Application of ramp limitation regulations for smoothing the power fluctuations from offshore wind farms

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Abstract

This paper deals with the smoothing regulation strategies for reducing the effects of the wind farm power fluctuations. Concretely, realistic available power is obtained from an aggregated simulator of an offshore wind farm, developed and validated in previous papers. Being curtailed the power through positive ramp limitation and through a delta constraint linked with a negative ramp limitation. Then, the smoothing of the fluctuations is compared for an equivalent energy cost. Showing the reduction in the reserve requirements and ramping rates the power system needs for compensating them.

1 Introduction

Regarding the integration of wind energy in power systems with high wind penetration, the power fluctuations are a relevant issue for maintaining the balance between generated and consumed power. Because of the fluctuating nature of wind speeds, the increasing use of wind turbines for power generation has caused more focus on the fluctuations in the power production of the wind turbines, especially when the wind turbines are concentrated geographically in large wind farms. Those fluctuations can also be a security issue in the future for systems with weak interconnections like Ireland or the Iberian Peninsula.

As example of the significance of these power fluctuations in Energinet.dk (the Danish Transmission System Operator), according to [1], Energinet.dk has observed that power fluctuations from the 160 MW offshore wind farm Horns Rev in West Denmark introduce several challenges to reliable operation of the power system in West Denmark. And also, that it contributes to deviations from the planned power exchange with the Central European Power System

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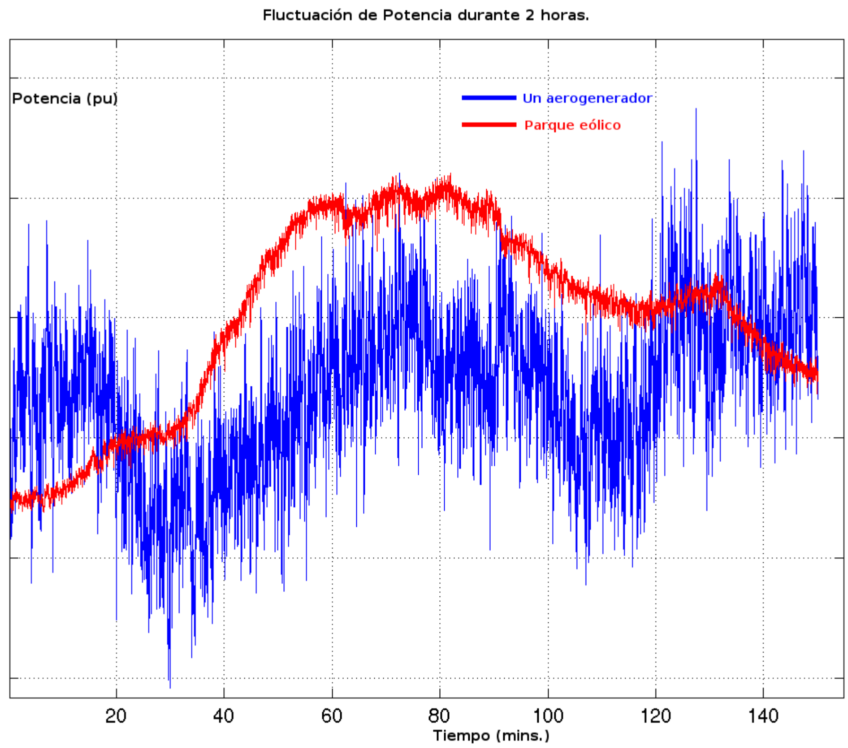

Figure 1: Example of power fluctuation when the wind farm is working under the nominal power.

(UCTE). Moreover, it was observed that the time scale of the power fluctuations was from tens of minutes to several hours.

As example of those fluctuations, in the figures 1 y 2, the power fluctuation in a wind turbine (WT) and in the whole wind farm is shown in 2 different normal situations.

Such fluctuations are characterised and modelled in papers like [2]. Specifically, the aggregated model used hereinafter is described and validated in [3, 4].

In this paper, is studied the use of regulation strategies, found in [5], for smoothing the effects of such fluctuations.

