CIRED 2020 Berlin Workshop (CIRED 2020)

22-23 September 2020

Theme 3: Flexibility Platforms and the Role of future DSO's

Microgrids as energy and flexibility providers for TSO-level networks

ISSN 2515-0855
doi: 10.1049/oap-cired.2021.0226
www.ietdl.org

Hosna Khajeh ✉, *Hooman Firoozi, Hannu Laaksonen,*
Miadreza Shafie-khah

School of Technology and Innovations, University of Vaasa, Vaasa, Finland
✉ *E-mail: hosna.khajeh@uwasa.fi*

Abstract: In the future, the utilisation of technical services from distribution network connected flexible energy resources will be increasingly needed. Microgrid (MG) typically has multiple different flexible resources like distributed generation units, battery energy storages, electric vehicles and controllable loads. Therefore, MGs can be also seen as flexible resources from the power system point of view. This study will present a new method to adopt the flexibility of MGs for transmission network needs. Therefore, an MG aggregator is proposed to be responsible for scheduling several MGs with various resources aiming to participate in the transmission system operator (TSO)-level energy and flexibility markets. The results of the scheduling and different market participation of the MGs are simulated for the hypothetical MGs in Finland and the results will be discussed as well.

1 Introduction

Power systems are experiencing revolutionary changes in which renewable-based distributed energy resources (DERs) are largely replacing the traditional huge fossil-fuel based power generation plants. Weather dependent renewable energy resources are intermittent which increases the power fluctuations at all voltage levels in the power systems. In order to address this issue, different new flexibility services are needed. These flexibility services could be potentially provided by various flexible resources which can be located at different levels in the power systems, e.g. at distribution network [distribution system operator (DSO)] or transmission network [transmission system operator (TSO)] levels [1].

TSO-level flexible resources can be located in both the demand-side and supply-side of the system. They can consist of aggregated customers and prosumers who have the capability to adjust to their consumption and/or production to provide the transmission grid with flexibility services. Some supply-side resources proposed in the literature are traditional thermal generators [2], wind power producers [3], virtual power plants [4], large or aggregated energy storage systems [5], and any large-scale generators which are able to react to the TSO's flexibility needs. Although traditional generators are conventionally utilised as the only TSO-level flexibility providers, they have been shut down to a large extent due to environmental reasons.

Microgrids (MGs) could be seen as a combination of or sub-system with different flexible resources located at the DSO level. MG can consist of DERs like renewables, battery storages, electric vehicles (EVs) as well as controllable and non-controllable loads. By controlling these flexible resources intelligently, MGs have the potential to respond to the changes in the power system in a rapid and cost-efficient manner. This paper aims to schedule several MGs to enable them to sell their flexibility services to TSO-level energy and flexibility markets.

2 Methodology

In this paper, MGs' flexible resources are managed and scheduled by an MG aggregator (MGA). The MGA also aims to build the optimal bidding strategy so that the aggregated MGs would be able to participate in the wholesale energy market and provide balancing-based flexibility services for the TSO-level networks. The MGs' flexible resources are considered to be demand response (DR) resources that can react to the changes by curtailing or shifting the loads, storage-based resources including batteries and EVs, and roof-mounted solar panels.

2.1 MGs scheduling

As mentioned above, the flexible resources of MGs are proposed to be scheduled taking into account the costs they incur for generating or consuming power during the studied time slots as well as constraints that can restrict their generating power.

2.1.1 Storage-based resources: Batteries and EVs are taken into account as storage-based flexible resources in MGs. These resources can provide the grid with flexibility by charging in time slots with low prices or surplus generation and discharging when the demand exceeds the total generation or the prices are higher. However, the operation costs of the batteries which consist of battery degradation should be regarded in the scheduling process. The operational cost of the battery s at t, $C_{s,\,t}$, is equal to the total cost of buying a new battery divided by its total lifetime cycling capacity [6]. Although the batteries charging and discharging status can be easily managed, utilising EVs as flexible resources are highly dependent on the complex behaviour of their owners in determining the desired charging/discharging timetables.

