A COMPARISON OF DIFFERENT CURTAILMENT STRATEGIES FOR DISTRIBUTED GENERATION

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ABSTRACT

In this article we translate in a planning study different ways to implement curtailment of a DG unit in real time. Two different approaches are presented, one that only relies on measurements and another that employs short term forecast for productions and loads.
Whereas the second technique allows anticipating the constraints, the first one is activated when some thresholds are exceeded and it has therefore been implemented using some security margins.
We show in our example how the curtailment can be implemented in a planning tool using a single DG unit and only to solve current constraints. The operation of the network is simulated in this software for several years, using as inputs 10-minute time step load and generation profiles. Volumes of energy curtailed and number of hours of activation are calculated.

INTRODUCTION

A distributed generation (DG) unit may pose current and/or voltage constraints, during its operation, under given conditions.
In order to solve these constraints, expensive network reinforcement may be required (increasing the cables' sections, upgrading a transformer in the primary substation, etc...). Moreover, these works delay the DG connection. If the constraints due to the DG unit are limited in their occurrence, a smart way to solve them may be to curtail its power generation only when the constraints appear, using so called "Alternatives to grid reinforcement" [1][2].

Reverse power flows are more and more common in distribution LV and MV network with a high share of renewables, most of times in rural areas. There may be moments during the network operation when the combination of low consumption and high generation (wind, PV, etc…) could lead to reverse flows overcharging the primary substation (PS) transformer over its ratings.
Curtailment may be used in these cases as a leverage to avoid replacing the transformer or installing another one. For this reason our focus will be on strategies used to solve current/overcharge constraints.

In this paper we shall analyze different strategies that could be used in implementing this type of curtailment.

These strategies vary depending on the practical implementation of the curtailment technique: whether during its operation a short term forecast is used, which kind of communication and measurements are available during the DG operation, which margins need to be considered, etc...

For this reason we have compared several strategies, four of which have been selected and included in a planning tool (based on DIgSILENT PowerFactory®) that we have previously presented [3]. This tool makes it possible to simulate the operation of the DG unit in a distribution network over multiple years in a fast and precise manner, using 10-minute time step load and generation profiles.
We have therefore been capable of evaluating the yearly duration of curtailment and the volumes of lost energy using the four strategies.
As explained, the calculations detailed here only tackle the current constraints in the lines and transformers.

DESCRIPTION OF THE STRATEGIES

The curtailment order consists in a set point *Pset* of the maximum active power the DG is allowed to inject during the curtailment cycle.

Ideal strategy

The first strategy (that shall be called "P ideal") is the ideal one. It behaves as if the DG unit had a perfect knowledge of the constraints it poses and curtailed itself in an optimal way every 10 minutes.
This strategy is activated when the power flowing in the PS transformer ($P_{transfo}$) exceeds the current/power threshold ($P_{threshold}$) that is chosen according to the thermal limits of the transformer.

The set point will be calculated every 10 minutes, as follows:
$P_{set} = P_{DG\text{-}t0} - \Delta P_C$
$P_{DG\text{-}t0}$ is the power produced by the DG,
ΔP_C is the power to be curtailed,
$\Delta P_C = P_{transfo} - P_{threshold}$

This strategy is a reference and shows the minimum energy that must be curtailed in order to solve 100% of the constraints.

Operational strategies

The other strategies we describe try to imitate a more realistic behavior that could be adopted in the operation of the "active network".

They all monitor the power flow at the PS transformer and/or the current flowing in the lines/cables every 10 minutes and send a curtailment order to the DG when the threshold is exceeded.
The curtailment cycles last 30 minutes and can be repeated several times until a criterion of release is satisfied.

We have supposed that the time of activation is small compared to the 10 minutes cycle in which curtailment calculations are executed. This point will be confirmed when the technical solution is chosen, and its dynamics characterized.
As we shall see the main problem is not in the activation of the first curtailment cycle but that after 30 minutes the algorithm should decide if the curtailment is to be continued or stopped. This is of course difficult since the net power at the HV/MV transformer is the result of the contribution of all the network's loads and generators which can be of different types. Furthermore, those powers are not all measured (for instance the load or the Low Voltage PV generators).
Also, once the generator is curtailed there is no sure way of knowing to which power it will go back if the curtailment order is released. Thus, only estimations of the flow in the transformer after deactivation of the curtailment can be calculated from $P_{transfo}$.
One solution is to use short term forecasts for all the different quantities and aggregate them. This is the strategy that we shall call "P forecast" which will be described in further detail. Its main advantage is the possibility of acting in advance before the constraints appear on the transformer, and are measured.

Strategies without forecast

Firstly, we have tried to devise two strategies that could work without the need for a forecast, but only using $P_{transfo}$ and $P_{DG\text{-}t0}$. $P_{DG\text{-}t0}$ is the power produced by the DG at the moment when the curtailment is activated.

Thresholds for curtailment's activation / deactivation

These strategies are activated when $P_{transfo}$ exceeds $P_{threshold}$.
They are deactivated after 1 or multiple 30 minutes cycles if $P_{transfo\text{-}t0+30} < P_{threshold} - \Delta P_{marg}$. This is the example shown in the following figure, where the curtailment cycle starts at t_0 and stops at t_0+30min when the above-mentioned criterion is verified.

