Economic evaluation of Active Network Management alternatives for congestion avoidance - the DSO perspective

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***Abstract*—The introduction of distributed renewable energy generators in the electricity grid implies a number of challenges for energy suppliers and utilities. One of these challenges is the increased risk for grid congestion issues due to the installation of large amounts of e.g. solar panels and wind turbines to the existing grid. As alternative to costly grid reinforcements several Active Network Management (ANM) techniques to mitigate this risk are researched, including (1) dynamic line rating and (2) demand side management. In this paper, we make an economic evaluation of those options from a Distribution System Operator (DSO) perspective. We discuss the aforementioned techniques and elaborate their business case for a specific use case in the MV-grid. Our calculations show that dynamic line rating can be considered as an alternative to network reinforcement, depending on the regulatory framework**

***Index Terms*—Active Network Management, Smart Grid, Storage, Dynamic Line Rating, Demand Side Management**

I. Introduction

The share of Distributed Renewable Energy Sources (DRES) in the worldwide energy generation is becoming increasingly important. This trend is stimulated by governmental initiatives such as the EU "20-20-20" targets [1], that aim to increase the share of renewable energy sources, and reduce energy consumption and emission of greenhouse gasses. The power grid was however not designed to support this type of local energy production. The distributed and intermittent nature of DRES introduces several new challenges for energy producers and utilities with respect to balancing of supply and demand and preserving power quality. In this work, we focus on the specific challenge of grid congestion issues due to the introduction of wind turbines in the distribution grid.

Distribution System Operators (DSOs) planning the connection of wind turbines to an existing part of the grid are confronted with the question how to mitigate the risk for network congestion as cost-efficiently as possible. Traditionally, DSOs anticipate the risk with network reinforcements, which require considerable investments. Therefore, several alternative solutions, so-called Active Network Management (ANM) techniques, are being studied, in order to reduce, defer or avoid the network investments by the DSO.

A first assessment of the economic impact of several ANM techniques for a basic use case in [2] showed that power flow management techniques combined with DLR allow to integrate up to 67% of additional distributed generation. Furthermore, [3] simulates the potential of demand response solutions for congestion management in distribution networks, focusing on a concrete use case in Sweden. The simulations show that 1900 residential DSM-participants are sufficient to balance out 5 MW of additional generation in the distribution net.

The main contribution of this paper is the economic evaluation of two ANM techniques – Dynamic Line Rating (DLR) and Demand Side Management (DSM) – in comparison to the network investment option, simular to the approach in [2], but focusing on specific aspects. Summarized these aspects can be described as follows: (i) The economic evaluation is done from the DSO perspective, with the focus on congestion avoidance. (ii) A realistic case study is performed for a Medium Voltage (MV) network, in which a considerable amount of new wind turbines will be installed. (iii) The impact of the regulatory situation on the business cases is evaluated.

First Section II provides a clear view on the studied ANM techniques. Section III presents the used test network, the scenarios and the business case assumptions. Section IV quantitatively compares the business cases, while Section V summarizes the conclusions and future work.

II. Active Network Management Techniques

A. Dynamic Line Rating

Dynamic Line Rating (DLR) helps the network operator to dynamically assess the capacity of individual power lines and cables, in order to reduce the risk of line overloading during operation. This way, DLR allows that lines and cables fully utilize their maximum capacity for transmitting electric power.

Previous work has shown that DLR has the potential to increase the capacity of existing power lines. The application of DLR to defer network reinforcement due to the introduction of wind turbines has been described in [4] and in [5], more specifically for overhead lines in the transmission network. An extensive use case that demonstrates the potential of DLR to resolve transmission capacity constraints is elaborated in [6].

In this paper, the potential of DLR will be studied for a MV case with underground cables in the distribution network. The dynamic limits will be calculated based on measurements of the cable temperature, which represents a relatively low investment cost. Wind — an important parameter in DLR calculations for overhead lines — is not taken into account in the calculations for underground cables.

B. *Demand Side Management*

Demand side management (DSM) is a portfolio of measures to improve the energy system at the side of consumption, and can be categorized in the following: Energy Efficiency, Time of Use, Spinning Reserve and Demand Response. Demand Response (DR) can be described as the changes in electric usage by customers from their normal consumption patterns in response to changes in the price of electricity over time [7]. The different types of Demand Response and the benefits related to the introduction of DR are discussed in [7],[8] and [9]. A clear view on the regulatory requirements and market models for demand response is given in [10].