There exist some constraints associated with storage-based resources restricting their charging and discharging schedules. These constraints are defined as follows:

$$E^{\min}_{s,t} \le E_{s,t-1} + \eta_{\mathrm{s}} p^{\mathrm{ch}}_{\mathrm{s}} \Delta t - \frac{p^{\mathrm{dis}}_{\mathrm{s}} \Delta t}{\eta_{\mathrm{s}}} \le E^{\max}_{s,t}. \tag{1}$$

$$N^{\mathrm{ch,min}}_{\mathrm{ev},t} \le N^{\mathrm{ch}}_{\mathrm{ev},t} \le N^{\mathrm{ch,max}}_{\mathrm{ev},t} \tag{2}$$

$$N^{\mathrm{dis,min}}_{\mathrm{ev},t} \le N^{\mathrm{dis}}_{\mathrm{ev},t} \le N^{\mathrm{dis,max}}_{\mathrm{ev},t} \tag{3}$$

where (1) calculates the state of energy of a storage-based resource in time slot t, i.e. $E_{s,t}$. The power of charging and discharging are denoted with $p^{\mathrm{ch}}_{\mathrm{s}}$ and $p^{\mathrm{dis}}_{\mathrm{s}}$, respectively, and the efficiency of the storage-based resource is η_{s}. Equations (2) and (3) indicate the constraints associated with EVs, stating that the MGA should consider the maximum and minimum number of EVs willing to be charged/discharged.

2.1.2 DR resources: Customer consumption has also the potential to be modified according to the system's flexibility requests [7]. However, there should be enough incentives for the owners to compensate for the inconvenience resulted from changing their consumption behaviour. This incentive was proposed to be presented as DR programs which were roughly categorised into price-based and incentive-based DR programs [8]. A price-based program is deployed in this paper meaning that customers are offered to receive monetary benefits based on the modification they make to reshape their load. For this paper, customers can decide to curtail the part of their loads or shift them to the other time slots in order to inject flexibility into the grid while making profits through the DR programs [9]. As a result, the costs of activating DR resources are equal to the money paid to the customers to change their load:

$$C_t^{\mathrm{DR}} = \lambda_t^{\mathrm{DR}}\left(p_{\mathrm{cur}}^{t} + \sum_x p_{\mathrm{shift}}^{t+x}\right). \tag{4}$$

where λ_t^{DR} is the money paid to the customers taking into account the amount of power curtailed (p_{cur}^{t}) or shifted to other time slots ($\sum_x p_{\mathrm{shift}}^{t+x}$) at t [9].

In order to react to the flexibility requests at the customer level, households require to be equipped with home energy management systems (HEMSs) so that they can easily be aware of the DR programs and incentives and take an action accordingly. Through the use of HEMS, intelligence and comfort can be added to the home environment and flexible appliances are able to be controlled and rescheduled to fulfil the grid's needs [1].

2.1.3 Roof-mounted PV panels: DERs like PV panels are increasingly employed not only to increase self-sufficiencies of communities but also to enhance green energy resource utilisation in the power system. In addition, they can be considered as a cost-efficient resource as long as they incur a negligible marginal cost for their owners. However, these resources are intermittent and uncertain due to their dependency on different environmental factors (e.g. the weather, cloud patterns, etc.). As a result, the owners may have a problem with forecasting and scheduling solar power. Hence, the only cost that can be imposed on the owners is the penalty costs of not producing power they had scheduled and offered to the market. This cost is indicated through the following equation:

$$C_t^{\mathrm{PV}} = \lambda_t^{\mathrm{penalty}}\left(P_t^{\mathrm{PV\text{-}real}} - P_t^{\mathrm{PV\text{-}scheduled}}\right). \tag{5}$$

where $\lambda_t^{\mathrm{penalty}}$ is the penalty imposed for deviation from the scheduled PV generation. This deviation indicates with $P_t^{\mathrm{PV\text{-}real}} - P_t^{\mathrm{PV\text{-}scheduled}}$.

2.2 MGs bidding strategy

Having scheduled various flexible resources, the MGA will build the optimal bidding strategy in order to participate in energy and regulating balancing markets aiming to maximise the profits of the MGs. The total profit of the MGs obtained from the participation in energy and regulation markets can be defined as follows:

$$\begin{aligned}\mathrm{Profit}^{\mathrm{MGA}} = \sum_t &\left(P_t^{\mathrm{energy\text{-}sell}}\lambda_t + P_t^{\mathrm{reg\text{-}up}}\lambda_t^{\mathrm{reg\text{-}up}} + P_t^{\mathrm{reg\_dn}}\lambda_t^{\mathrm{reg\text{-}dn}}\right. \\ &\left.- P_t^{\mathrm{energy\text{-}buy}}\lambda_t\text{-}C_t\right).\end{aligned} \tag{6}$$

where the first term denoted the profits from selling power to the energy market. The second and third terms are the profits from selling flexibility (regulation up and regulation down) to the TSO. The term $P_t^{\mathrm{energy\text{-}buy}}\lambda_t$ shows the cost of buying power from the wholesale market and C_t is the total cost of the downstream MGs' resources supervised by the MGA. This cost is equal to the sum of flexible resources related costs introduced in Sections 2.1.2 and 2.1.3.