2 Simulation case & Power Fluctuation analysis

The simulations have been done using the layout and the characteristics of Nysted Offshore Wind Farm. That Wind Farm is compound by 72 Bonus 2.3MW WTs (now Siemens).

The needs of regulation in the electrical system, in order to compensate the fluctuations of large wind farms, is being considered by using the definition of ramp rates and reserve requirements found in [2]. These definitions are based

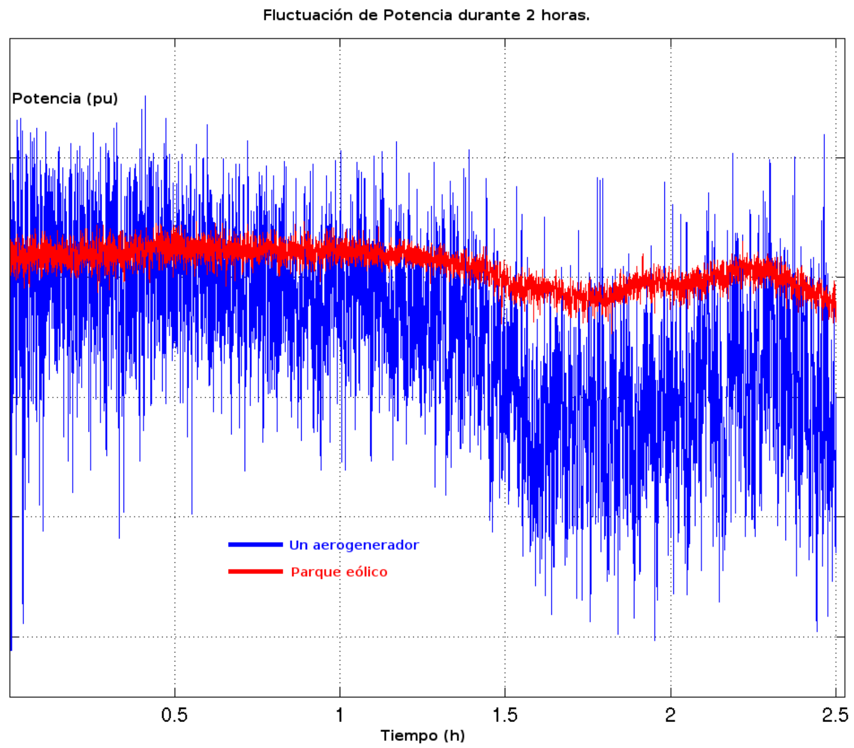

Figure 2: Example of power fluctuation when the wind farm is working around the nominal power.

on the load following and regulation definitions [6], which can be applied to different time scales (T), here the focus is fixed mainly in 30 minutes periods.

Dividing the series of simulated or measured power generated in the wind farm $(P(t)$) into smaller series of length T $(P_n(t))$, the ramping rate $(P_{\mathrm{ramp},T})$ between each two small series would be given by

$$P_{\mathrm{ramp},T} = \frac{\overline{P_{n+1}(t)} - \overline{P_n(t)}}{T} \tag{1}$$

where $\overline{P_n(t)}$ is the average of the power production of the wind farm in the n time period of size T.

Therefore these power ramp rates are the ramp requirements the electrical system would have to compensate these fluctuations, keeping constant the production. For instance, this can be done by regulating the other power plants with an opposite ramp.

Another interesting parameter regarding the high penetration wind energy integration is the reserve requirement $(P_{\mathrm{res},T})$. This parameter deals with the energy reserves that have to be allocated in advance, and so it quantifies the difference between the instataneous power in the following period and the averaged power at the current period, i.e.