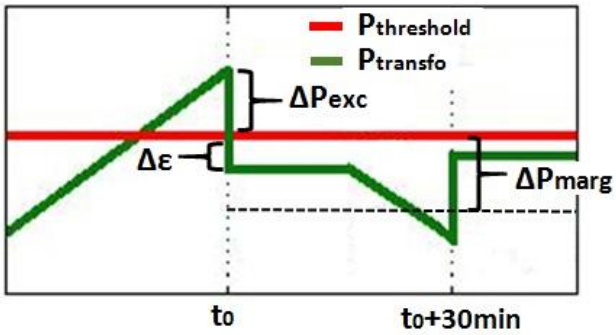

Figure 1 – Measure of power in the transformer. The curtailment cycle starts at t_0 and stops at t_0+30min

This margin ΔP_{marg} is calculated considering a conservative evolution of the DG power in the 30 minutes following the curtailment activation (or each time a curtailment order is updated).
$\Delta P_{marg} = P_{maxDG} - P_{DG\text{-}t0}$
P_{maxDG} is the nominal DG power.

P measured
In the optimized strategy called "P measured" the set point depends on the measure of the DG active power at t_0 and is defined as follows:
$P_{set} = P_{DG\text{-}t0} - \Delta P_C$
ΔP_C is the power to be curtailed,
$\Delta P_C = \Delta P_{EXC} + \Delta\varepsilon$
$\Delta P_{EXC} = P_{transfo} - P_{threshold}$

$$\Delta\varepsilon = \begin{cases} 1st\ cycle: min(0.3 * PmaxDG\,;\Delta Pmarg) \\ 2nd\ or\ nth\ cycle: \quad \Delta Pmarg \end{cases}$$

The value 0.3 has been chosen after a statistical analysis of the possible evolution of generation in different wind farms installed in distribution networks. In practical terms, when a 99% confidence interval is considered, the power of a DG unit does not vary in 30 minutes more than 30%. This value could allow in some cases to take a smaller margin and therefore to curtail less energy.
To improve the deactivation criterion it could be possible to devise an intermediate set point between P_{set} and P_{maxDG} before deactivating completely the curtailment. This could avoid unnecessary curtailment cycles.

P base
A simpler strategy, namely "P base" consists in the definition of a fixed set point parameter P_{base}, which is defined as the maximum power the DG unit can inject at any moment of its operation in the distribution network, without causing a constraint.
Every time a constraint is detected the curtailment order consists in the same set point
$P_{set} = P_{base}$.
Thus, here the curtailed power is:
$\Delta P_C = P_{DG\text{-}t0} - P_{base}$.

As we will show, the strategy P base implies an equal number of hours of curtailment, but a bigger volume of curtailed energy, as compared to the strategy P measured.

As we have seen, it could be possible in simple cases (for instance when the curtailment is operated on a single generator) to implement a curtailment strategy without the need for a forecast. Two main limits have been highlighted. On the one hand, constraints still appear during a short time at the beginning of each cycle; it will be necessary to check that the time of detection plus activation is small regarding the equipment capacity. On the other hand, this solution is acceptable only for simple configurations where the constraint can be observed: 1 generator to be curtailed with current constraint.

Strategy using forecast

A more complete strategy based on forecasts is needed in more complex cases: constraints are difficult to be measured, various DG units need to be controlled simultaneously, different active network techniques (like active demand management, storage, etc…) are combined, or different network services need to be optimized.

Furthermore, if forecasts of load and of different productions (Wind, PV, etc…) are available, it is possible to anticipate the constraints, which could be very important in the operation of the active network.

The main issue is that even short term forecasts have a margin of error.
We have therefore defined a strategy in which forecasts are available 30 minutes in advance.
To analyze the impact of the forecast errors, three level of error have been considered, as detailed in the following table:

	Load	WG	PV
Level 1	-7%	+20%	+30%
Level 2	-6%	+15%	+20%
Level 3	-5%	+10%	+10%

Table 1 – Level of forecast errors

Level 1 is close to the state of art of forecast error whereas Level 3 represents a possible future aim for forecast precision.

PRACTICAL CASE AND RESULTS

A practical case has been simulated on a real distribution network with a very high amount of distributed generation, namely big Wind Generators and small diffused PV generators.

Not all of the generators are present in the real network, but the interest was in forcing the constraints on the HV/MV transformer in the Primary Substation. The sum of the installed generation is 3 times bigger than the maximum load on the network and 40% bigger than the nominal power of the HV/MV transformer.
This case is a specific one, but it seemed interesting because the network configured as it is presents reverse power flows very often (around 30% of the time).