The following constraints should be considered when finding the optimal bidding strategy:

$$\begin{aligned} D_t + P_t^{\mathrm{ch\_EV}} + P_t^{\mathrm{ch\_battery}} + P_t^{\mathrm{energy\text{-}sell}} + P_t^{\mathrm{reg\text{-}up}} &\le P_t^{\mathrm{PV}} \\ + P_t^{\mathrm{dis\text{-}EV}} + P_t^{\mathrm{dis\text{-}battery}} + P_t^{\mathrm{DR}} + P_t^{\mathrm{energy\text{-}buy}} &+ P_t^{\mathrm{reg\text{-}dn}} \end{aligned} \tag{7}$$

$$P_t^{\mathrm{reg\text{-}up}} \le P_t^{\mathrm{dis\_battery}} \tag{8}$$

$$P_t^{\mathrm{reg\text{-}dn}} \le P_t^{\mathrm{ch\_battery}} \tag{9}$$

Equation (7) states that the required power for the MGs which is consisted of the demand of the MGs, D_t, the power needed for charging EVs and batteries, $P_t^{\mathrm{ch\_EV}} P_t^{\mathrm{ch\_battery}}$, the power selling to the energy ($P_t^{\mathrm{energy\text{-}sell}}$) and up-regulating market ($P_t^{\mathrm{reg\text{-}up}}$) shod be lower than the power taken from flexible resources, including PV pane (P_t^{PV}), discharging EVs ($P_t^{\mathrm{dis\text{-}EV}}$), discharging batteries and DR resources (P_t^{DR}) and the power bought from the market and offered for regulation-down flexibility services, i.e. $P_t^{\mathrm{energy\text{-}buy}}$ and $P_t^{\mathrm{reg\text{-}dn}}$. Equations (8) and (9) define that the power offered for flexibility services should not be produced from uncertain flexible resources. Since the only non-uncertain flexible resource of the proposed MGs is batteries, the source of power offered for regulation is suggested to be battery energy storage.

TGA main objective function would be to maximise the profits of its downstream MGs, (6), subjects to the constraints restricted the power of flexible resources such as (1)–(3) as well as (7)–(9).

3 Simulation results

This paper considers hypothetical MGs which consist of 2000 residential households, 1500 of them are equipped with Tesla's Powerwall as a battery as well as a 3 kW solar system. For simplicity, EVs are assumed to be Nissan Leaf's with 30 kWh battery capacity. In addition, we assume that EVs with a desire for charging will be charged up to 90% of their capacity and those with discharging requests will be discharged to 20%.

The MGs are considered to be located in Finland, so the information about wholesale market prices (Nord pool) and the ones related to the up-regulating and down-regulating balancing markets are extracted from [10, 11] and shown in Fig. 1. Note that the scheduling process is performed for the date 1.9.2019. The maximum number of available EVs requesting charging or discharging along with the minimum number who must be charging or discharging (i.e. their charging/discharging status cannot be determined by the MGA) are also shown in Fig. 2. The other information on MG demand and DR resources are obtained from the work of Khajeh et al. [9].

