this regard, the LEC is proposed to provide active power support for the distribution system operator (DSO) in order to control voltage and manage the congestion of the local LV feeders. The LEC also simultaneously provides frequency containment reserves for normal operation (FCR-N) to the transmission system operator (TSO) for system-wide flexibility needs. The proposed model is implemented for a hypothetical case study. The results demonstrate the high potential of the LEC as a flexibility services provider for both DSOs and TSOs.

1 Introduction

Modern power systems need increased amount of services from different flexible energy resources (FER) in order to deal with the increased operational challenges (e.g. rapid power, voltage and frequency fluctuations) due to large-scale integration of intermittent renewable energy resources at different voltage levels in DSO and TSO networks. Fast controllable FERs have high potential to help the system operators (TSOs and DSOs) to effectively operate their networks [1].

FERs can be located at different voltage levels either in TSO HV network or DSO MV and LV network. Currently, DSO network-connected FERs are not widely utilized to satisfy the flexibility needs of TSOs and DSOs [2]. To the light of deploying DSO-level FERs, this paper aims to utilize these resources for providing flexibility services to both TSO and DSO. One potential flexibility services provider in the DSO-level network could be LECs with different FERs. Therefore, LEC is considered to contribute to the provision of local (DSO) and system-wide (TSO) flexibility services. A community manager in this LEC is in charge of controlling the operation of LEC as well as communication with the DSO and TSO.

This paper analyzes the optimized participation of the LEC in providing local and system-wide flexibility services as follows:

1) The LEC provides active power (*P*) support for the local DSO network. The considered local flexibility services are voltage control and congestion management.

2) FCR-N is considered as TSO-level flexibility service which is also provided by the LEC.

The paper first introduces the local and system-wide flexibility needs in in Section 2 and 3. Then, Section 4 introduces LEC as a potential flexibility services provider. Section 5 defines the proposed model and Section 6 implements the model for a case study. Finally, Section 7 concludes the paper.

2 Local Flexibility Needs

In general, local flexibility needs refer to the flexibilities that help the DSO fulfilling its operational responsibilities. The main responsibility of the DSO has traditionally been reliable high-quality electricity supply to its customers. However, the increasing penetration of often variable distributed generation (DG) as well as charging of electrical vehicles (EVs) within the distribution networks causes new challenges for the DSO. As a result, increasing amount of DSOs will need more flexibility to deal with these challenges and maintain the security of supply [3], [4].

Traditionally, DSOs have used re-dispatching methods, on-load tap-changers (OLTCs), switched capacitors, and step voltage regulators to operate their networks [5]. These devices usually measure the local voltage and if it deviates from the set target value, they try to control the voltage accordingly. However, the bi-directional power flows and active power fluctuations due to DGs as well as charging of EVs increases the voltage and thermal limit violations related congestions in the DSO networks. However, the control principles of the traditional voltage control devices are not compatible with these new needs. Therefore, new active network management (ANM) methods (e.g. related to voltage control and congestion management) are needed. These voltage and thermal limit violations in DSO networks could be managed with increased utilization of multiple DSO network-connected flexible energy resources e.g. through local flexibility markets. In the future, it is expected that DSOs can deploy different methods (e.g. technical, bilateral agreements and market based solutions) in a coordinated manner for fulfilling their flexibility needs.

FERs should be capable of controlling their active (P) or/and reactive power (Q) either in a discrete or continuous way. For instance, customers with FER located at distribution networks could adjust their active power consumption according to DSO needs. In LV distribution networks, active power has more influence on the voltage of the nodes due to higher resistance/reactance (R/X) -ratio. Thus, active power of DSO network-connected FER can highly affect to the local voltage level.