$$P_{\mathrm{res},T} = \overline{P_n(t)} - \min\left(P_{n+1}(t)\right) \tag{2}$$

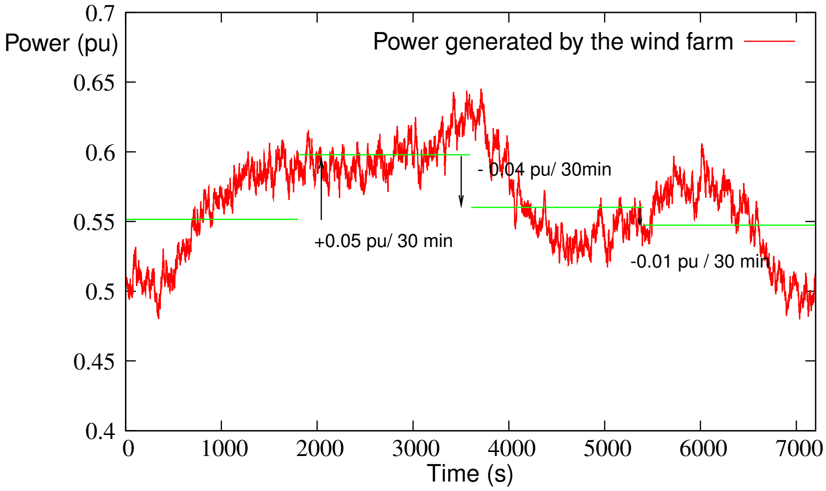

Figure 3: Example of ramping rates of the fluctuations in the power produced by a wind farm.

where $\min(P_{n+1}(t))$ is the instantaneous minimum of the power production of the wind farm during the $n+1$ time period.

In this case, the stronger requirements correspond to the greater $P_{\text{res},T}$, as that fall of energy in the wind farm would be covered by the energy reserves of the grid. For instance, such reserves requirements can be accomplished by using energy storage systems in that time frame and rotational energy depending on the limits of the frequency oscillation fixed by grid codes.

Therefore, in both parameters, the greater requirements are related with the most negative ramp rates or the greatest reserves requirements. Analogously to the way of analysing the electrical loads in power generation, the duration curves are used as a suitable tool for evaluating these extreme conditions. These duration curves are build by ordering in descending order the ramp rates and the reserves requirements. In this way, such curves can be used for calculating percentiles for the most negative ramps and greatest reserves, which is a good way to estimate the general grid requirements for compensating the power fluctuations. In this way, at this work it has been calculated the 1% percentile in the worst case, i.e. the 1%-percentile of greater reserves, or the 1% of more negative ramp rates, which will be called hereinafter the 99% percentile as ramp and reserves are being ordered descending.

3 Application of control strategies

From the available types of regulations in the Danish Code [5], two of them has been selected, because they can also be useful for reducing the effects of the fluctuations. Concretely, the positive ramp limitation ($\lambda_{R,-}$) and the delta production constraint (δ_P) linked with a negative ramp limitation ($\lambda_{R,-}$). An example of the application of these strategies are shown in figures 5 and 6.

When one of those strategies is applied, the resulting power output ($P_{curt}(t)$), which has been curtailed, is less (or equal) than the original available power

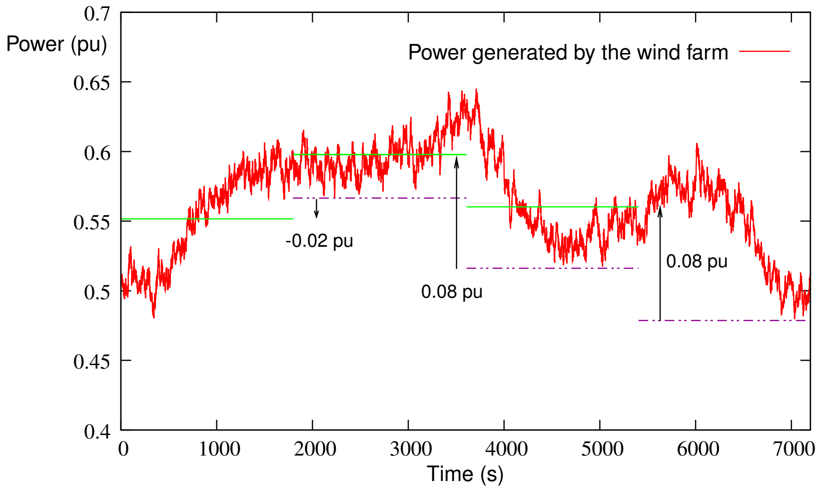

Figure 4: Example of reserves requirement due to the fluctuations in the power produced by a wind farm.

