DSO CONGESTION MANAGEMENT USING DEMAND SIDE FLEXIBILITY

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ABSTRACT

The increase in electricity demand has exerted pressure on distribution networks to provide efficient and reliable services. In addition to this, the deployment of Distributed energy resources (DERs) is increasing vastly. Thus, new strategies for congestion management are required to cope with these new changes. This paper, proposes an algorithm to optimize the total operational cost of Distribution system operator (DSO) in congestion management using Demand side flexibility (DSF) while considering the payback effect. The proposed algorithm is integrated with MATPOWER in MATLAB, to assess the benefits of this approach from technical and operational perspectives through a case study on the CIGRE European MV distribution benchmark grid.

INTRODUCTION

At this moment, the electricity sector is reforming by moving from a passive to an active paradigm. In an effort to adapt with the introduction of smart grid concepts and the promotion of Distributed Energy Resources (DERs), Distribution System Operators (DSOs) are facing several challenges in maintaining the efficiency of the network while optimizing its economic output. The integration of DERs in the electricity networks boosted the transition from the traditionally passive (fit and forget) networks to more active networks. The grid ageing infrastructure places further responsibilities on the DSOs as DERs depend often on variable intermittent energy resources.
DSOs are required to accommodate the increasing use in DERs while maintaining high levels of reliability and security of supply. This can only be achieved by improved network capacity planning and congestion management. Although there are many approaches to solving congestions within the grid, demand side flexibility (DSF) is one of the very recent approaches that possess a high potential in increasing the overall system efficiency and reliability standards. DSF can significantly help optimize distribution networks and solve local grid constraints. Moreover, It can potentially reduce or postpone infrastructure investment needs within grids that suffer from frequent congestions [1]. Many authors have addressed the impact of DSF in current distribution networks. In [2], the authors presented the advantages behind load aggregation and flexibility in deregulated markets using neural networks. The authors of [3] addressed the technical and regulatory challenges facing the achievement of better integration of flexible demand within Smart grids. In [4], the authors presented an optimization framework for customers flexibility aggregation. Moreover, in [5] the authors presented a novel mathematical model to highlight the economic impact the load recovery or payback have on the customers. Besides, in [6] the authors examined the characteristics of payback and the effect it has on optimal scheduling of power systems during critical events.
This paper aims to study the effect of DSF on solving congestions while taking into account the payback effect. In order to evaluate DSF's potential on congestion management; thorough studies are carried out to assess its feasibility technically and economically while considering all the affecting factors. As the mechanisms of load aggregation and flexibility pricing, are not yet agreed upon in the future markets, the case study presented only assumes them in order to demonstrate the paper's objectives.

DEMAND RESPONSE & FLEXIBILITY

Demand response programs (DRP) allow customers to have an active role in the operation of power systems. This active role is translated in changing load patterns based on price signals in order to the customer's payments while maintaining system security. DRP could be classified into two important types. First type is the Price-based DRP, where the customers can respond to daily changes of market prices by reducing their load thus reducing their electricity bills. The second type is Incentive-based DRP, these types of programs are supported by the electric utilities and grid operators. They incentivize customers by providing compensations for their load reduction when needed to solve network congestions.
One of the recent Incentive-based DRP is the Demand side flexibility (DSF) program. DSF is a service provided to the energy system by modifying the generation injection and/or consumption patterns in reaction to an external signal which could be a price or activation signal [7]. On one hand, DSF provides the opportunity for customers to bid for their own load reduction according to their preferred time duration and availability. On the other hand it benefits the DSO by providing multiple services such as peak shifting, demand adjustment and relieving grid constraints. The DSO can use these bids of load reduction to manage the grid's contingencies. This type of program could be very profitable for large customers where their load reduction could reach to 10 MW. Moreover, small residential customers could also benefit from this program and reduce their electricity bills by a considerable amount. However, since the customers might not have the enough knowledge or experience to participate in such program, they will need some kind of a broker who can efficiently handle their flexible load. This broker is a new market player called the aggregator. An aggregator's target is to

maximize the flexibility potential for the grid users by aggregating the customers' load reduction or local generation opportunities and offering them for sale in a legalized market [8]. In addition, the aggregator assists the DSO to increase the grid reliability and to meet his demand reduction goals by facilitating the usage of the flexibility services. Figure 1 illustrates in a simple manner how the aggregator manages the flexibility customers while coordinating with the DSO.

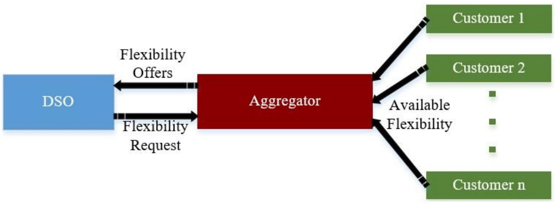

Figure 1. Aggregator's Role.