3 System-wide Flexibility Needs

System-wide flexibility needs mainly refer to those requirements related to the frequency control of the system. In Europe, system-wide services mainly comprise different types of reserves based on the level of deviation from the reference frequency (50 Hz). FCR-N, for example, needs to react to the frequency deviations between 49.9-50.1 Hz within 3 minutes. In this way, the consumption or production of the FER are continuously adjusted as a function of the frequency. In contrast, FCR-D (frequency containment reserve for disturbances) are being adopted when the frequency deviation is less than 0.5 Hz with 30 seconds. On the other hand, frequency restoration reserves (FRR), both automatic FRR and manual FRR, aim to return the frequency to the range 49.9-50.1, so that FCR can be activated afterwards. Regarding Finnish power systems, FFR (fast frequency reserve) is a recently introduced system-wide service with the target of utilization in extremely low-inertia situations [6].
Each reserve service has its own characteristics, specification, and marketplace. In other words, the flexible energy resources need to go through the technical requirements and prequalification process of each reserve service in order to be able to provide that service. For example, FCR-N services require the bidirectional flexible capacities. Thus, the related FERs should be able to inject power as well as consuming it. Regarding FCR-D, the FER needs to provide upward flexibility. Thus, the resource should inject active power whenever required or disconnect loads (demand response). Traditionally, conventional generators have been the main source of the provision of system-wide flexibilities. However, demand-side flexible resources in an aggregated manner are other potential resources.

4 LEC as Flexibility Services Provider

In general, an energy community consists of a group of prosumers and/or active consumers who voluntarily join together with their energy resources. Energy community typically has some shared assets which can enable it to sell energy or/and flexibility to the grid utility. For example, the community can have a battery energy storage system (BESS) and a PV system, which are shared assets between the members of the community. The capital costs of these assets and its related costs and profits are also shared between the members [7]. The objectives of energy communities can be different. For instance, the objective can be minimization of the energy costs of prosumers from consuming energy or maximization of the community's revenue from selling energy and flexibility to the DSO or TSO [8]. In addition to the mentioned objectives, a community may have some environmental objectives. As an example, environmentally aware consumers and prosumers join as a carbon-free community trying to consume and produce renewable energy at their vicinity.

The community members might join from different geographical areas. However, the members of a LEC are geographically close. Hence, all of the members can benefit from the energy or/and flexibility produced by the shared assets as well as trading energy with their neighbours. LEC has the potential of being the flexibility provider as well. In this way, the flexible capacities of prosumers and consumers are aggregated. It enables them to easily participate in different flexibility markets as well as energy markets. In addition, some technical requirements of being a reserve provider can be fulfilled in an energy community form. For example, LEC can provide bidirectional flexibility by aggregating both consumers and prosumers as well as some resources that provide bidirectional power such as BESSs. Besides, there exists minimum capacity limits for reserve units as a TSO-level service provider. The LEC is able to aggregate several prosumers so that they are able to contribute to the provision of TSO-level flexibilities as well as local ones.

4.1 LEC as a local flexibility provider

The consumers and prosumers of LEC can be located at different nodes of the LV network. They can react to the grid flexibility needs by changing their consumption or/and production at each time slot. For example, if the voltage of a node drops, the consumer or prosumer at that node can increase its production or decrease its consumption to regulate the voltage. Moreover, the DSO can manage congestion by controlling the injected and consumed active and reactive power of prosumers and consumers located at different nodes of the LV network. Thus, LEC can play an important role in providing local flexibility service for the DSO. Upward flexibility is defined as an increase of production or a decrease of consumption. In contrast, downward flexibility is an increase of consumption or a decrease of production/generation.

The coordination between the members of the LEC is of vital necessity. In this regard, this paper proposes that a community manager is responsible for the members' coordination. In addition, the LEC manager is proposed to receive the flexibility signal from the system operators and pass them to its members. Regarding local flexibility, the LEC should be in touch with the DSO to recognize the list of weak nodes at each time slot.

4.2 LEC as a system-wide flexibility provider

The LEC can provide frequency-related services for the TSOs as well. However, the technical requirements for each system-wide service should be satisfied. In other words, the community manager should choose the type of system-wide flexibility that fits the resources of members. Additionally, the provision of system-wide service should not jeopardize the security of local networks.

In this paper, we assume that the LEC is providing FCR-N service for the TSO. The reason is that this service is relatively more expensive compared to FCR-D service and does not need higher minimum capacities. Hence, the LEC could make more profits by providing FCR-N. Having said that, FCR-N is a symmetrical service, which means that the LEC should be able to provide the same amount of flexibility either in upward or downward directions. In real-time, the TSO decides about the direction of flexibility need (i.e. upward or downward), and whether it is required to activate this service or not.

