TECHNICAL ANALYSIS OF AN AGGREGATOR'S OPERATION FOR THE GOTLAND POWER SYSTEM

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ABSTRACT

The large scale deployment of distributed generation from renewable energy sources may undermine the network safe operation and may require network reinforcements. In order to avoid or postpone the infrastructural investments it is possible to exploit other resources. In this paper the operation of a load aggregator is simulated on the Swedish island of Gotland in different wind penetration condition to test two different business models, one oriented to the price following and the other oriented to the wind following. The adopted methodology is described and the results presented and commented.

INTRODUCTION

The state of the art of communication technology together with the structure of the energy market make Demand-Side Management (DSM) a feasible solution, able in principle to bring significant benefits to all the actors involved in power system management. Since the single end users do not have the size to significantly affect the power system on their own, they have to be managed as a whole in order to successfully implement DSM solutions. There is the need of an entity, usually named aggregator, which takes care to gather and manage the end users in order to pursue its objectives. The business models on which such a system could be based are several and have to be chosen taking into account the characteristics of the system in which the aggregator is going to operate [1] [2].
This paper presents a study about the implementation of an aggregator on the Swedish island of Gotland. The aggregator's mission is to balance local wind generation and electricity consumption acting on the end users heat load profiles in order to minimize the power flow and the losses on the HVDC cable that connects the island with the mainland. The study has been performed within the frame of the Smartgrid Gotland project [3].

BUSINESS MODEL

As previously stated the aggregator's business model has to be defined according to the characteristics of the environment in which the aggregator is going to operate. In this study two different business models have been considered.
In the first one the aggregator operates according to a "price following" logic trying to maximize the heat load when the energy price is low and minimize the heat load when the energy price is high. In the second case the aggregator operates according to a "wind following" logic trying to match the local wind generation with heat load.
In both cases the aggregator sells its services to the Distribution System Operator (DSO) which remunerates the aggregator in proportion to the generated savings. In the case of Gotland, the DSO has in fact to pay the Transmission System Operator (TSO) for the transmission losses on the HVDC cable which are related to the energy spot price. A more extensive and detailed investigation about the aggregator business opportunities on Gotland may be found in [4].
The enrolment of the end users to the aggregator's portfolio is assumed to be driven by the possibility for the end user to know the electricity consumption in real time, which on its own can produce a 10% saving on the electricity bill [6], the contribution to the reduction of the electric energy carbon footprint all without decreasing the comfort level.

PROBLEM FORMULATION

Every day the aggregator has to calculate the best heat load profiles for its service providers for the next day. This is accomplished by solving an optimization problem in which the function to minimize depend on the adopted business model.
In the price following case the function to minimize is the product between the electric energy spot price and the heat load of the service providers.
In the wind following case the function to minimize is the difference between the forecasted load and the forecasted wind generation, i.e., the power flow on the HVDC link.
The constraints are basically on the indoor temperature in the individual households which has to be kept within the assigned comfort thresholds.
It is assumed that the aggregator can control the electric heating of 13500 households sorted in three different categories:

- summer houses,
- medium houses,
- passive houses.

Summer houses are typically uninhabited during the winter and heated only to avoid damage due to the low temperatures. Medium houses are regular villas and passive houses are larger buildings compliant with the current standard for passive houses in Sweden [5]. The assumed parameters for the different service providers clusters are summarized in Table I.

Table I Service providers parameters

Concept	Symbol	Summer house	Medium house	Passive house
Quantity	K	5750	5750	2000
Installed power [kW]	P^{max}	3	5	8
Temperature setting [°C]	T^{ref}	15	20	20
Minimum Temperature [°C]	T_{min}	10	18	19
Maximum Temperature [°C]	T_{max}	25	22	21
Thermal resistance [W/K]	Λ	100	75	60
Time constant [h]	τ	75	150	300

NETWORK MODEL

A power system model has been used to simulate the network behaviour with and without the aggregator. The model is basically limited to the subtransmission system and is made up of a 75 kV meshed network and several transformers that provide connection with the lower voltage level nodes where wind generators and loads are located. Since the data come from a model used to evaluate the network hosting capacity the wind generators data are quite detailed while the loads are represented as MV aggregate. The model is implemented in the Matpower [7] environment and used to perform static power flow calculations.

In the absence of more precise information the service providers are spread among the different load nodes considering that in the larger towns the building heating is mainly provided by district boilers the majority of the passive houses are located in the nodes with low load while medium and summer houses are placed among the nodes with high load.