The focus of this paper will be on incentive based demand response, more specifically the interruptible/curtailable programs. Based on feedback of the DSO participating in this study, this type of DR programs appears to be the most suitable for congestion avoidance. In these programs, customers receive an incentive in exchange for agreeing to reduce or increase their load in case of network congestion. As we are looking at industrial customers in the MV-network, the exact incentive details will be part of a commercial agreement. Nevertheless, different incentive mechanisms can be distinguished:

- *Reservation fee*: the DR-participant receives an incentive payment in function of the flexible amount of power-demand he can offer, independent of the number and duration of the events during which the flexibility is requested — although obviously certain limitations will be included in the commercial agreement.
- *Activation fee*: the DR-participant will receive an incentive payment in function of the amount of flexible energy demand he offers, each time the flexibility is actually called upon.
- *Combination* of reservation and activation fee.

At this point in time it is quite difficult to assess a realistic level of incentive payment for industrial DR-customers. As starting point in our work we assume a DSM activation fee of €30/MWh. Afterwards, the maximum incentive level is calculated that would still make the DSM case profitable compared to the situation where no investments are made to avoid congestion issues in the grid.

III. Test Case

A. *Network*

The study is performed for a medium voltage network of a Belgian DSO. A single-line diagram of the network is depicted in Fig. 1, where 17 locations of new wind turbines to install are indicated.

Simulations using realistic wind profiles over the course of a full year have shown that the installation of these wind turbines will cause congestion issues in the grid, resulting in 4 wind turbines that need curtailment in order to avoid current congestion. These 4 wind turbines are distributed over

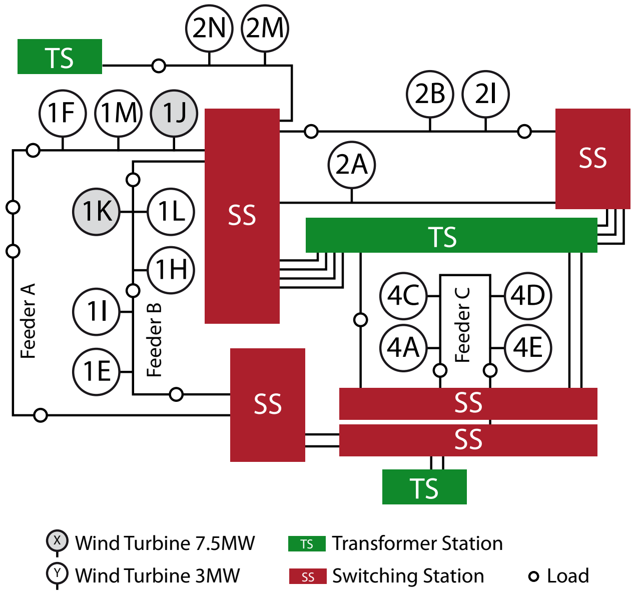

Fig. 1: Line diagram of the Test Network

3 feeders: feeder A (1M & 1F), feeder B (1H) and feeder C (4A).

Table II shows the characteristics for each feeder, including the length of the feeder and the length of the congested cable segment.

B. *Options*

Following options will be compared in the business case evaluation:

1) No investments: no specific investments will be made. In that case, the benefits and costs for the DSO are related to the compensations that have to be paid to the wind turbine owner every time a wind turbine has to be curtailed due to congestion issues in the MV grid. The amount of the compensation strongly depends on the regulatory framework (see further).

2) Network reinforcement: the DSO will invest in extra underground cables in order to avoid all congestion issues and corresponding curtailment. In this case, only the segment where the congestion issues occur is reinforced.

3) Dynamic Line Rating: DLR equipment is installed on the feeder, allowing to avoid a part of the curtailment.

4) Demand Side Management: DSM equipment is installed on several customer sites on the feeder, allowing to avoid a part of the congestion issues and corresponding curtailment.

C. *Scenarios*

As the regulatory framework for curtailment of wind turbines in Belgium has not been defined in detail up to now, we will elaborate the business cases for 2 scenarios corresponding to different regulatory situations. An important aspect of the regulatory framework are green certificates. Green certificates represent the environmental value of renewable energy and are used by several countries (e.g., Belgium) to support the generation of green energy in a standardized way. For

Network Reinforcement	Cable cost: 104€/meter
DLR	DLR equipment: 1000€/feeder
DSM	DSM equipment: 15k€/participant

TABLE I: Investment costs

example, a wind turbine owner will receive green certificates corresponding to the production of the wind turbine for a period of 15 years. In the situation of curtailment of a wind turbine for congestion avoidance, the wind turbine owner will miss out on energy revenues and subsidies corresponding to green certificates, and should be compensated for this.