The FCR-N capacities should be determined based on the available flexibility of each member. For instance, for a member who owns BESS, the state-of-the-charge, maximum charging and discharging rate, and the capacity of the BESS should be considered. In real-time, the community manager receives the TSO signals regarding the activation of flexibility. The manager needs to immediately pass the signal to the corresponding members to activate their flexible resources. For instance, regarding the BESS, at each time slot, the community manager specifies if it needs to be charged or discharged. The power of charging/discharging should also be determined based on the activation strategy of the TSO.

5 Proposed Methodology

The LEC is capable of providing both local and system-wide services simultaneously. In this paper, we consider that the LEC sells its flexible capacities to the local DSO and the TSO. Regarding the system-wide services, the LEC is going to provide FCR-N. However, the proposed method can be extended to providing other types of services for the TSO. It should be noted that the provision of local flexibility and DSO needs should be the first priority of the LEC. This is due to the fact that the LEC is connected to the distribution network. The security of distribution network is essential for the LEC since the LEC members cannot trade energy and flexibility within an insecure network. Therefore, providing TSO-level services should not violate the security of the local network.

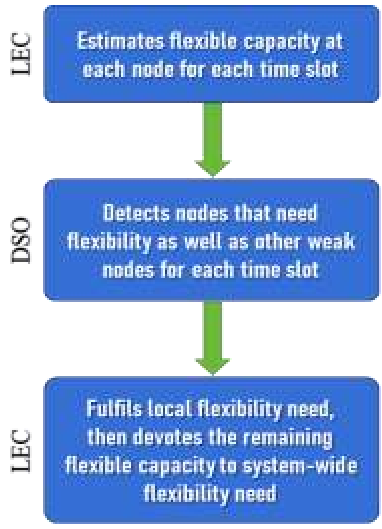

Fig. 1. The proposed three-step model

The proposed model consists of three steps:

1) In the first step, the LEC manager estimates its available flexible capacities based on the LEC's resources.
2) In the second step, the DSO sends the LEC manager the list of weak nodes and the corresponding time slots.
3) The remaining flexible capacities of the LEC will be devoted to the FCR-N services. However, the LEC manager should not use the flexible capacities of weak nodes.

Fig. 1 summarizes the proposed method and illustrates the steps. Regarding the first step, the LEC manager needs to estimate the flexible capacities of its shared assets. In addition to the shared asset, each member should send the LEC manager their available flexibility. They should inform the LEC if they can provide upward or/and downward capacities, and the time slots that these capacities are available.

In the second step, the DSO solves power flow problem for the LV feeder at which the LEC is located. This problem should be solved considering the forecasted production/generation and demand of the network. By solving the power flow problem, for each time slot, the required flexibility (i.e. the extra active power that should be injected or consumed at each node) is determined. In addition, the DSO should specify other weak nodes. These weak nodes can be detected by checking the voltage deviations of the nodes. The nodes in which voltage has higher deviations from the ideal value (1 p.u.) can also regarded as weak nodes. Moreover, if the value of the current flowing between two nodes is close to its maximum thermal limit, these nodes are also considered weak.

In the third step, the LEC manager finds the optimal capacity that can be provided by the LEC. Since FCR-N is a symmetrical service, the LEC should provide the same amount of upward or downward flexibility at the promised time. Hence, the minimum value of upward or downward flexible capacity should be selected. However, it should be noted that the FCR-N must not be provided from the lists of weak nodes. The list of weak nodes consist of those requiring flexibilities and those that are operating close to their operational limits.

6 Case Study and Simulation Results

The proposed model was implemented for a hypothetical residential community located at a weak rural LV network that consists of 11 nodes. Fig. 2 illustrates the network of the case study. The prosumers of the network are located at node n2-n10. Furthermore, the community has some PV panels as shared assets that can be found in the figure.