$(P_{aval}(t))$. Being that difference the power losses $P_{leak}(t)$ caused by these regulation strategies.

$$P_{aval}(t) = P_{curt}(t) + P_{leak}(t) \tag{3}$$

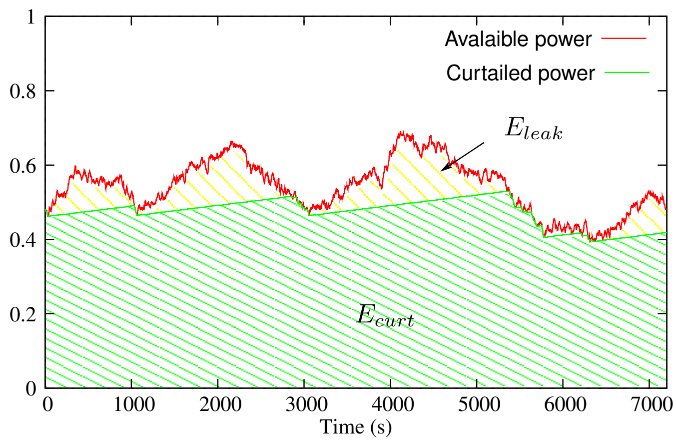

Figure 5: Example of the application of a positive ramp limitation ($\lambda_{R,+} = 0.28\,MW/min$) to 2 hours of simulated available power.

Both strategies are compared by choosing its parameters (limiting ramps, delta value), so that they have a similar cost, in this case an energy cost, i.e. the considered parameters are selected for each strategy, so that they produce similar energy leakages (E_{leak}). Being given the energy leakages in a serial of length T_s (here 2h.) by the integral of the power losses in such period.

$$E_{leak} = \int_{T_s} P_{leak}(t)dt \tag{4}$$

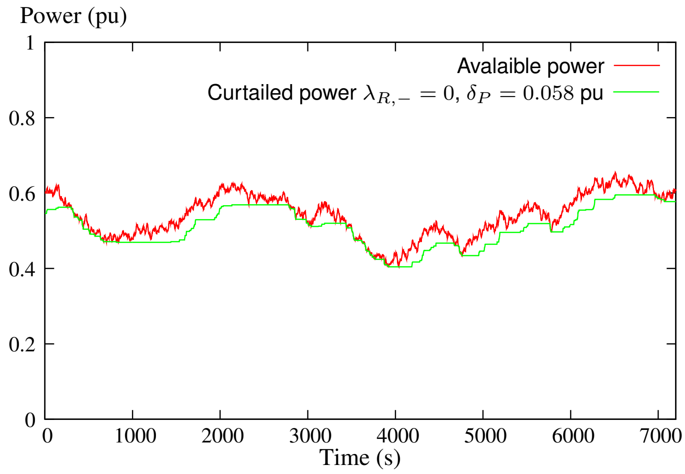

Figure 6: Example of the application of a delta constraint linked with all negative ramp limitation ($\lambda_{R,-} = 0$, $\delta_P = 0.058\,pu$) to 2 hours of simulated available power.

For instance, when calculating the leakage in N_s series, they are calculated by summing the leakage in each serial ($E_{leak} = \sum_{n=1}^{N_s} \int_{T_s} P_{n,leak}(t)dt$). The series used for calculating the available power are generated with random mean wind speed and direction. So that their values are representative of the real ones, e.g. through a Weibull distribution fitted to real data.

