Demand Flexibility Benefits from the DSO Perspective – a SuSTAINABLE Case-Study

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ABSTRACT

This paper evaluates the benefits derived from demand flexibility from the DSO perspective. It presents various simulations in the network of Evora, considering different scenarios for load, generation and the network capacity. Moreover, for each scenario business cases are developed for the provision of the customer flexibility as a service to the DSO.

The results of the business cases indicated that demand flexibility has a potential to improve the operational conditions of the network, reducing losses and increasing renewable energy sources (RES) hosting capacity. These benefits are more relevant for networks operating close to the operational limits, since this flexibility can contribute to deferring upgrade investments.

INTRODUCTION

This paper evaluates the use of load flexibility and hoe it can contribute to provide benefits both from an operational and from a network planning perspective. The research presented in this paper was developed for the SuSTAINABLE European project, supported by the 7th Framework Programme and considered the network of Evora, which was part of the demonstration sites of the project.

In particular, a customer was identified as potentially being able to control its consumption profile according to network operational conditions, influencing network parameters at any given moment. A survey was made to that customer, assessing the flexibility that could be offered. Based on the customer's preferences, realistic scenarios were considered for the simulations of load flexibility. Finally, according to the results of these simulations, the business case for the provision of the customer flexibility to the DSO was analysed. This considered the time horizon until 2030 and followed the methodology that was described in the JRC reference report [1].

CASE STYDY DESCRIPTION

The SuSTAINABLE project demonstration was associated with the existing project InovGrid, located in Evora. Therefore, the analysis that was done assessed a HV and MV network located in that municipality.

The case study and the methodologies description are in the deliverable 6.2. of SuSTAINABLE: "Description of tools integration on infrastructure" [2].

The selected customer is connected to the MV network through a 30 kV feeder associated with the Caeira HV/MV substation. The substation has two Power Transformers (PT), with a combined 63 MVA installed capacity. These transformers are connected to two MV busbars – one 15 kV and the other 30 kV. In Fig. 1, the Evora network is shown and the customer is marked with a white square.

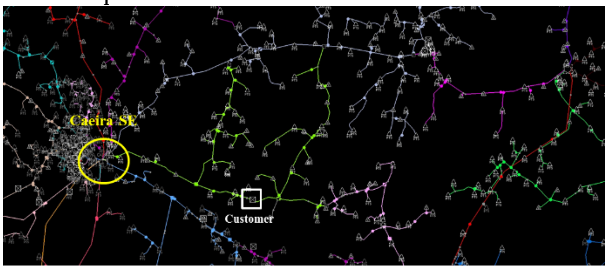

Fig. 1 Evora Network and selected customer for load flexibility

The customer represents 20% of the total installed capacity of Bairro da Vigia feeder contributing, in 2014, to about 50% of the feeder's total consumed energy. Fig. 2 illustrates the average daily of:

- Power measured in 2014 for the 60/30 kV PT (in yellow, the right axis);
- Consumption of Caeira Substation (in grey, right axis);
- Power of the B. Vigia feeder (blue colour, left axis);
- Customer's consumption (orange colour, left axis).

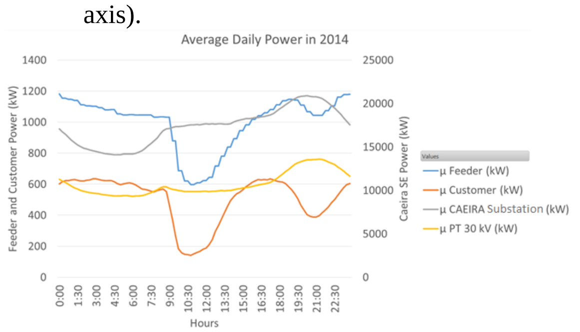

Fig. 2 Average Daily Power in 2014 for the customer, feeder and the substation.

Customer peak demand occurs between 22 PM and 9:30 AM. The feeder has a similar load diagram as the customer, while Caeira substation behaves differently, showing mostly an urban consumer profile (with peak hours occurring between 19 PM until 22 PM), with some industrial consumer profile during the day. The substation is located within an urban area, while also

feeding part of Evora's industrial area.
The substation had a peak load of 34.9 MW in 2014. The transformer and the 30 kV PT, with 31.5 MVA, had in the same year a peak power of 19.1 MW. The correlation for 2014 between the customer demand and Bairro Vigia's feeder is 70%, which means that they have a similar behaviour. However, the customer and the substation have a very different load diagram (correlation equals to *-2%*).