As much potential the DSF holds in increasing system efficiency, it is often subjected to a consequent event called the payback/rebound effect. The payback effect indicates the desirability of customers of consuming back the energy reduced from them due the flexibility services, or in some cases a part of it, at a different hour during the day. Since there are no constraints on the type of customers that can provide DSF whether they are residential, commercial or industrial customers, the payback effect could easily lead to new peaks formation along the day leading to further grid contingences. Therefore, further responsibilities are put on the aggregator by managing the payback effect [9], [10].

CUSTOMERS' FLEXIBLE LOAD

DSF success is dependent on many factors such as the customers' types and their load characteristics. For residential customers, many studies [11], [12] were carried out in Europe to investigate the most applicable home appliances for DSF. Such studies suggested that appliances that can work independently from customers such as refrigerators, washing machines and electric space and water heating are most likely to be used in such programs of load reduction. Depending on the customers' willingness to lose some of their comfort to reduce their electricity bills, these types of loads could be curtailed or shifted to either an earlier or later time of the day. Load shifting is another synonym for energy payback where a certain amount of energy is moved from one hour to another in the load profile. The amount of energy to be paid back is strongly affected by its accompanying hour. For example, if the load to be reduced from the customer is an air conditioning system, the amount of energy needed for payback if the load to be shifted for one hour is smaller than that needed if the load to be shifted for 6 hours [6]. Commercial customers as well share the same load reduction characteristics of the residential customers but with different load types such as cooling in hotels and restaurants, commercial air conditioning and water storage and heating [13]. On the other hand, industrial customers have different characteristics when it comes to load types and load reduction. With high end machinery and equipment and relatively large productions, these customers can be limited by their processes' technical constraints and requirements. Due to their high cost production, sometimes only load reduction is applicable and energy payback is not needed, which is the case for cement mills, steelmaking in electric arc furnaces and electrolytic refinement of copper [9].

DSF CASE STUDY

The case study was carried on the CIGRE European MV distribution benchmark grid to illustrate the intended objectives of the paper [14]. The CIGRE grid consists of 14 nodes as presented in Figure 2 and two types of customers: residential and commercial/industrial. All grid data including line and transformers parameters, power profiles and power factor are available in [14]. Moreover, the optimization algorithm was integrated with MATPOWER, a package of MATLAB m-files for solving optimal power flow problems [15] to ensure the feasibility of the chosen offers technically and economically.

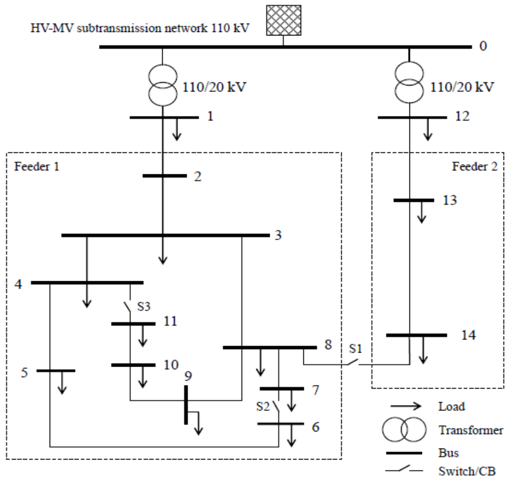

Figure 2. CIGRE European MV Distribution Network.

In this case study, the grid customers, the aggregator and the DSO all participate in an organized energy market such as the Spanish day-ahead market. Therefore, the hourly price of electricity [16] presented in Table I are considered from a typical summer day from the Spanish day-ahead market. In addition to this, buses 10 & 11 are the only buses providing DSF. The daily profile in MW for them is presented in Figure 3. It is assumed that a congestion will occur at hour 20 in the branch linking buses 9 and 10. The aggregator, who acts as a mediator between his affiliated customers and the DSO, presents to the DSO multiple offers for load reduction. In response, the DSO optimizes his decision to select the most economical offer that will solve the congestion [17]. However, in order for the DSO to take the decision, certain conditions regarding the customers providing the DSF must be provided by the aggregator. The customer and the aggregator agree upon two issues: the flexibility percentage and the payback percentage [10]. The flexibility percentage is the percentage of load that the customer accepts to be reduced from him. The payback percentage is the percentage of the reduced load that the customer requires to be returned later or earlier in the day. These conditions are easily affected by the type of the customer, their load nature and their preferences. Table II presents the above mentioned conditions for bus 10 and 11 along with the buses' scheduled load at hour 20. The values of the flexibility and payback percentages were only assumed in order to demonstrate the study's goal.