In this way, the figure 7 represents the energy leakages depending on the chosen ramp limit $E_{leak} = f(\lambda_{R,+})$. So, the positive ramp limit $\lambda_{R,+}$ corresponding with a 5% of energy leakages is $\lambda_{R,+} = 0.790\,MW/min$ ($0.14\,pu/30min$). And the ramp limit corresponding to a 10% leakage is $\lambda_{R,+} = 0.283\,MW/min$ ($0.05\,pu/30min$). Analogously, for the other type of regulation corresponding

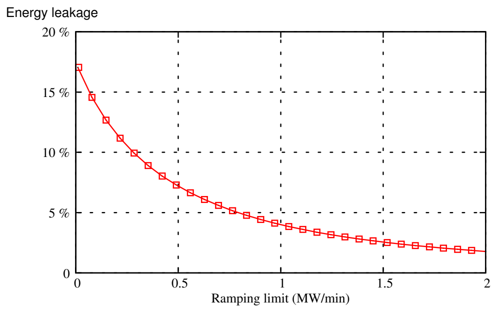

Figure 7: Energy leakage produce by the use of a positive ramp limitation.

with a 5% of energy leakages in the wind farm it is being selecting $\lambda_{R,-} = 0.37\,MW/min$ ($0.07\,pu/30min$), $\delta_P = 0.025\,pu$; and $\lambda_{R,-} = 0$ with $\delta_P = 0.031\,pu$. And when allowing a 10% of energy losses, it is chosen the following cases $\lambda_{R,-} = 0.215\,MW/min$ ($0.04\,pu/30min$) with $\delta_P = 0.05\,pu$; and $\lambda_{R,-} = 0$ with $\delta_P = 0.058\,pu$.

Then, the smoothing effect is studied by comparing the change in the percentiles corresponding to the ramp rates and reserve requirements for the curtailed power in each case with regard to the ramp rates and reserves requirements of the available power.

Concretely, when applying the delta constraint, the reserve requirements get reduced in near a 5% with regard to their original value when the control strategy is producing the loss of a 5% of the available energy and a bit less than a 10% when the losses of the control strategy are a 10% as it is shown in the figure 8. However, the reduction in the reserves is proportionally greater for the average wind speeds whose reserve needs are smaller. Furthermore, ramping rates do not reduce significantly.

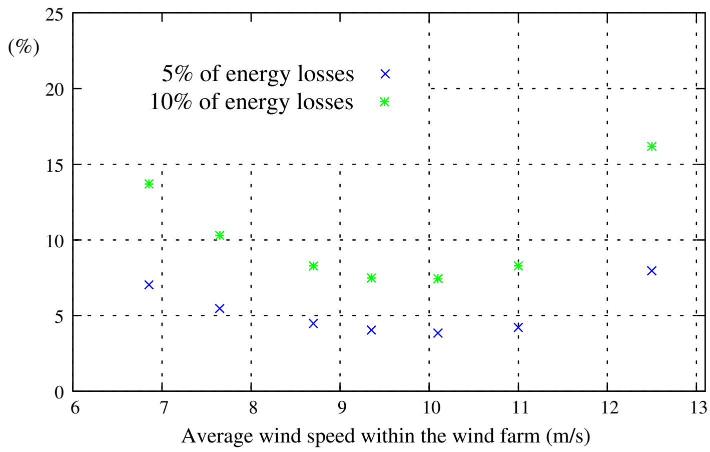

Figure 8: Comparison of the reduction of the reserve requirements (1%-percentile) for the curtailed power with delta+negative ramp limitation characterised by $\lambda_{R,-} = 0$, $\delta_P = 0.031\,pu$; and by $\lambda_{R,-} = 0$, $\delta_P = 0.058\,pu$ with regard to the available power.

On the other hand, the reductions produced by the positive ramp limitation are plotted in figure 9, showing that when the energy leakages are around the 5% of the available energy, this control type reduces the needs of energy reserves, for compensating the power fluctuations, between a 10% and a 15%. Being this reduction in the worst cases ($\overline{V} \in [9,\, 10.5]$ m/s) between 0.04 and 0.05 pu. And for the 10% losses positive ramp limitation, there is a reduction over the 20% of the reserves requirements, being in the worst cases that reduction between 0.06 and 0.08 pu. The 99% percentiles of these rates for the available power, the curtailed power with $\lambda_{R,+} = 0.79\,MW/min$ and with $\lambda_{R,+} = 0.283\,MW/min$ are compared in the figure 10. Where in contrast to the previous control type, the ramp rates are reduced by this kind of limitation. Keeping that reduction more or less constant up to a wind farm wind speed average of 10 m/s. However the effect in the non-linear part of the power curve is not that good, and specially in the case of 11 m/s, where there is not a significant influence on the ramp rates.