LOAD FLEXIBILITY AND USE CASES SELECTION

In order to achieve benefits for the DSO, this customer is willing to perform load shifting, by reducing the customer load at 1/3 of his consumption during the substation's peak at 22 PM (Fig. 2) and by transferring it to the period between 9:00 to 14:00 AM.
To analyse the benefits of such load shifting actions, various simulations of Evora network were done, involving the comparison of a baseline situation with the case of load flexibility, which is enabled through a market actor. This market actor, also referred as Virtual Power Plant (VPP) can be an actor that has contracts with many consumers, based on which they can be controlled to provide flexibility services.
The network was characterized by focusing on the peak load diagram occurred in 2014. In Fig. 3 the peak load profile occurred on the 17th of July for the baseline scenario (left side) and for the simulation of demand flexibility (right side) is shown.

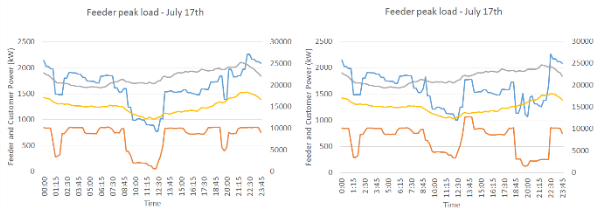

Fig. 3 Substation peak load Daily Load profile.

The network simulations included the current scenario (2014), along with demand growth until 2020 and 2030, also referred to as "central" scenario. This analysis also included an evaluation of a maximum demand growth scenario (with 90% confidence level of not being exceeded), i.e., a scenario of high demand growth rates. Furthermore, the Bairro Vigia feeder does not have any producers, but Caeira substation does have two PV producers associated with it, each with 1 MVA of installed capacity. Therefore, scenarios for 2014, 2020 and 2030 that consider hypothetical PV producers in the feeder were also considered. In this situation, demand flexibility also contributes to voltage control benefits, by transferring consumption to the periods with high PV production, increasing in this way the RES hosting capacity. Finally, Evora's network is robust, with solid feeder cross section. Therefore, a final "what-if" scenario simulation was included, assuming that the Caeira substation has just one power transformer with 31.5 MVA installed capacity, instead of the two existing transformers.
In summary, the analysed scenarios were the following:

- S1 – Actual Situation;
- S2 – Feeder with hypothetical PV power plant;
- S3 –Caeira substation with only one PT.

The flexibility benefits for each scenario were evaluated according to the KPIs presented next and calculated based on the JRC reference report [1] and the deliverable 2.4 of the SuSTAINABLE project [3].

Deferred T&D Capacity Investment (KPI1)	*DTDCI*
Reduction of Technical Losses (KPI2)	ΔL
Increasing of DER (Distribution Energy Resource) Hosting Capacity (KPI3)	*HC*
Share of Electrical Energy produced by RES (Renewable Energy Sources) (KPI4)	$\Delta\lambda$
Voltage and Power Quality (KPI5)	Δd_v, ΔPNS
Reduction of Carbon Emissions (KPI6)	ΔCE
Reduction in DER cut-off due to congestion (KPI7)	ΔE

SIMULATIONS

The simulations results are presented in the deliverable 6.3. of the SuSTAINABLE project "Final detail impact assessment report" [4].

Scenario 1

The first simulation refers to the Evora network. Peak current on the feeder was 45.7 A. With a reduction of the demand of the customer to 1/3 of the actual load at peak hours, the feeder peak current is reduced to 33.7 A, contributing to the total load reduction at 30kV PT of Caeira substation.
For this scenario, no excessive voltage variations or overcurrent occurred for the study period on both load growth scenarios. The network losses were reduced, as a result of the customer demand flexibility. The results for the losses benefits are presented in Table 1.

Table 1 KPIs results for S1

Year	Central		90%	
	ΔL (kWh)	KPI2 (%)	ΔL (kWh)	KPI2 (%)
2014	8265	-0.2%	8265	-0.2%
2020	11912	-0.2%	15598	-0.2%
2030	20350	-0.3%	26745	-0.3%

Scenario 2

For the S2 scenario, the insertion of a PV producer in Bairro Vigia feeder was simulated, located at two thirds of the distance from the substation to the end of the feeder. The PV producer is shown in Fig. 4. For this simulation, the load diagram of an existing PV producer was used, connected to Caeira Substation.

Fig. 4 Scenario 2 grid simulation

The losses are calculated for the peak power of Evora network, as in S1. To calculate the KPI associated with the increase of RES, the increase of the installed capacity of the PV producer was simulated until the allowed network limit was reached.