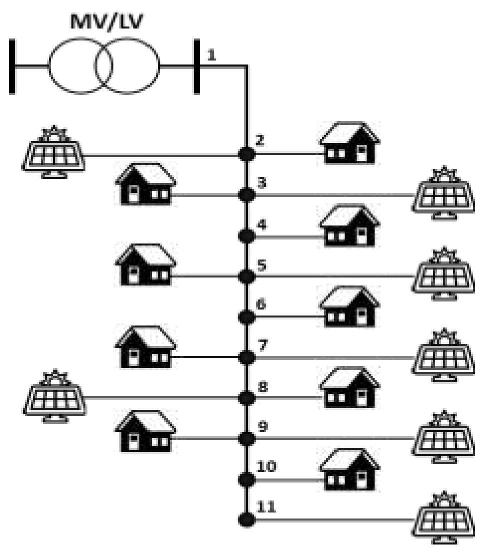

Fig. 2. The case study of LEC

Regarding the first step, the prosumers are considered to send their available flexibility to the LEC manager. In the case study, we consider that each prosumer is able to provide 2 kW upward and downward flexibility through its battery at all of the time slots.

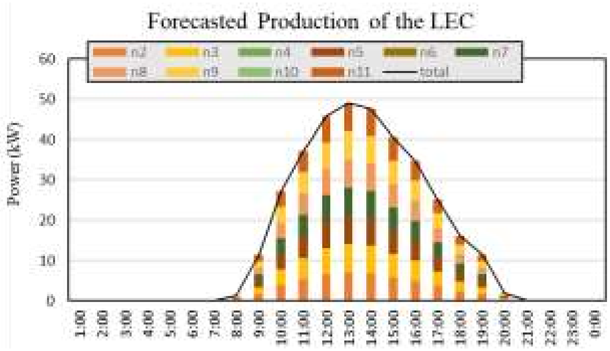

Fig. 3. The hourly forecasted production of the LEC

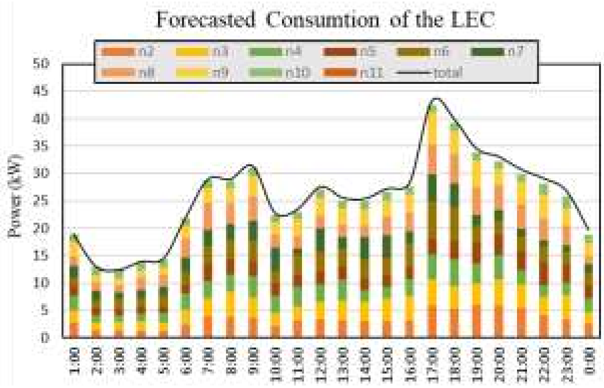

Fig. 4. The hourly forecasted consumption of the LEC

In the second step, the DSO estimates the required flexibility through solving the power flow problem. In this way, the DSO needs to forecast the generation and consumption of each node. These values were forecasted for the next 24 hours and illustrated in Fig. 3 and Fig. 4. Afterwards, the DSO finds its required flexibility, considering the thermal limits of each line. In addition, the DSO considers that the voltage of each node is allowed to vary between 0.95-1.05 p.u. The results demonstrate that the DSO only needs upward flexibility for the next 24 hours. These results are depicted in Fig. 5.

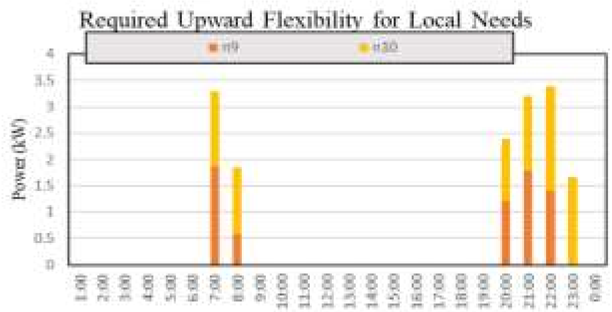

Fig. 5. The required local flexibility for each node at each time slot

Moreover, in this simulation, it is proposed that the DSO finds the nodes in which voltage magnitudes are between 0.95-0.96 and 1.04-1.05. These nodes were also considered as weak nodes. According to the results, no lines were operated with the current value close to its thermal limits. Fig. 6 shows the lists of weak nodes. The results state that the nodes located at the end of feeder are considered weak at time slots with high consumption.