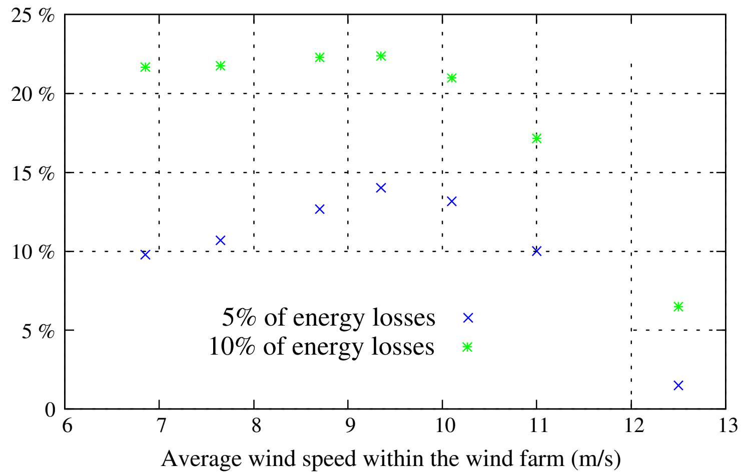

Figure 9: Comparison of the reduction of the reserve requirements (1%-percentile) for the curtailed power with a positive ramp limitation characterised by $\lambda_{R,+} = 0.79\,MW/min$ and by $\lambda_{R,+} = 0.28\,MW/min$ respect the available power.

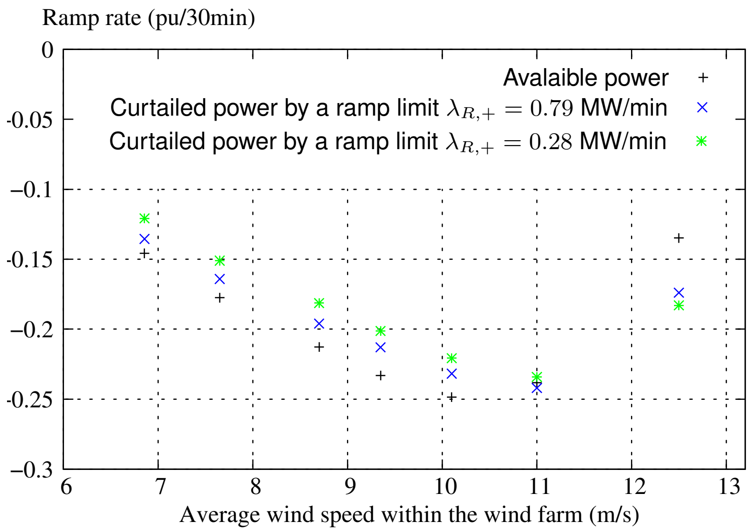

Figure 10: Comparison of the 99%-percentile of the ramp rates for the available power and the curtailed power with a positive ramp limitation characterised by $\lambda_{R,+} = 0.79\,MW/min$ and by $\lambda_{R,+} = 0.28\,MW/min$.

4 Conclusions

An aggregated simulator, for the power fluctuations from offshore wind farms, has been used for analysing different ways of smoothing the power fluctuations. The kind of regulations studied have been chosen from those which are included in the Danish Grid Code, and therefore are implemented at the large wind farms in Denmark. Specifically, the regulation strategies checked have been the delta constraint associated with a negative ramp limitation, and the positive ramp limitation.

The comparison has shown that the positive ramp limitation is a quite better strategy than the other, when considering the reduction of the reserves requirements and also for the ramp rates in the wind farm itself.

Leading the use of positive ramp limitation to a reduction in the reserve needs of around the 15%, being the reduction in the worst cases around 0.04 and $0.05\ pu$ for an energy cost of a 5% of the available energy used for this regulation. If the energy cost of the control is increased up to the 10% of the available energy, then the reserve requirements in the grid, for compensating the power drops in the curtailed power, descend over the 20%. Being that reduction in the worst cases between 0.06 and $0.08\ pu$.

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