Simulations were done for two situations, the base case and the demand flexibility case. In the baseline scenario, overvoltages occurred with a 10.15 MVA PV producer. In the flexibility scenario, overcurrents occurred in three sections of the feeder with a 10.55 MVA PV producer. Therefore, the demand flexibility increased the DER hosting capacity by 400 kVA. Consequently, the DER cut-off was reduced by 432 MWh annually (assuming 1,080 hours of utilization of installed capacity).

The reduction of CO2 emissions was also estimated, assuming that renewable marginal production reduces the production associated with CCGT (Combine Cycle Gas Turbine) power plants, and that these emit 0.35t CO2/MWh [5]. The total energy produced is equal to the load energy, and the PV produces approximately 10.9 GWh in the baseline and 11.3 GWh in the flexibility scenario, obtaining a carbon reduction emission of about 150 tons.

Finally, the customer flexibility eliminates overvoltages at the point of common coupling of the PV producer. Voltage deviations that are within the voltage limits established by the Quality of Service Regulation (which refers to EN 50 160) are not considered as benefits.

In Table *2* and in Table *3* the results for S2 with both demand growth scenarios are shown.

Table 2 KPI results for S2 for the "central" case

Year	ΔL (kWh)	HC (kW)	Δλ (%)	Δdv (%)	ΔCE (ton)	ΔE (MWh)
2014	**6421**	390	0,5	-0,5	-151	-432
2020	**9662**	342	0,4	-0,6	-132	-379
2030	**17160**	390	0,5	-0,7	-149	-427

Table 3 KPI results for S2 for the maximum demand growth

Year	ΔL (kWh)	HC (kW)	Δλ (%)	Δdv (%)	ΔCE (ton)	ΔE (MWh)
2014	**6421**	390	0,5	-0,5	-151	-432
2020	**12861**	335	0,4	-0,6	-134	-383
2030	**22731**	383	0,5	-0,8	-149	-427

Scenario 3

In S3 it was assumed that Caeira substation has just one 31.5 MVA power transformer. The Caeira demand is expected to reach 31 MVA in 2020 and 37 MVA in 2030. On that year, suppressed demand would be 5.5 MVA (37 – 31.5 MVA). The demand flexibility associated with the customer reduces the supressed demand, which leads to power not supplied benefits, ΔPNS. The customer flexibility contributes to a reduction of 14% of power not supplied in 2030.

Furthermore, the investment in a new power transformer can be deferred for 2 years. For this KPI the discount rate of 6.75% was used, which is accepted by the Portuguese regulator and used by the DSO for investment planning. The same simulations were made for the maximum demand growth scenario, where this constraint appears firstly in the 4th year, and since the load is higher, the investment deferral is just for 1 year.

In Table 4 the results for this scenario are presented.

Table 4 KPI results for S3.

Year	Central			90%		
	DTDCI (k€)	ΔL (kWh)	ΔPNS [kW]	DTDCI (k€)	ΔL (kWh)	ΔPNS [kW]
2014	0	8898	0	0	8898	0
2020		12660		59 €	16492	710
2030	117 €	21367	770		27981	870

COST BENEFIT ANALYSIS RESULTS

The cost benefit analysis for the provision of the load flexibility considered for the studied time horizon all the expected benefits for each scenario and the cost of providing the service. This cost does not include the installation costs of telemetering and communication infrastructure at the site of the consumer, since installing such equipment would not be done only for the provision of this service. A sensitivity analysis was also carried out for each business case, with regards to the maximum load growth scenario. Deliverable 7.3 of SuSTAINABLE Project can be used for more details [6].

The results of the cost benefit analysis for S1 are shown in the left side of Fig. 5 . The results for the variation of the demand growth on S1 are also shown in the right side of the figure.

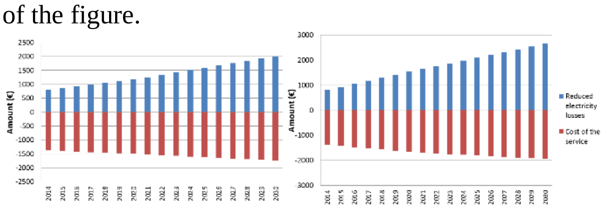

Fig. 5 Cost benefit analysis results for load flexibility – S1

The values for 2014, 2020 and 2030 were calculated and a linear evolution was assumed for the values in the intermediate years.

The benefits for the reduced electricity losses increase every year, and on year 2026 the business case becomes positive for the DSO. For the whole period, the DSO would have a net monetary loss of 3,138 €. This value indicates a small loss for a 15-year time horizon.