TABLE I. HOURLY MARKET PRICE (€/MWH)

Hr	Market Price	Hr	Market Price	Hr	Market Price	Hr	Market Price
1	49.99	**7**	57	**13**	68.99	**19**	60.11
2	46.6	**8**	59.69	**14**	67	**20**	65
3	46.02	**9**	62	**15**	63.1	**21**	65.05
4	46.37	**10**	67.17	**16**	59.69	**22**	64.41
5	46.71	**11**	68.99	**17**	59.69	**23**	65.15
6	49	**12**	69.1	**18**	60.11	**24**	60.49

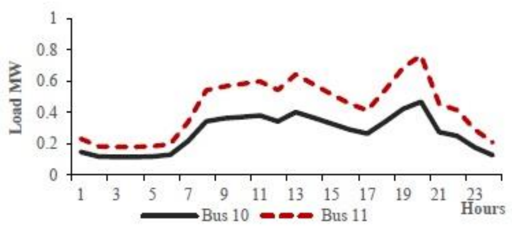

Figure 3. Load Profile for Bus 10 & Bus 11.

TABLE II. FLEXIBILITY BUSES CONDITIONS

Flex Buses	Load (MW)	Flexibility %	Payback %
Bus 10	0.469	45%	100%
Bus 11	0.297	65%	100%

Since, the future market rules of DSF and the mechanisms of load aggregation and pricing are not currently known, in this case study, it is assumed that the flexibility services takes place after the daily market clearance in an assumed flexibility market. In this market, at the flexibility hour activation, the DSO can buy the flexible energy from the aggregator at a higher price than that of the system marginal price. In addition to this, as a way of encouraging customers in defining payback conditions preferences for better energy payback planning, the DSO sells the payback energy to the aggregator at a lower price than that of the market price at the payback hour. Normally, generation bids are presented in a stepwise form in the market. Therefore, it was safe to assume that the aggregated flexibility offers will be presented in the same manner. Figure 4 presents the flexibility bid for the buses 10 and 11 respectively. It can be remarked from Figure 4 that the energy reduction offered to the DSO is represented on the horizontal axis of the bids. The customers' incentives for participation can be shown clearly as well. The more energy the customer sells, the higher the selling price. As for the payback price incentive, it was assumed to be 50% lower than the market price at the hour of energy payback.

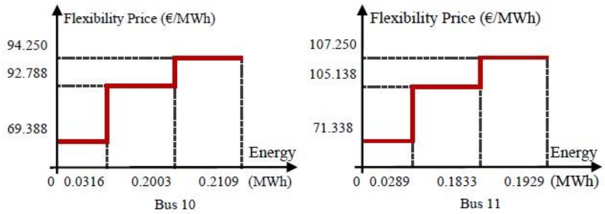

Figure 4. Flexibility Bids for Bus 10 & Bus 11.

To solve the congestion, the DSO is presented with 3 possible solutions for buses 10 and 11, either by buying from both buses' flexibilities simultaneously or buying separately from only one of them. Therefore, the proposed algorithm will assess the flexibility bids by running an OPF for the 3 possible solutions. However, the DSO decision on the feasible offer must be taken after considering the payback effect. In this case, it is assumed that both buses are residential customers and the loads involved in the DSF are household appliances. According to their load nature [9], it is assumed that the payback of energy for both customers has to be in full and on the following hour of flexibility activation i.e. hour 21. In Table III, the results for the 3 scenarios are presented. Flexible load indicates the amount of energy bought by the DSO at the flexibility activation while the payback load is the amount of energy the DSO will supply back at the payback hour. As shown, the DSO total cost comparison suggests that buying energy from both buses would be more feasible than buying only from either one of them.

TABLE III. RESULTS WHEN BUS 10 IS RESIDENTIAL

Results	Bus 10 Only	Bus 11 Only	Bus 10 & 11 Simultaneously	
			Bus 10	Bus 11
Flexible Load (MW)	0.15	0.15	0.12	0.03
Payback Load (MW)	0.15	0.15	0.12	0.03
DSO Total Cost (€)	8.41	10.04	7.79	

In order to show the effect the customer's type and load nature has on the DSO decision, Table IV presents the results for the 3 scenarios when Bus 10 is considered as an industrial customer with an industrial load that requires energy payback of 120%. In this case, considering the same payback hour, although the flexibility offers are feasible technically, the high payback energy percentage will cause a congestion in the grid at hour 21. This will drive the DSO to accept only the offer from Bus 11 only.

However, if the industrial load at bus 10 does not require energy payback [9], the DSO will favour accepting the offer of Bus 10 only as it is the most economical offer. Table V presents the results when the payback energy is not considered for bus 10.