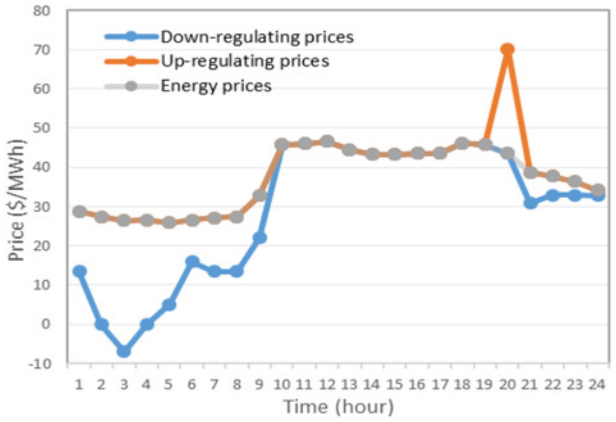

Fig. 1 *Prices of energy, up-regulating and down-regulating market*

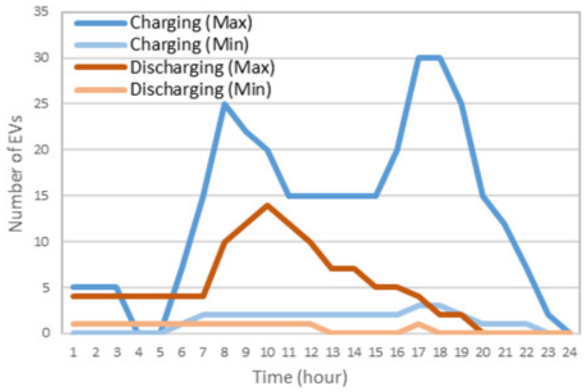

Fig. 2 *Minimum and maximum number of EVs willing to participate*

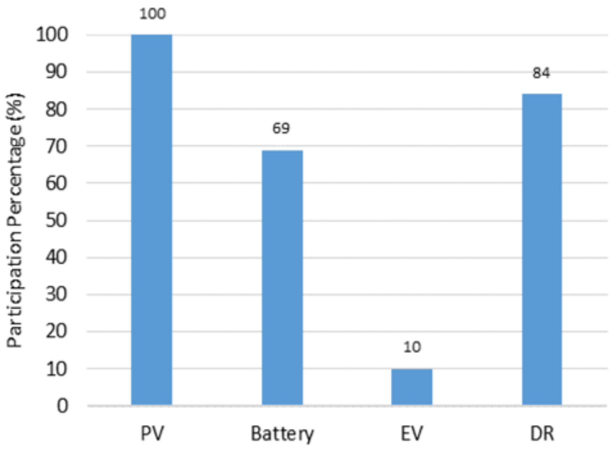

Fig. 3 *Optimal participation factor for various flexible resources*

3.1 Participation of flexible resources

The percentage of the optimal participation of each flexible resource is considered to be determined from the following equation:

$$C^{\text{participation}}\% = \frac{\sum_t C_t^{\text{opt}}}{\sum_t C_t^{\max}} \times 100 \qquad (10)$$

As a result, this factor was calculated for all of the flexible resources including DR resources, solar power, battery resources, and EVs and the results are illustrated in Fig. 3.

As can be seen from Fig. 3, the highest flexibility participation in the MGs was allocated to the solar power with the optimal participation of 100%, meaning that all of the PV generations will be utilised by the MGA. The next highest level of participation was by DR resources with an 84% participation factor. The participation factor of batteries was 69%. The results state that EVs are not considered optimal resources because their operating costs were greater than with the other flexible resources. EVs 10% participation factor is due to the minimum charging and discharging limits imposed by the EV owners of the MGs.

3.2 Effect of flexibility-related participation on the MGs' profits

Since the prices of the wholesale energy market and the up-regulating market are the same in most time slots, the optimum participation of the MGs is mainly allocated to the energy market (Fig. 4). However, a considerable amount was also devoted to down-regulating participation during 24 h (Fig. 4). The non-zero MGs' optimal participation for up-regulating balancing flexibility occurs at hour 20 (Fig. 4) when its price reaches the peak value.

