PILOT PROJECT USING CURTAILMENT TO INCREASE THE RENEWABLE ENERGY SHARE ON THE DISTRIBUTION NETWORK

Tine L.Vandoorn*, Lieven Degroote*, Pieter Lindeboom*, Dieter Meire*, Lieven Vandevelde+, Patrick Reyniers*

*Eandis - Guldensporenpark 52 Zwijnaarde
9800 Merelbeke, Belgium
Tine.Vandoorn@Eandis.be; Patrick.Reyniers@Eandis.be

+Ghent University – Technologiepark-913, 9052 Zwijnaarde
Lieven.Vandevelde@UGent.be

ABSTRACT

Going to a green electricity landscape needs to cover not only the cost of the renewable production units, but also the cost for their full integration in the system. Hence, the additional costs of congestion and balancing need to be considered as well. Solving congestion issues by investing in new grid assets can be a costly and time-consuming way to integrate new renewables to the grid. Hence, the Belgian distribution network operator Eandis started a pilot project on wind turbine control where a traditional connection would not have been possible for the wind turbines. This 'smart' connection solves congestion issues and allows more renewable energy on the grid. This seems contradictory, but controllability does not necessarily mean curtailing, as discussed in the paper. It signifies an opportunity for better utilizing the grid assets and allowing more green energy production units in the electric power system. This paper discusses the results of the pilot project.

INTRODUCTION

The transition to a "green" energy landscape can only be gradual and will be a long journey. The biggest challenge to facilitate this transition is to act in the right way at the right time [1]. Flexibility of as many grid assets as possible will play an important role [4,5]. However, adding flexibility into the energy landscape will only be possible if the right policies, control systems and market mechanisms evolve at the same pace [1].

The paper [1], presents the triangle of efficiency, shown in Figure 1. To achieve global efficiency of the new green energy landscape, the three efficiency types depicted in this triangle are important. The triangle test entails that a solution designed to help on one of the three axes should always have no or only a positive impact on the other axes.

Energy efficiency is the most commonly used definition of efficiency, i.e., using less energy. However, efficiency of usage of the networks is also very important. The right network architecture will allow local generation to flow to nearby demand points. This will reduce losses on the network and on investments.

Financial efficiency means consuming at the lowest possible cost, while taking into account the impact of the cost of the networks. Building a network that can integrate all peaks of energy will cost a lot more than trying to optimize the usage of these networks.

Green efficiency demands that we should optimize and maximize the usage of green energy with the goal to reduce greenhouse gas emissions.

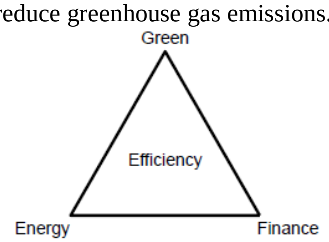

Figure 1 The triangle of efficiency

Taking the triangle of efficiency into account when integrating new wind farms is a challenge for distribution system operators (DSOs). Hence, the objective of the Belgian DSO Eandis for "more green efficiently integrated in the grid" led to the start-up of a pilot project in the left bank of the Scheldt in the Antwerp port area. In this pilot project, new wind turbines are connected to the medium-voltage network [3]. These wind turbine are called the "smart wind turbines" as they are equipped with several control algorithms. The motive for the control actions is firstly, to avoid actual congestion issues, and secondly, to conduct test cases concerning congestion on one of the assets in the distribution or transmission grid, i.e., technical flexibility. These test cases investigate the potential of active network management (ANM) to facilitate the integration of large volumes of renewable distributed generation (DG) without the need of traditional reinforcements [6].

In this paper, the main results of the project, focusing on 'more green in the grid' and 'more renewable production by controlling the wind turbines' are presented.

PILOT PROJECT

The cost of producing energy from wind or sun is the summation of the cost of the wind turbines or solar panels and their installation and other indirect costs such as network investments and the cost of the necessary balancing power to maintain the instantaneous and structural balance [1,7]. Today, this is an additional cost of about 40% as shown in Figure 2 [2]. This figure shows the expected cost of wind power as a function of the wind power penetration in the electric power production. This cost is the summation of the integration and generation costs of wind power, showing that the integration costs also need to be evaluated. Hence, grid costs, including the costs to solve congestion issues have a large impact on the integration of DG units in the grid.

Traditional connection of DG units

The traditional way of integrating DG units to the grid is to integrate the units when a network study showed that they will not cause congestion issues, including in worst case situations. Otherwise, investments in the grid assets – often significantly delaying the renewable projects –need to be made. Furthermore, for security reasons, distributed generation (DG) units can be required to turn off in degraded network situations.