In the first scenario, we study the situation where the wind turbine owner is fully compensated for the curtailed energy and lost green certificates. As we assume that the DSO will pay for the green certificate of the wind turbine owner in the situation without curtailment, the compensation for the lost green certificates is not considered as an additional cost for the DSO.

In the second scenario, we assume that 2% of the energy produced by all wind turbines on a feeder can be curtailed by the DSO for congestion avoidance purposes without the obligation to pay compensations to the wind turbine owner. In this case, following the same reasoning as in scenario 1, the avoided compensations for the green certificates for 2% of curtailed energy can be considered as a benefit from DSO perspective.

D. Methodology

The reference point for the business case comparison is the no investments option. In this option, all congestion issues are addressed by curtailment of the wind turbines. The costs and benefits for this option correspond to the curtailment-compensations that have to be paid to the wind turbine owner.

In options 2 to 4, the amount of curtailed energy will be strongly reduced (even reduced to zero in option 2), resulting in considerably lower compensations payments. The amount of curtailed energy in the no investment option can be considered as the flexibility that has to be provided by the ANM techniques in option 3 and 4. The costs and benefits of delivering this flexibility are the input for the business case for the different options.

The business cases will be elaborated for each scenario, option and feeder by calculating the Net Present Value (NPV). NPV is a method to use the time value of money to appraise long-term project and is calculated as follows:

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

In our calculations we assume a period of 20 years (N) with a discount rate of 3.35% (i). R_t is the net cash flow (revenues minus costs) for the year t. The more positive the NPV result, the more interesting the option is for the DSO.

	Feeder A	Feeder B	Feeder C
Lenght of cable-segment	1.25 km	0.79 km	1.08 km
Curtailed energy	2254.80 MWh	2175.58 MWh	280.80 MWh
Max flex required	3.128 MW	3.002 MW	1.545 MW

TABLE II: Details per feeder

	Feeder A	Feeder B	Feeder C
1. No investments	100%	100%	100%
2. Network reinforcement	0%	0%	0%
3. DLR	31.4%	5.8%	61.8%
4. DSM (assumption)	20%	20%	20%

TABLE III: Percentage of curtailed energy.

E. Business Case Assumptions

The energy price and green certificate values are assumed to be €48.8/MWh and €68.8/MWh respectively, corresponding to the values used in the long term business evaluations by the DSO participating in this study. As periods with network congestion are likely to have lower energy prices, a variable energy price over time would result in a more realistic business case. Energy price variability will be included in future research.

The investment costs are different for each scenario as listed in Table I.

The specific assumptions per option are as follows.

1) No investments:

- The energy that needs to be curtailed per feeder to avoid congestion is given in Table II.

2) Network reinforcement assumptions:

- The length of the cable that is reinforced (segment or complete feeder) is given in Table II.
- The reduction of the network losses due to the cable investment is considered as a benefit.

3) DLR assumptions:

- The dynamic cable limits are calculated based on temperature measurements, as this method represents limited investment costs and energy losses.
- DLR does not offer a solution for cases of voltage congestion.
- In this case study only underground cables are present, so no overhead lines are included in the DLR calculations.

4) DSM assumptions:

- 20% of the customers on each feeder individually, are assumed to participate in the DSM program and will be able to offer 80% of the required demand flexibility.
- In the business case comparison an activation incentive fee of €30/kWh is assumed.
- The DSM-participants will be requested to increase (or decrease) their electricity consumption when congestion occurs. It is likely that there will be a reduced (or increased) demand of the DSM-participant after the congestion event, i.e. the so-called rebound effect [7]. This rebound effect is assumed not to cause network congestion at a later point in time.

