PROBABILISTIC PLANNING FOR A HIGHER INTEGRATION OF WIND TURBINES TO MV DISTRIBUTION NETWORKS

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ABSTRACT

The presented approach aims to show a way to integrate a larger number of on-shore wind turbines into MV grids through probabilistic network planning. The goal is to increase the possible amount of feed in energy without or low additional network investment costs and a minimum of not feed in energy by using active power control.

INTRODUCTION

The goals of the European Commission forces all market participants to increase energy efficiency and feed in renewable energy. Especially the feed in by on-shore wind power plants into the MV-grid represents a particular challenge for the DSO. The requests for connections are primarily for several wind turbines or small wind farms in the power range of a few MW. These connections are distributed across the same part of the MV- distribution network. A connection to a higher voltage level, by setting up an own substation, is technically unrealistic and is not economical for the DSO and for the owner of the wind turbine. In order to enable the feeding in and to guarantee power quality, it is necessary to reduce the installed feed in power or to extend the distribution network.
From the perspective of the producer, the optimum is, by low direct grid connection costs, to deliver the full feed-in power at any time into the grid to be able to increase the energy output and thus to optimize the return. From the perspective of the DSO the optimum is to keep the network cost as low as possible. This different positions results, however, very often in a reduction of the installed feed-in power. The sum of these single optima does not result in a total optimum for the overall system of the production and distribution. In order to support the objectives of the EU and to enable more feeding in through distributed generation into the grid, it is necessary from our point of view to find an overall economic optimum and therewith a compromise between network investments and produced energy quantity.
The LINZ STROM Netz GmbH has made an investigation and describes in this document different planning methods, such as the conventional planning and a probabilistic planning approach, based on a real MV-grid section. Furthermore, the necessary conditions and the economic aspects are considered for a realisation.

DESCRIPTION OF THE CONSIDERED GRID

The selected network is part of a MV rural distribution network with an operating voltage of 26.5kV. In this network, a 1.2 MW wind turbine is already connected via a 17.5 km long overhead line with 95mm² Aldrey. Additionally, a 250 kW biogas plant is connected to the network. At the connection point of the existing wind turbine there is planned a further 2 MW wind turbine.

CONVENTIONAL ASSESSMENT

The conventional assessment assumes that the maximum power is feed in to the worst operating condition in the distribution grid. The evaluation is usually carried out on the four operating points, peak load with and without feeding and off-peak load with and without feeding. Additionally the DSO has to take into account the control variation of the substation output voltage. Only, if for each operating point the conditions comply with quality standards, the DSO can guarantee a full feed in at any time. The limit for the voltage increase is determined by the maximum allowable primary voltage at the distribution system transformers (over excitation) and through compliance with the upper voltage limit into the LV-grids Un +10% according to EN50160. This results in the MV-grid of LINZ STROM Netz GmbH, a maximum allowable voltage increase to 27.3 kV. In addition, the requirements apply to TOR D2 [1], whereby the voltage increase caused by all feeds in the MV- grid, should not exceed 2%.

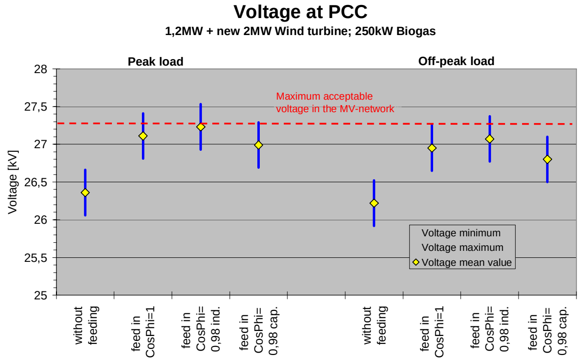

Figure 1 Result of the conventional assessment

The example of an additional 2 MW wind turbine shows that at the time of peak load with a feeding of cosφ= 1, the maximum voltage is exceeded and is reached at feeding with cosφ = 0.98 cap. just the voltage limit (Figure 1). Additional the total allowable voltage increase will exceed 2%. Exceeding the upper voltage limit into the time of peak-load occur because a current-dependent voltage control of the substation transformer is used.