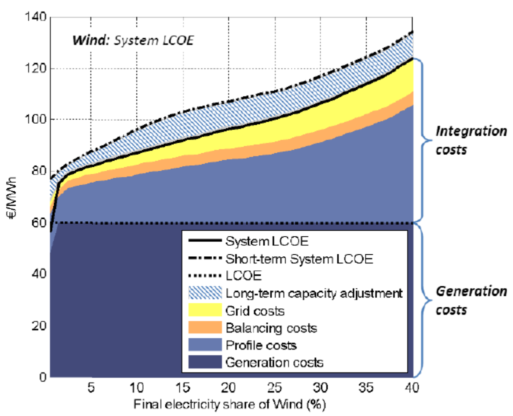

Figure 2 Additional integration cost of wind turbine integration in the power system [2]

The integration of renewable energy sources in the distribution network is often limited by voltage issues (mainly in low-voltage (LV) networks) or current issues (mainly in medium-voltage (MV) networks). This was also the case in the left bank of the Scheldt in the Antwerp port area where a large onshore wind park of over 15 new wind turbines was integrated, with even more turbines requested. Six of them already caused congestion problems.

The HV/MV transformer feeding the area where the turbines are connected to could be congested in N-1 situation. The network operates in N-1 situation when, for instance, one of the two transformers is turned off, e.g., because of failure or maintenance reasons. This congestion problem in N-1 operation is possible, but has a low probability, because of the low probability of concurrent high injection, low consumption and N-1 occurrence. Still, with the traditional approach of integrating new units to the grid, this would have prohibited several wind turbines to be installed in the short term, i.e. in the existing infrastructure of the distribution network. Therefore, in 2015, these six wind turbines were installed in a “smart manner”, i.e., they are automatically controlled by the DSO Eandis to avoid congestion problems

Smart control for integrating renewables

The aim of this pilot project is to investigate how technical flexibility can be committed to avoid/reduce/delay investments in the grid assets (cables, transformers) of the transmission system operator (TSO) and/or the DSO by maximally using the existing infrastructure. This, of course, without compromising the reliability of the network, while maximizing the renewable energy production (or even increasing it compared to using a classical connection of the assets), and to significantly lower the connection times of new DG units. The park was set up as a pilot park for investigating smart control algorithms. The results from the pilot project indicate that by providing the possibility to curtail wind turbines, more DG units can be integrated in the distribution network with minimal investments and more renewable energy can be generated. This is illustrated for the case of congestion management.

Increase of hosting capacity thanks to smart control

In the considered area, two HV/MV transformers of 50MW each are present, each separately feeding part of the power (N situation). The limits shown in Table 1 are limits given by the TSO of the total power through the transformer station that is considered in the pilot project, i.e. summation of the two transformers. The percentages are with respect to the nominal power of one transformer.

When one transformer is turned off, the power of the whole area is redirected to one transformer (N-1 situation).

< 90%	Continuously allowed (both in N and N-1)
90% - 130% of the nominal power through one transformer	Installation allowed, if in N-1 condition, this power is reduced to < 90% in 15min

Table 1 Limit of power through the transformer station

The loading of the HV/MV transformers in harbor area was studied. The 90% limit is exceeded in worst-case situations, with simultaneity factor equal to one. This is the situation that is considered in the traditional way of connecting the units to the grid, because reliability of the electric grid is utterly important. With traditional control, larger MV/HV transformers needed to be installed. Hence, an alternative for this was proposed using flexible control algorithms for installing these wind turbines on the existing local network.

Control algorithm

The control algorithm is visualized in Figure 4. When the measurement through the congestion point (here the active power through a HV/MV transformer) exceeds the control upper limit, the active power setpoints of the smart wind turbines are decreased such that the active power goes back to the control point. A setpoint of active power of a wind turbine denotes the maximal value the unit is allowed to produce. When the current goes below the control lower limit, the setpoint is again increased.