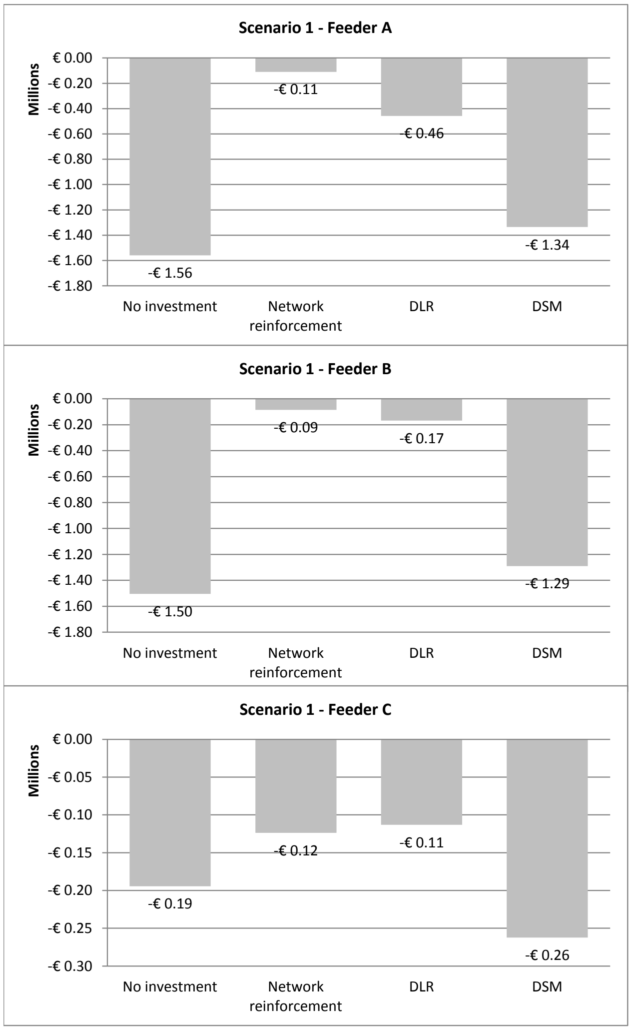

Fig. 2: Business Case comparison - Scenario 1: Green certificate compensation

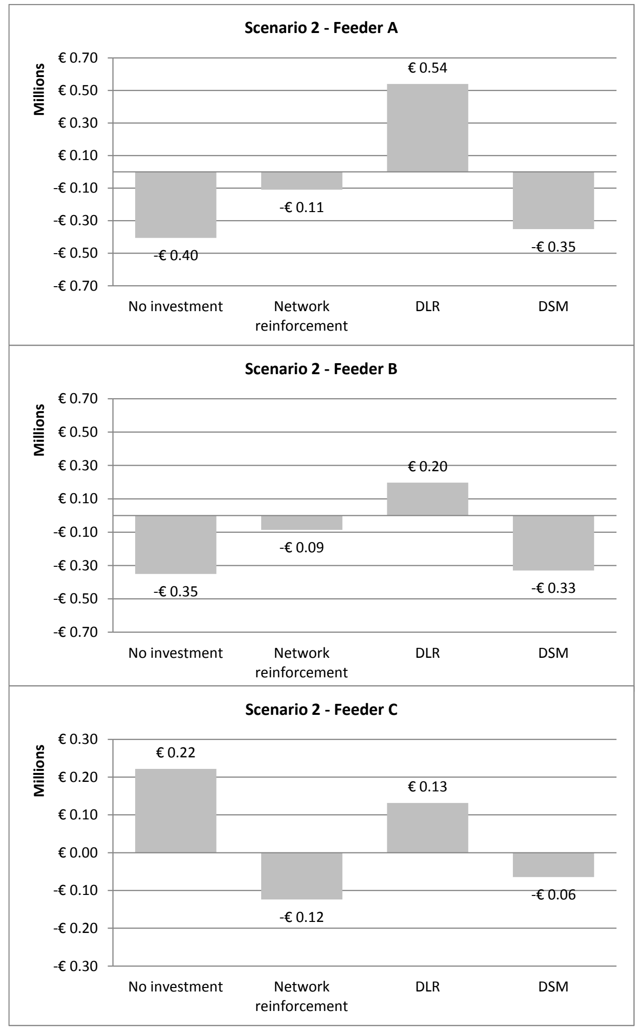

Fig. 3: Business Case comparison - Scenario 2: 2% curtailment allowed

- The impact of the location of the flexible loads on the feeder is not taken into account in the calculations. Obviously, the location the DSM-participant on the feeder is a very important factor, as the congestion issue has to be addressed locally, and will be part of future studies.
- The flexibility of the demand is assumed to be offered in periods of 1 hour, resulting in an amount of flexible demand that is higher than the actual curtailed energy.