To allow a feeding at this location, a reduction of the installed feed in power to 1 MW is necessary. Due to this reduction, an energetic potential cannot be used by around 1000 MWh.
Alternatively, a connection have to be realized over an own 3 km long MV-voltage cable to a connection point with a higher short-circuit power. The estimated cost for this cable is 0.5 Mio. € and have to be paid as direct grid connection costs from the investor of the wind turbine. Therefore, the profitability of the plant is not given.
But if we are looking at the actual network conditions, we notice that the described worst operating conditions occur only very rarely. Therefore it follows that a major integration of wind turbines would be possible and the assessment is too conservative.

PROBABILISTIC PLANNING

At present the concept SMART GRIDS is the synonymous for more efficient networks, for more market and more self determination of customers. However it is not really clear what should be understood beyond SMART GRIDS. At present the situation shows different pictures depending on the position of consideration. Therefore different visions or definitions for SMART GRIDS are available. [2] [3]. From our point of view we do not speak about SMART GRIDS in general, but it is necessary to distinguish between SMART Functions because different market participants are involved. This differentiation is important because in the case of roll-out of a SMART Function we have to bear in mind the different roles of the involved participants.
We regard the smart network planning, and especially the probabilistic planning, as one of the most efficient SMART function.
The new way to assess the on-shore wind turbines takes into account the statistical behaviour of the influencing parameters such as:

- Output voltage in the Substation
- Current in the branch of the network
- Feed in power of the wind turbine

The objective of the new assessment is

- to calculate the probable voltage at the PCC
- to calculate the probable active power, which is affected by the control of the feeding
- to calculate the probable not feed in energy

and therefore to increase the installed feed in power and feed in energy, by a minimum of investments into the grid and a minimum of not feed in energy. This objective is only achievable if the DSO is allowed to control or switch off one ore a few power producers for short time periods if the upper voltage limit is reached.

Description of the calculation method

For the probabilistic planning a calculation module has been developed based on EXCEL. The model is based on the Monte Carlo method by randomly selecting values from the annual duration curves of the substation voltage, branch current and feed in power. With these random values, the voltage $U_{PCC,n}$ at the PCC is determined by the use of a simplified network calculation. To get the probable annual duration curve of the voltage at the PCC the calculation according [Eq 2a .. 2c] and [Eq 3] will be repeated more than 10.000 times.

To determine the node factors “*a*” according [Eq 1a ..1c], a base load flow with an output voltage at the substation U_{SS_Calc} and a branch current I_{Calc} is calculated. By changing the branch current, the active power and reactive power of the feeding the voltage change at the PCC can be calculated and the node factors can be derived.

$$a_{branch} = \frac{\Delta U_{PCC}}{\Delta I_{branch}} \qquad \text{[Eq 1a]}$$

$$a_{Gen\_P} = \frac{\Delta U_{PCC}}{\Delta P_{Gen}} \qquad a_{Gen\_Q} = \frac{\Delta U_{PCC}}{\Delta Q_{Gen}} \qquad \text{[Eq 1b .. 1c]}$$

$$\begin{aligned} \Delta U_{branch,n} &= (I_n - I_{calc}) * a_{branch} \\ \Delta U_{Gen\_P,n} &= P_n * a_{Gen\_P} \\ \Delta U_{Gen\_Q,n} &= P_n * \tan(\varphi) * a_{Gen\_Q} \end{aligned} \qquad \text{[Eq 2a .. 2c]}$$

$$\begin{aligned} U_{PCC,n} = &(U_{SS,n} + (U_{PCC\_Calc} - U_{SS\_Calc})) \\ &+(\Delta U_{branch,n} + \Delta U_{Gen\_P,n} + \Delta U_{Gen\_Q,n}) \end{aligned} \qquad \text{[Eq 3]}$$

P_n	random selected feed in power
I_n	random selected branch current
$U_{SS,n}$	random selected output voltage at the substation
n	number of iteration (n= 1 … 10.000)

Based on the calculated voltage $U_{PCC,n}$ at the PCC and the maximum allowable voltage U_{PCC_lim} at the connection point the necessary reduction of the feed in power P_{red} can be determined by equation [Eq 4].

$$P_{red} = \frac{(U_{PCC,n} - U_{PCC\_\lim})}{a_{Gen\_P}} \qquad \text{[Eq 4]}$$

Result of the probabilistic planning

Based on the example of the conventional assessment for the probabilistic calculation the cumulated relative frequency distributions of the feed in power, branch current and voltage at the substation are used as shown in Figure 2.