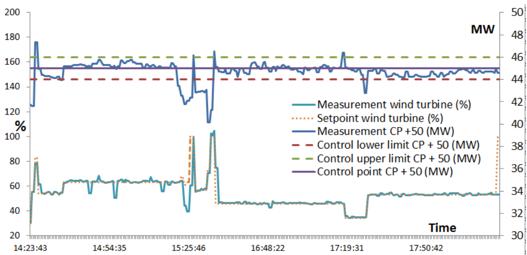

Figure 3 Flexibility with respect to TSO transformer

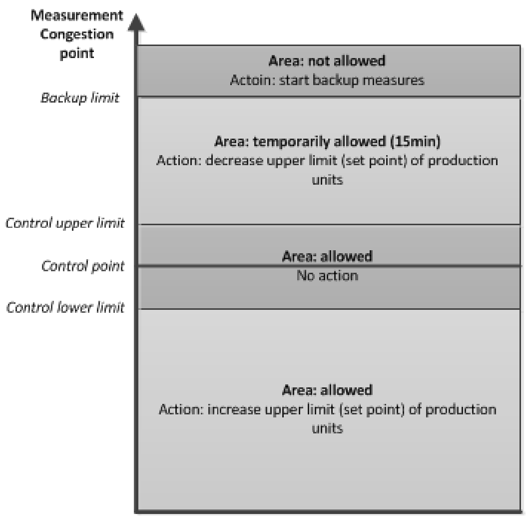

Figure 4 Control algorithm for smart wind turbines

TEST CASES

In the pilot project, several test cases are considered. Below, two cases with respect to current congestion are discussed.

a) Flexibility with respect to HV/MV transformers

When one of the two redundant HV/MV transformers fails, the power output of the smart wind turbines connected to the transformers is reduced when necessary. The curtailment is shared in a pro rata manner among the smart wind turbines. This complies with the aim for connecting more production units on a transformer station, i.e., better utilizing both transformers in a normal network situation, while still obtaining the first objective of a reliable network operation.

The test results of such test are depicted in Figure 3. All measurements in MW refer to the right ordinate, the ones in % refer to the left one. 50MW is added to the measurements in MW. The control point in the congestion point (HV/MV transformer) equals 45MW, with control upper limit 46MW and control lower limit 44MW. Set points are sent to the smart wind turbines (here called APs) such that the power through the transformer is in the control band, and only exceeds the upper control limit during a short amount of time (maximally 15min). The result of active power output of one of the smart wind turbines is depicted in the figure. Around 15h20, the power at the congestion point (CP) level, i.e., the transformers, is under the control band. Hence, the control algorithm calculates new setpoints for the wind turbines, here 100%, and sends them accordingly. When the current through the CP is in the control band, there are no new setpoints calculated. Around 17h15, the current is above the upper control limit, enforcing a lower setpoint to be sent to the wind turbines.

These tests are performed in real-life in the port area. From the tests, it is shown that a) wind turbines react well and sufficiently fast to the setpoints, b) the control algorithm is able to restrict the power at HV/MV transformer level. In this way, more wind turbines are allowed on MV networks without additional investments as a) the probability of an unplanned N-1 situation concurrently with high injection and low consumption in the local MV network is low and b) the control algorithm proves its operation.

b) Flexibility with respect to DSO Feeders

The same control concept is used for limiting the current through distribution network feeders, i.e., for delaying or avoiding investments in these distribution lines which should have been required in a worst-case situation. Again, the aim of controlling wind turbines is to allow more wind turbines to be connected in the existing infrastructure where the expected curtailment is low. Opposed to the previous test case, in this test case, only one wind turbine influences the feeder current, hence, only this turbine is controlled.

Figure 5 shows the results of changing the control limits in order to see the effect of the current on the temperature in the line, here called the PA50 line. The maximal current in the line is gradually decreased. The three lines above in parallel are the upper control limit, the control point and the under control limit of the congestion point (CP). The line in between those is the current measurement in the cable. The lowest lines are the setpoint and measurement of the wind turbine (AP) in %. The current in the CP is well in between the control limits.

The points with the highest temperatures are the ones where the cable is positioned vertically to go below some obstacles. Although the test started with high currents through the line, the temperature remained below its 90 degrees Celsius maximal value. Also, the time constant of temperature changes is somewhat slower than that of current changes as depicted in Figure 6. The blue line shows the current through the cable (same as in Figure 5) and the other lines show the temperature in different locations in the cable.

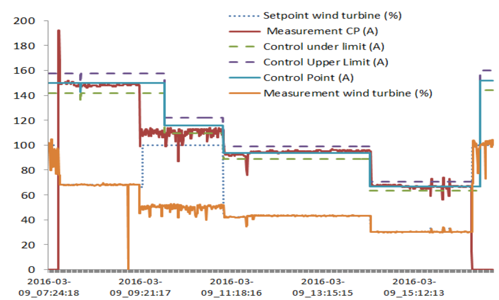

Figure 5 Testing of current limiting in small line

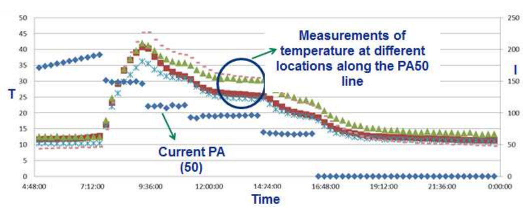

Figure 6 Temperature measurements in the line during the test

MORE RENEWABLES, LESS INVESTMENTS

a) Key figures

For the period from 01/11/2015 until 09/08/2016, an analysis of the production of the wind turbines in the park has been made.