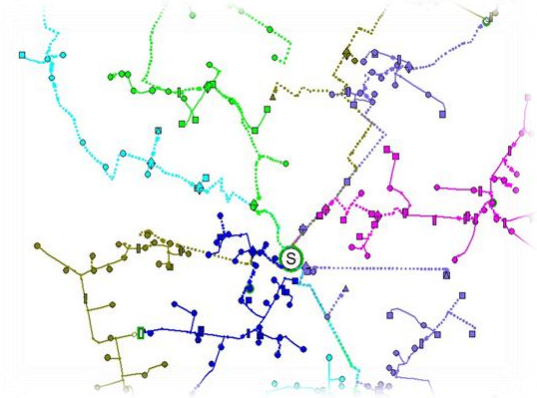

Figure 2 – The distribution network used in our study

The curtailment is dispatched on a single DG and the behavior of the network and of the curtailment has been simulated over 5 years to obtain volumes of energy curtailed and number of hours of activation per year.

Results for the strategies without forecast

We present here the comparison of the number of hours and volume of curtailed energy when strategies P base and P measured, which do not use forecast, are simulated. To evaluate the real energy curtailed we have accounted for the fact that the producer may actually produce less than the curtailment set point during the activation of the curtailment cycle.

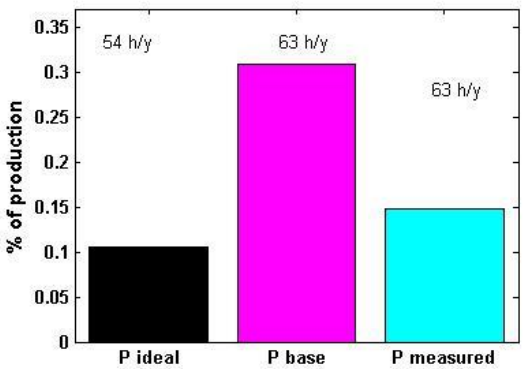

Figure 3 – Comparison of the volume of curtailment (energy curtailed and hours of activation) for the ideal strategy with the strategies without forecast (Pbase and Pmeas)

It is interesting to see in Figure 3 that the number of

hours increases when the "P base" and "P measured" strategies are used, as compared to the ideal strategy.
This is due partly to the fact that the curtailment is activated for a minimum of 30 minutes (whereas it is activated for a minimum of 10 minutes in the ideal case). This increase also follows the fact that once the curtailment is activated the power in the transformer needs to go under the threshold by a margin $\Delta\varepsilon$, so it normally stays active slightly longer than needed.

The volumes of energy change a great deal between the two strategies P measured and P base, which highlights the interest of the more complex strategy. This comes from the fact that the *Pbase* parameter is a relative low set point (it is sized on the worst constraint that could be found during the years of operation), and most of the time implies a bigger volume of power curtailed than the one really needed.

Results for the strategy with forecast

With the current available data, it is not possible to carry out a similar simulation on this network, as we do not know the instantaneous uncertainty that would be present on production forecast on each time step.

Every conservative hypothesis on the forecast error (considering that the error is maximal at every moment, for example) would lead to artificially lower the threshold on the transformer, implying a substantial increase of the curtailed energy.

The method that will be used is the comparison of data from a DG unit where both short-term production forecast and power measurements are available. This way, it would be possible to characterize the actual precision of forecast compared to the real production, and take it into account in our simulation. Two solutions could be imagined:

- Find the maximal error between forecast and production (over a significant amount of time), and apply it to every time step of the simulation. This is a conservative method that would lead to a high volume of curtailed energy, but would ensure 100% of deleted constraints.

- Reproduce a forecast profile respecting the same error distribution around the production, in order to comparatively simulate the behavior of the DG unit with the real production and with the "forecast + error" profile.

Further work needs to be carried out to characterize the forecasts available and therefore better evaluate the volumes of energy that would be curtailed using the strategy with forecast.

CONCLUSIONS

We have analyzed different possible ways of implementing a curtailment strategy to solve current constraints in a PS transformer. We have shown that it is possible, in a simple case where one generator implements the curtailment, to devise a strategy that does not need short term forecasts, but only relies on measurements of the power flowing in the PS transformer and the power produced by the DG. Adequate security margins have been considered to account for the possible variation of the power of the generator after the curtailment is deactivated. Two possible set points for the generator have been shown that result in different volumes of curtailed energy.

A strategy based on short term forecast has also been examined. Having a forecast is more interesting because the constraints can be anticipated and can also be useful in more complex active networks where different services (like active demand management or storage) need to be handled at the same time.
The method to take forecast error into account has been described. Nevertheless, due to the lack of data on actual historical forecast and measured data, the calculation remains to be performed. Further inquiries should be made to compare the two methods in terms of curtailed energy volumes.

The following table shows a comparison of the three strategies in terms of efficiency, material and limits:

Strategy	**P base**	**P measure**	**P forecast**
Constraints suppression	Curative		Preventive
Curtailed energy	↘	↘↘	?
Limits	Constraints during activation		Error on forecast
Material	Comm DSO → DG	Comm DSO ←→ DG	Forecast generation system, comm DSO ←→ DG

Table 2 – Comparison of the curtailment strategies

We have shown that the curtailment can help to solve network constraints and therefore eases the connection of distributed generation.
It could also be interesting to devise a hybrid strategy that takes advantage of forecast, but also of measurements to minimize the volumes of curtailed energy, whilst ensuring correct and reliable operation of the active distribution network.

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