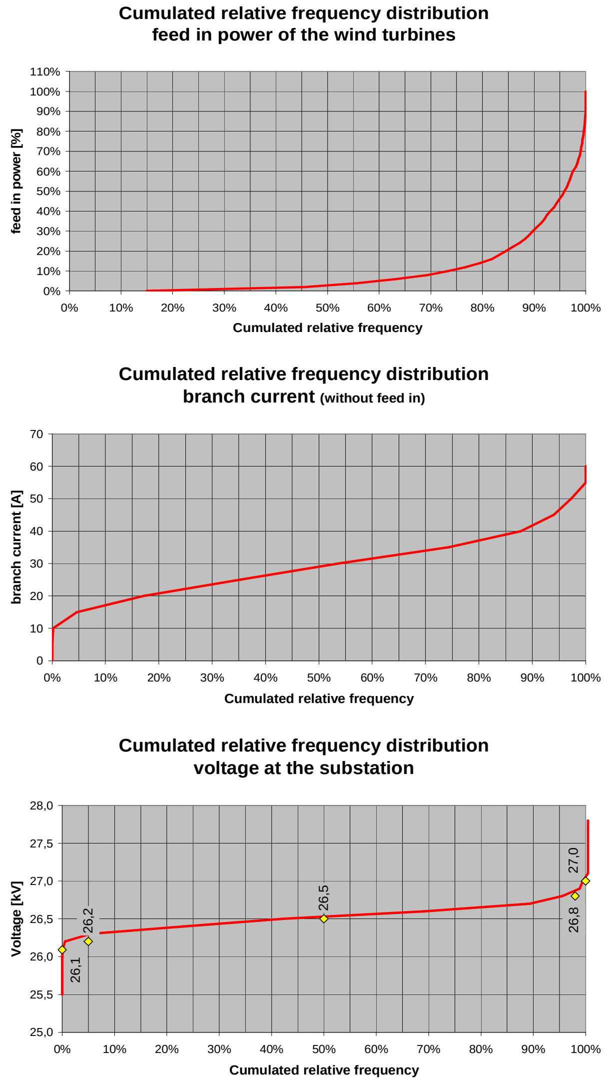

Figure 2 Cumulated relative frequency distributions

The result of the probabilistic calculation with an additional 2 MW wind turbine shows (Figure 3), that the voltage at the PCC exceeds only at very short times the allowable voltage. The maximum of the calculated voltage is equivalent to the voltage as calculated with the conventional assessment and the 98% quantile is far below the allowed voltage limit.

By a theoretically generated annual amount of energy of about 3.000 MWh (1.2MW + 2MW new wind turbine) the percentage of not feed in energy is about 860 kWh or 0.03% of the annual amount of energy. The maximum reduction of the active power amounts up to 1370 kW. With a feed-in tariff of 9.6 ct/kWh it is be expected an annual revenue loss of less than 100 €.

Assuming that a not feed in energy amount of 5% is acceptable for producers, so at this connection point 7.5MW wind turbine power could be installed. Due to the higher increase of the voltage it is necessary to control the active power of the wind turbines as shown in Figure 4.

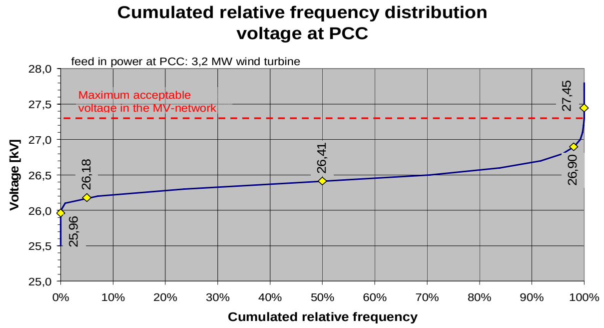

Figure 3 Result of the probabilistic calculation

The annual amount of energy produced would increase to 6650 MWh (Figure 5). This represents an increase of the energy yield by 220% without additional network investments.