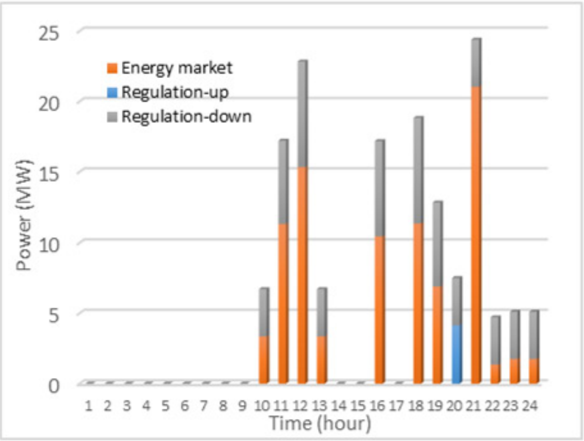

Fig. 4 *Optimal participation of MGs to energy and flexibility markets*

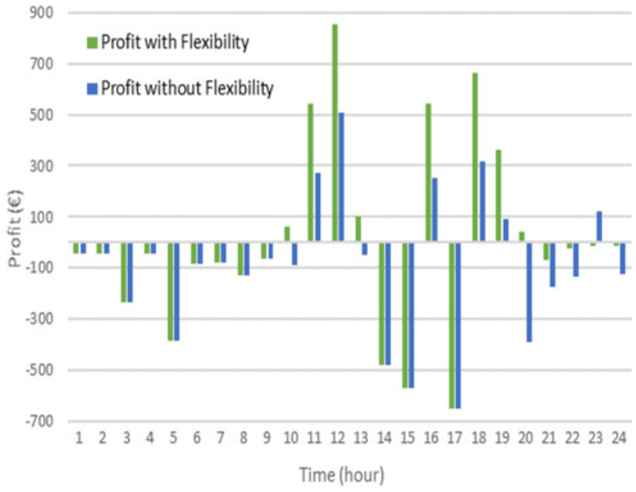

Fig. 5 *Profits of MGs with and without participation in regulating balancing markets*

In Fig. 5, the calculated profits of the MGs are shown with and without participation in regulating balancing markets.

As Fig. 5 shows, the profit of MGs without participating in balancing markets become considerably lower, meaning that balancing flexibility markets increase the revenues and profits of the MGs. Note that in most of the time slots, the profits of the MGs are negative due to the fact that MGs were not able to or it was not profitable to sell energy and flexibility to the markets.

4 Conclusion

This paper considered several MGs aggregated by an MGA, aiming to provide energy and flexibility for the TSO-level networks. The main objective of these MGs was to maximise their profits through scheduling flexible resources as well as participating in different markets. A case study was analysed to obtain the optimal and cost-efficient participation of distribution network located flexible resources. The results also state that participation in regulating balancing markets enhance the MGs' profits considerably.

5 Acknowledgments

This work was supported by the FLEXIMAR -project (Novel marketplace for energy flexibility) which is funded by Business Finland and Finnish companies (https://www.univaasa.fi/en/research/projects/fleximar/)

6 References

1 Khajeh, H., Laaksonen, H., Gazafroudi, S., *et al.*: 'Towards flexibility trading at TSO-DSO-customer levels: a review', *Energies*, 2020, **13**, (1), p. 165

2 Khoshjahan, M., Moeini-Aghtaie, M., Fotuhi-Firuzabad, M.: 'Developing new participation model of thermal generating units in flexible ramping market', *IET Gener. Transm. Distrib.*, 2019, **13**, (11), pp. 2290–2298

3 Wang, Z., Shen, C., Liu, F., *et al.*: 'An adjustable chance-constrained approach for flexible ramping capacity allocation', *IEEE Trans. Sustain. Energy*, 2018, **9**, (4), pp. 1798–1811

4 Saboori, H., Mohammadi, M., Taghe, R.: 'Virtual power plant (VPP), definition, concept, components and types'. 2011 Asia-Pacific power and energy engineering Conf., Wuhan, China, 2011, pp. 1–4

5 Parthasarathy, C., Hafezi, H., Laaksonen, H., *et al.*: 'Modelling and simulation of hybrid PV & BES systems as flexible resources in smartgrids–sundom smart grid case'. 2019 IEEE Milan PowerTech, Milan, Italy, 2019, pp. 1–6

6 Nguyen, T.A., Crow, M.L.: 'Stochastic optimization of renewable-based microgrid operation incorporating battery operating cost', *IEEE Trans. Power Syst.*, 2015, **31**, (3), pp. 2289–2296

7 Firoozi, H., Khajeh, H.: 'Optimal day-ahead scheduling of distributed generations and controllable appliances in microgrid'. 2016 Smart Grids Conf. (SGC), Kerman, Iran, 2016, pp. 1–6

8 Hajibandeh, N., Ehsan, M., Soleymani, S., *et al.*: 'The mutual impact of demand response programs and renewable energies: a survey', *Energies*, 2017, **10**, (9), p. 1353

9 Khajeh, H., Foroud, A.A., Firoozi, H.: 'Robust bidding strategies and scheduling of a price-maker microgrid aggregator participating in a pool-based electricity market', *IET Gener. Transm. Distrib.*, 2018, **13**, (4), pp. 468–477

10 Nordpool: Available at https://nordpoolgroup.com/Market-data1

11 Fingrid: Available at https://data.fingrid.fi/en