If a larger demand growth over the following years is assumed for the current network (right side in Fig. 5), the DSO can have a monetary benefit of 841 € and the business case starts being positive from year 2022.
The results for S2 are shown in Fig. 6, for the expected demand growth (left) and for the larger demand growth (right).

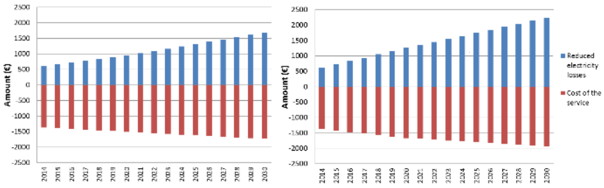

Fig. 6 Cost benefit analysis results for load flexibility – S2

The reduced losses benefit is lower, due to the integration of the PV producer. The DSO monetary loss over the whole study period was calculated at 7,395 €. If the PV producer installed in the feeder had 10.15 MVA it would originate voltage violations, and therefore the feeder would have to be reinforced. The estimated cost of reinforcement is 106,423 €. According to the Portuguese regulation, this cost would be covered by the producer. However, it demonstrates that the load flexibility can reduce the overall system's costs.
For the case with the larger demand growth evolution the loss of the DSO is 4,289 €, which is lower than the one calculated for the use case's initial demand growth scenario.
The results of the cost benefit analysis for S3 are shown in Fig. 7.

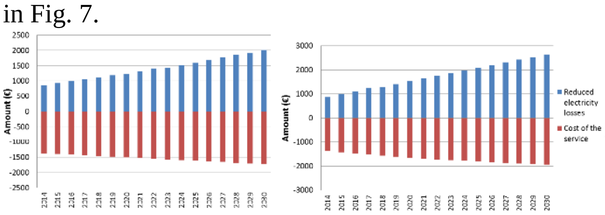

Fig. 7 Cost benefit analysis results for load flexibility – S3

It should be noted that this Figure includes only the operational costs, however in this case investment costs were also considered. Load flexibility can defer the network investment by 2 years, from 2021 to 2023. The deferred distribution capacity investments are added to the results presented in Fig. 7, estimating for the DSO a net present value of 110,939 €. This indicates that the use of load flexibility can have a large benefit for the DSO if it contributes postponing investments in network upgrade.
The results for the reduced electricity losses and the cost of the service for the larger demand growth are presented also in Fig. 7 in the right. In this case, the upgrade in the baseline case would be required in 2017, whereas load flexibility can defer in this case the investment by only one year. For the whole study period the net present value for the DSO associated with using load flexibility is 59,817 €.

CONCLUSION

The business case indicated that load flexibility has a potential of ensuring benefits to the DSO, especially when the network is operating close to its limits. Three different scenarios were analysed, all considering the network in Evora and the load flexibility of an industrial consumer.
The first scenario considered the actual network, which doesn't include RES, and studied the potential benefits for the DSO associated with the load flexibility. The net present value presents a negative value, which is almost negligible considering the 15-year time horizon. The sensitivity analysis showed that, for a larger demand growth, the business case becomes positive.
The second scenario included a PV producer associated with the analysed feeder. The business case failed to yield positive results for the expected demand growth. Even for a larger demand growth, the sensitivity analysis indicated that the net present value still does not present a positive for the analysed period. However the benefits become larger than the costs in 2026. In both cases, the load flexibility can introduce monetary benefits for the owner of the PV. According to the Portuguese regulatory framework, this is a cost covered by the PV owner; therefore, it was not included in the business case of the DSO.
The third scenario considered that the primary substation only has one transformer. It was proven that the load flexibility contributed to investment deferral and, considering also the reduced losses benefits, the business case was positive for the DSO, for both load growth scenarios considered.

REFERENCES

[1] JRC Reference Reports, "Guidelines for conducting a cost-benefit analysis of Smart Grid projects", 2012.

[2] SuSTAINABLE Deliverable 6.2, "*Description of tools integration on existing infrastructure*"," 2015.

[3] SuSTAINABLE Deliverable 2.4, "*KPI Assessment Methodology*"," 2013.

[4] SuSTAINABLE Deliverable 6.3, "Final detail impact assessment report"," 2016.

[5] See, M., (2001) Greenhouse Gas Emissions: Global Business Aspects, New York, NY: Springer

[6] SuSTAINABLE Deliverable 7.3, "*Economical interactions of entities controlled by VPP for providing potential services to enhance the operation of distribution networks*"," 2015.