TABLE IV. RESULTS WHEN BUS 10 IS RESIDENTIAL WITH HIGH PAYBACK PERCENTAGE

Results	Bus 10 Only	Bus 11 Only	Bus 10 & 11 Simultaneously	
			Bus 10	Bus 11
Flexible Load (MW)	0.15	0.15	0.12	0.03
Payback Load (MW)	0.18	0.15	0.15	0.03
DSO Total Cost (€)	N/A	10.04	N/A	

TABLE V. RESULTS WHEN BUS 10 IS INDUSTRIAL WITH ZERO PAYBACK PERCENTAGE

Results	Bus 10 Only	Bus 11 Only	Bus 10 & 11 Simultaneously	
			Bus 10	Bus 11
Flexible Load (MW)	0.15	0.15	0.12	0.03
Payback Load (MW)	0	0.15	0	0.03
DSO Total Cost (€)	3.47	10.04	3.79	

CONCLUSION

The paper presents the effect of the payback on congestion management of a DSO using the customers' flexibility. Improper consideration of this effect could lead to further grid problems and the mishandling of customers' flexibility. In this paper, it is proposed that the payback time and conditions should be agreed beforehand between the DSO and the aggregator, instead of it being forecasted by the DSO. This might also allow a better modulation and management of this energy. Such precise flexibility and payback conditions could award customers with more incentives. The paper shows an example of proper management of flexibility and payback effects that promotes the need and advantages of the proposed procedure.

REFERENCES

[1] European Distribution System Operators for Smart Grids (EDSO), 2014, "Flexibility: The role of DSOs in tomorrow's electricity market,"

[2] S. Barsali, M. Ceraolo, R. Giglioli, and D. Poli, 2003, "Aggregation and management of the demand in a deregulated electricity market," in *Power Tech Conference Proceedings, 2003 IEEE Bologna*, vol. 4, p. 4 pp. Vol.4.

[3] H. S. Farmad and S. Biglar, 2012,"Integration of demand side management, distributed generation, renewable energy sources and energy storages," in *Integration of Renewables into the Distribution Grid, CIRED 2012 Workshop*, pp. 1–4.

[4] A. Roos, S. Ø. Ottesen, and T. F. Bolkesjø, 2014, "Modeling consumer flexibility of an aggregator participating in the wholesale power market and the regulation capacity market," *Renew. Energy Res. Conf.*, vol. 58, pp. 79–86.

[5] D. T. Nguyen, M. Negnevitsky, and M. de Groot, 2013, "Modeling Load Recovery Impact for Demand Response Applications," *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 1216–1225.

[6] S. C. Park, Y. G. Jin, and Y. T. Yoon, 2015, "Designing a Profit-Maximizing Critical Peak Pricing Scheme Considering the Payback Phenomenon," *Energies*, vol. 8, no. 10, pp. 11363–11379.

[7] CEER, 2013, "Regulatory and Market Aspects of Demand-Side Flexibility," A CEER Public Consultation Document C13-SDE-38-03.

[8] Regulatory Recommendations for Smart Grids Deployment (EG3), 2015, "Regulatory Recommendations for the Deployment of Flexibility," Expert Group 3.

[9] H. C. Gils, 2014, "Assessment of the theoretical demand response potential in Europe," *Energy*, vol. 67, pp. 1–18.

[10] E. A. M. Ceseña, N. Good, and P. Mancarella, 2015, "Electrical network capacity support from demand side response Techno-economic assessment of potential business cases for small commercial and residential end-users," *Energy Policy*, vol. 82, pp. 222–232.

[11] A. Grein and M. Pehnt, 2011, "Load management for refrigeration systems: Potentials and barriers," *Energy Policy*, vol. 39, no. 9, pp. 5598–5608.

[12] R. Shipman, M. Gillott, and E. Naghiyev, 2013, "SWITCH: Case Studies in the Demand Side Management of Washing Appliances," *Energy Procedia*, vol. 42, pp. 153–162,

[13] I. Stadler, 2008, "Power grid balancing of energy systems with high renewable energy penetration by demand response," *Util. Policy*, vol. 16, no. 2, pp. 90–98.

[14] CIGRE, 2013 "Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources."

[15] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, 2011, "MATPOWER: Steady-State Operations, Planning, and Analysis Tools for Power Systems Research and Education," *IEEE Trans. Power Syst.*, vol. 26, no. 1, pp. 12–19.

[16] "Omie." [Online]. Available: http://www.omie.es/inicio.

[17] C. Zhang, Y. Ding, N. C. Nordentoft, P. Pinson, and J. Østergaard, 2014,"FLECH: A Danish market solution for DSO congestion management through DER flexibility services," *J. Mod. Power Syst. Clean Energy*, vol. 2, no. 2, pp. 126–133.