SCENARIOS

Static power flow simulations are run in order to analyse the effects of the aggregator operation on the power system in terms of power flows, voltages and losses. The whole heating season is simulated using historical data of load, wind, outside temperature and energy price. Since these data are only available as aggregate figures for the whole island they are spread among the nodes according to the rated values of the wind generators and load connected. Also simple rules for the reactive power dispatch and voltage regulation are implemented so that the network safely operates during the whole heating season in the base case.

The two different aggregator strategies are investigated in two different wind penetration conditions.

- 2010 settled value (114 MW installed, 99 MW peak production)
- two times the 2010 settled value (200 MW peak production).

The base load is the same for all the simulated scenarios equal to the 2010 historical value when the peak consumption was 183.5 MW.

INDICES

In order to compare the different business models in the different wind penetration scenarios some indices are calculated. These indices have a technical and economical nature and provide a numeric assessment of the effects of the aggregator strategies on the network. The adopted indices are:

- aggregator profit
- network losses
- HVDC power flow
- bus under voltage
- bus over voltage
- line overload

Aggregator profit index

The money earned by the aggregator expressed in € according to (1)

$$profit(h) = P_{HVDC}^{2}(h) \cdot \beta \cdot \lambda_{market}(h) \quad (1)$$

where P_{HVDC} is the power flow on the HVDC cable, λ_{market} is the energy spot price and β is a loss coefficient (equal to $5 \cdot 10^{-4}$).

Network losses index

Since the aggregator profit only depends on the losses on the HVDC cable the figure of the network active power losses is given because a reduction of the losses on the HVDC cable does not imply a general reduction of the losses on the whole network.

HVDC power flow index

The active power flow on the HVDC link with the mainland in MW.

Bus under voltage index

The number of buses which experience a voltage below 90% of the rated value at least once in the heating season. The total number of hours is calculated as well.

Bus over voltage index

The number of buses which experience a voltage above 110% of the rated value at least once in the heating season. The total number of hours is calculated as well.

Line overload

The number of branch elements which experience an apparent power flow above 100% of the rated value at least once in the heating season. The total number of hours is calculated as well.

RESULTS

In Fig. 1 and Fig. 2 the relative frequency histograms of the power flow on the HVDC cable with and without the aggregator in the 100% wind penetration scenario are depicted. Fig. 1 refers to the wind following strategy while Fig. 2 refers to the price following strategy.

In Fig. 3 and Fig. 4 the relative frequency histograms of the power flow on the HVDC cable with and without the aggregator in the 200% wind penetration scenario are depicted. Fig. 3 refers to the wind following strategy while Fig. 4 refers to the price following strategy.

The analysis of the obtained results reveals that in the low wind penetration scenario the wind following strategy only marginally modifies the histogram. This is because the wind generation is always consistently lower than the load thus, the aggregator has to try to limit the heat load in the moments in which the wind blows strong but then it has to deal with the payback effect due to the users comfort constraints. On the other hand the price following strategy is more effective in altering the HVDC power flow but according to its logic it changes the load in function of the price, despite the wind. For the high wind penetration case instead the wind following strategy succeeds in increasing the time in which the power flow on the HVDC cable is low. Dually the price following strategy is in this case less effective in changing the distribution of the power flow because the modifications in the heat load profiles are statistically compensated by the wind generation.

In Table II the indices calculated in the various simulations are reported. It is evident that, due to the lack of correlation between the local wind energy production and the energy spot price, the price following strategy grants higher profit than the wind following one. It has to be noticed that while the wind penetration increases the profit increases in the wind following and decreases in the price following suggesting that a break-even point exists between the two strategies.

The network losses general trend is to decrease with increasing wind generation penetration; the only exception is the price following with high wind generation which has larger network losses than the no aggregator and price following cases.

Finally the wind following does not imply any major voltage and overload issue while the price following causes some over voltages and overloads in a limited number of buses and lines. This happens when the wind blows strong but the price is high so the local load is reduced by the aggregator and the extra power has to be evacuated otherwise generating the aforementioned violations.