Each option amounts to a different percentage of curtailment that can be avoided. Table III shows an overview of the amount of energy that still has to be curtailed after introduction of the respective solution.

IV. Business Case Results

A. Scenario 1

The results for the business cases of the different options for scenario 1 can be found in Fig. 2.

When comparing the NPV values, one can see approximately the same proportional results for the different feeders, with the network reinforcement as the most profitable option, followed by DLR and DSM. For feeder C, the feeder reinforcement option is slightly less interesting than DLR, due to the relatively limited amount of congestion that occurs in this feeder.

DLR can be considered as the economically most interesting ANM technique. Although the DLR business case is less profitable than the network reinforcement case for feeder A and B, it is clear that the length of the reinforced network segment is an important factor. Therefore, we have calculated the theoretical tipping point, i.e., the segment length for which the DLR business case becomes more profitable than the network reinforcement case. The results of this calculation can be found in Table IV. It can be seen that the tipping point is relatively lower in case the amount of required flexibility is low (as in feeder C) or when the percentage of curtailment that can be avoided by DLR is high (as in feeder B).

DSM is economically less interesting than network reinforcement and DLR. On the other hand, DSM can be considered as more interesting than the no investments option for feeder A and B feeders (for our assumed activation incentive of €30/MWh). When the amount of curtailed energy is low (feeder C), DSM becomes even less interesting than the no investment option.

To assess under what conditions DSM would become profitable, we have calculated the maximum DSM-incentive that results in a business case that is more profitable than the no investments option, both for the activation fee and reservation fee incentive mechanism. The results per feeder can be found in Table V. The results for feeder A and B are comparable, as the amount of curtailed energy in these feeders is in the same range. When the amount of curtailed energy is low (as in feeder C), it can be seen that the maximum incentive payment is relatively low as well.

B. Scenario 2

The business case results for scenario 2 are shown in Fig. 3. In this scenario, the DSO is assumed not having to pay any compensations for curtailment up to 2% of the feeder production, resulting in a benefit due to the green certificates that do not have to be paid nor compensated for. This benefit implies a positive business case DLR option for all feeders.

For feeder C, where the amount of curtailed energy is lower than 2% of the feeder production, this also results in a positive NPV for the no investment option. For this feeder, the no investment option is the most interesting from the DSO perspective.

For feeder A and B, DLR is the economically most viable option, as it allows to reduce the curtailed energy below 2% of the energy produced in the feeder and still benefits from the avoided green certificate compensations. The relative difference with the network reinforcement result strongly depends on the amount of curtailment that can be avoided.

The maximum DSM incentives for scenario 2 are also included in Table V. As the no investments option is relatively less expensive, the maximum incentives for feeder A and B to make DSM still more profitable are considerably lower for scenario 2. Given the positive NPV for the no investment option in feeder C, the maximum incentive payment can not be calculated for this feeder.

	Feeder A	Feeder B	Feeder C
Segment length	7666 m	2245 m	939 m

TABLE IV: Cable length corresponding to tipping point between DLR and network reinforcement business case

	Feeder A	Feeder B	Feeder C
Scenario 1			
Activation fee (€/MWh)	37.3	37.3	12.2
Reservation fee (€/MW/y)	32108.4	32162.1	2661.1
Scenario 2			
Activation fee (€/MWh)	32.7	31.08	NA
Reservation fee (€/MW/y)	18401.8	17192.6	NA

TABLE V: Maximum DSM incentive to make it more profitable than the no investments option.

V. Conclusion

In this paper we have studied the business cases for two ANM alternatives in a specific MV-network. This comparison provides a view on the economic viability from DSO perspective for each option.

The calculations show that DLR can be an interesting alternative to network reinforcement. This strongly depends on the following factors: (i) the amount of curtailed energy per feeder and the percentage that can be avoided by DLR, (ii) the length of the reinforced cable segment and (iii) the applicable regulatory framework.

DSM appears to be more profitable than the no investments option in most cases and the maximum incentives corresponding to this situation are calculated. On the other hand, DSM is clearly more expensive than the network reinforcement and DLR option (under the current assumptions, which we believe are representative of current tariffs and relatively conservative regulation).

Future work will evaluate the business case for the Active Network Management techniques in further detail, for example by studying combinations of different ANM techniques, e.g. in order to address both current and voltage congestion issues. We will also look into the operational aspects of the ANM techniques, taking forecasts of wind production and local consumption into account. Furthermore, the impact of the location of the flexible loads in the DSM option will be studied.

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