Traditional connection of a distributed generation (DG) unit indicates that the unit can produce all available power under normal circumstances. It also implicates that it can produce no power in an abnormal situation, for reliability reason. The produced energy if the six smart wind turbines would have been connected with this traditional connection type, equals:

Totally produced energy if the wind turbines would not have had a smart connection (MWh)	30,288.4

Note that in the pilot project, without smart connection, a traditional connection would not have been possible for these six wind turbines. Hence the total produced energy would in fact have been 0MWh in the short-term, i.e., until additional investments would have been made, such as new HV/MV transformers.

Smart connection of a DG unit indicates that the unit can produce active power also in an abnormal network situation. The maximal value can however be restricted to avoid network congestion issues. In the pilot project, the control algorithms for this are fully automated by Eandis in the distribution management system. For the first testing period, the produced energy of the six smart wind turbines as they are installed with this connection type, equals:

Totally produced energy with smart connection (MWh)	38,767.7

The spectacular difference of 8,473.3 MWh (almost 28% more production because of the smart control) is due to four abnormal network situations at the connection point between the HV and MV networks in the considered period.

Result of control actions

The energy production and the curtailed MWh because of the smart control are given in Table 2. The column “All” indicates the curtailed energy in normal and abnormal (N-1) situation. The column “N” indicates the curtailed energy in the normal operation situation. The reason for curtailed energy in the normal situation is that in the pilot project, the control algorithms are tested and the test case “Flexibility with respect to DSO Feeders” is performed in normal situation.

During the test period, several (abnormally) long periods have taken place where only half the transformer capacity was available. Thanks to these smart control algorithms, the wind turbines were able to produce as shown in Table 3. The row {2} denotes all produced energy if the smart control algorithms would not have been installed. This equals the total produced energy as is with smart control minus the injected energy during abnormal network situations plus the curtailed energy during normal network situation. The latter amount of energy is due to the testing of the control algorithms in N situation.

The additional energy production during abnormal network situations is calculated based on an estimation of the available wind power provided by the transmission system operator.

Produced energy (MWh)	38,767.7	
Curtailed energy		
	All	N
Curtailed energy (MWh)	41.1	35.5
Curtailed energy (%)	0.106	0.092

Table 2 Percentage curtailment for the period 01/11/2015 until 09/08/2016

Additional energy production during abnormal network situations (MWh)		
Start N-1 event	End N-1 event	Total
01/02/2016 8:12	19/02/2016 11:54	3676.2
22/02/2016 8:42	04/03/2016 13:06	1696.2
07/03/2016 7:57	07/03/2016 9:37	0.5
07/03/2016 14:35	13/04/2016 13:36	3164.6
Injected energy during N-1 events		8537.4
{1} Total produced energy with smart control		38767.7
{2} Total produced energy without smart control		30288.4
{3} Extra produced energy because of smart control		8479.3
{4} Percentage extra produced energy because of smart control (%)		28.00

Table 3 Abnormal network situations for the period 01/11/2015 until 09/08/2016

MONITORING WEBSITE

The pilot project is made possible by close cooperation of a large number of partners, the DSO Eandis, the TSO Elia, the provider of Eandis' distribution management system GE, the forecasting provider 3E, the universities of Ghent and Leuven, Siemens, and the wind park developer *Wind Aan de Stroom*. Because of this close cooperation of partners, and for further research targets, a monitoring tool has been developed. This monitoring tool combines the wind turbines' output, the transformer output, other local renewable generators' outputs, wind power forecasting for each smart wind turbine, curtailment events and the reason for curtailing the wind turbines. This enables a swift monitoring by the partners involved.

CONCLUSIONS

The paper discusses some results of the smart wind turbine pilot project in the left bank of the Scheldt in the Antwerp port area in Belgium. The project proves that by equipping wind turbines with smart control algorithms that are centrally managed in the distribution management system of the DSO, wind turbines can be integrated 1) in a swifter manner 2) with less investments. Because of the controllability the wind turbines can be integrated in the existing network. This leads to a better integration of renewable energy sources with more green energy capturing and reduced investments as a result.

Acknowledgements

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