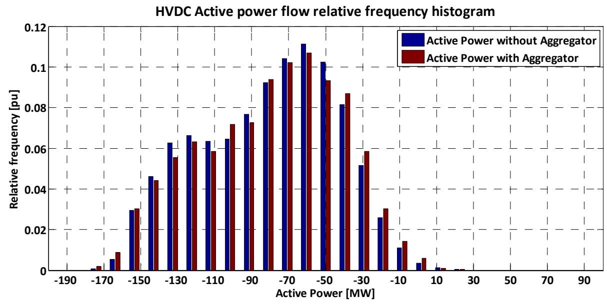

Fig. 1. Relative frequency histogram of the power flow on the HVDC cable during the heating season with and without the aggregator assuming the adoption of the wind following strategy in the 100% wind penetration scenario.

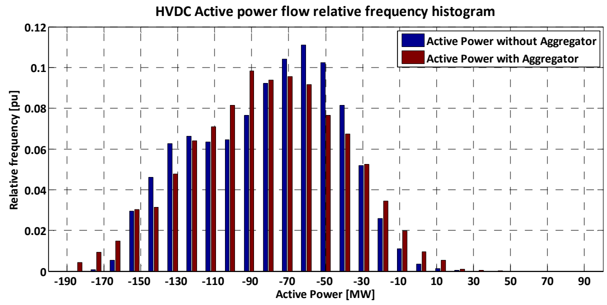

Fig. 2. Relative frequency histogram of the power flow on the HVDC cable during the heating season with and without the aggregator assuming the adoption of the price following strategy in the 100% wind penetration scenario.

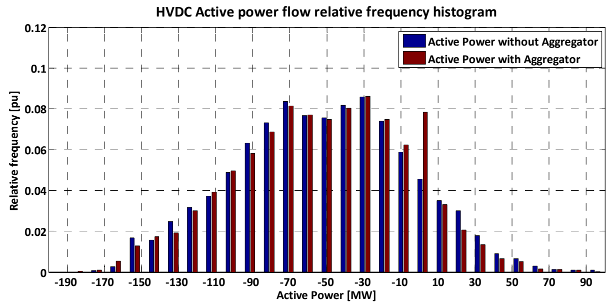

Fig. 3. Relative frequency histogram of the power flow on the HVDC cable during the heating season with and without the aggregator assuming the adoption of the wind following strategy in the 200% wind penetration scenario.

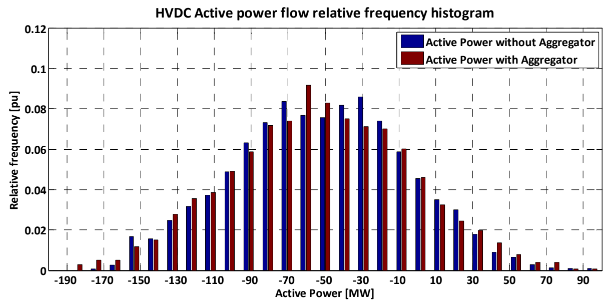

Fig. 4. Relative frequency histogram of the power flow on the HVDC cable during the heating season with and without the aggregator assuming the adoption of the price following strategy in the 100% wind penetration scenario.

Table II Simulation results

Scenario	Profit [€]	Network Losses [MWh]	Bus under voltage	Hours under voltage	Bus over voltage	Hours over voltage	Line overload	Hours overload
No aggregator 100% wind	0	15247,58	0	0	0	0	0	0
No aggregator 200% wind	0	13935,91	0	0	0	0	0	0
Wind following 100% wind	16965,03	15240,68	0	0	2	4	1	203
Wind following 200% wind	25796,41	13792,76	1	1	0	0	1	1
Price following 200% wind	51665,43	14260,15	0	0	6	376	3	636
Price following 100% wind	77270,14	14831,95	0	0	4	223	3	646

CONCLUSIONS

The results confirm that in the present conditions the price following strategy is the one that grants the higher profits. On the other hand this strategy not only does not decrease the HVDC cable's load but generates some power quality issues and also increases the network power losses. This fact might have a negligible economic effect since the losses are increased at points of low electricity price. This could mean that the total loss, when compared to the no-aggregator strategy, is a better deal assuming that the DSO pays for network losses according to the spot price.
No one of the proposed algorithms implies major problems for the network. The registered violations persist for a small portion of the heating season and only regard a few elements.
It is evident that the success of the different strategies strongly depends on the wind penetration conditions and on the regulatory frame which have to be duly taken into account at the moment when the business model is chosen. It has also to be noticed that the aggregator's service providers, i.e. the final customers that form the aggregator's portfolio, are located at the low voltage levels of the distribution system but the adopted network model only consider the subtransmission network and the loads are modelled as MV aggregates. So the effects of the aggregator's strategies in the different wind penetration condition should be investigated also taking into account the distribution system.

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