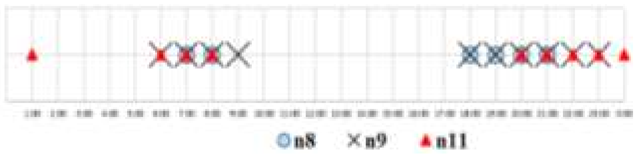

Fig. 6. Weak nodes and their corresponding time slots

In the third step, the DSO provides TSO-level flexibility services. In this regard, it removes the flexible capacities provided by weak nodes and devotes the rest to the FCR-N services. Fig. 7 illustrates the hourly value of FCR-N that can be provided by the LEC at each node. The results indicate that, in total, the LEC with 10 prosumers can provide 374 kWh FCR-N service for the TSO. This value can be more considerable for a community with more prosumers, which can also lead to the substantial increase in the profits of the LEC.

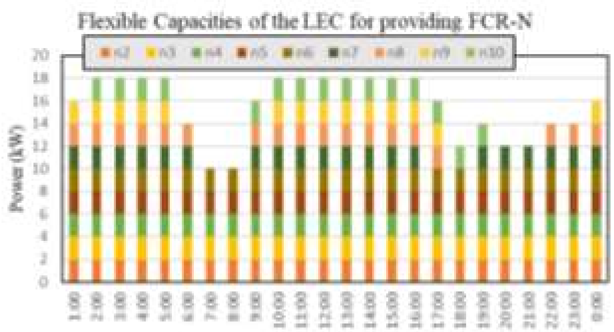

Fig. 7. FCR-N services that can be adopted from the LEC

7 Conclusion

This paper proposed the contribution of LEC to the provision of flexibility services for both TSO and DSO. The introduced model consists of three steps. In the first step, the LEC manager estimates its flexible capacities. In the second step, the DSO determines the weak nodes based on the forecasted consumption and production of the community and pass it to the community manager. In the third step, the community manager tries to provide FCR-N services from nodes, which were not considered weak. The proposed model was implemented for a case study comprising 10 prosumers. The results demonstrate that the LEC has a high potential to provide system-wide as well as local flexibility services.

8 Acknowledgements

This work was supported by FLEXIMAR-project (Novel marketplace for energy flexibility) which is funded by Business Finland and Finnish companies.

9 References

[1] H. Khajeh, H. Laaksonen, A. S. Gazafroud, and M. Shafie-Khah, “Towards flexibility trading at TSO-DSO-customer levels: A review,” Energies. 2019.

[2] H. Gerard, E. Rivero, and J. Vanschoenwinkel, “TSO-DSO Interaction and Acquisition of Ancillary Services from Distribution,” in TSO-DSO Interactions and Ancillary Services in Electricity Transmission and Distribution Networks, Springer, 2020, pp. 7–23.

[3] H. Laaksonen, C. Parthasarathy, H. Hafezi, M. Shafie-khah, H. Khajeh, and N. Hatziargyriou, “Solutions to increase PV hosting capacity and provision of services from flexible energy resources,” Appl. Sci., 2020.

[4] H. Laaksonen, C. Parthasarathy, H. Hafezi, M. Shafie-khah, H. Khajeh, “Flexible Control and Management Methods for Future Distribution Networks,” in CIRED 2020 Workshop.

[5] N. Mahmud and A. Zahedi, “Review of control strategies for voltage regulation of the smart distribution network with high penetration of renewable distributed generation,” Renew. Sustain. Energy Rev., vol. 64, pp. 582–595, 2016.

[6] H. Firoozi, H. Khajeh, and H. Laaksonen, “Optimized Operation of Local Energy Community Providing Frequency Restoration Reserve,” IEEE Access, p. 1, 2020.

[7] A. R. Servent, The European Parliament. Macmillan International Higher Education, 2017.

[8] S. Lilla, C. Orozco, A. Borghetti, F. Napolitano, and F. Tossani, “Day-ahead scheduling of a local energy community: An alternating direction method of multipliers approach,” IEEE Trans. Power Syst., vol. 35, no. 2, pp. 1132–1142, 2019.