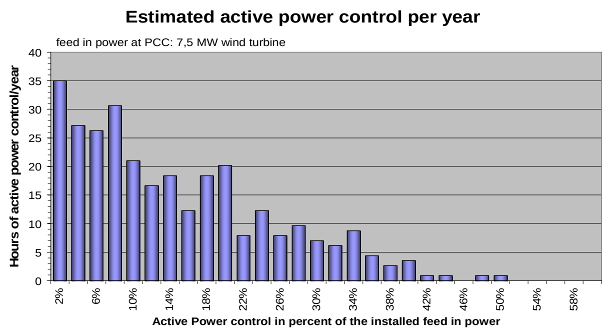

Figure 4 Estimated active power control per year

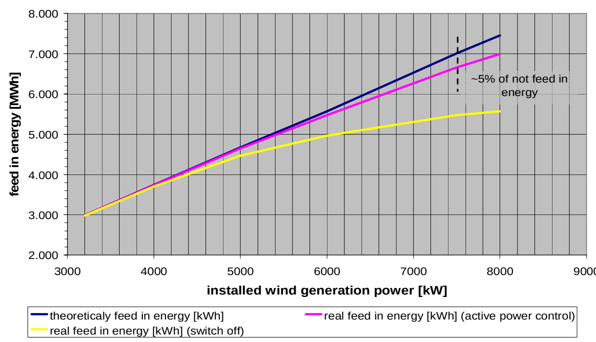

Figure 5 Yearly earning of energy of on-shore wind turbines and loss because of control or switch off if voltage level is too high

The following parameters are influencing the not feed in energy:

- feed in duration curve
- duration curve of the branch load
- duration curve of the voltage at the substation
- reactive power of the feeding
- measurement error of the voltage for the active power control at the PCC

As a result of our investigation, the influence of reactive power to the not feed in energy is shown in Figure 6. This potential can be used for additional wind turbines. The measurement error of the voltage for the power control can increase the not feed in energy and should therefore be considered.

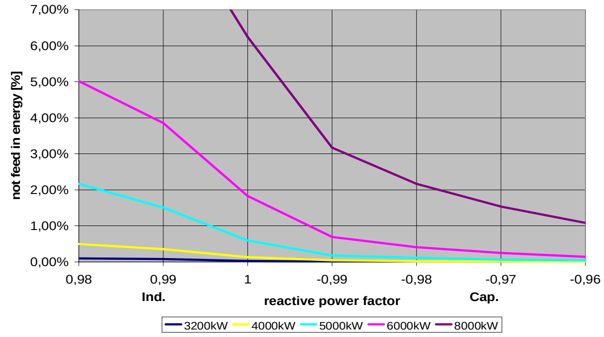

Figure 6 Relation between not feed energy and reactive power of the feeding

BASIC CONDITIONS; ECONOMIC ASPECTS

Neither the present frameworks nor the acceptance of the producers make it possible to carry out an active power control. The issue of contractual agreements between the DSO and producers is very difficult because the yield for the producer will be adversely affected by other additional supplies. The following questions should be clarified:

- who sets the date for additional network investments
- who bears the costs of these investments
- will be paid the investments by all or by the last connected feeder

Using the new assessment, it is possible to allow a larger number of distributed stochastic feedings like on-shore wind turbines into the existing network with a defined not feed in energy. This makes it possible to design an efficient and economically optimal energy system. The comparison between the conventional assessment and the new assessment shows the economic advantage, based on the considered network with an additional 2 MW wind turbine.

Conventional assessment:

- Cable connection to the nearest technically appropriate connection point is necessary
- 0.5 Mio. € have to be paid as direct grid connection costs, by the producer
- further feedings are only possible with additional network investments

New Assessment:

- without additional feedings to the grid, the decrease in profits is less than 100 € / year due to not feed in energy
- with a not feed in energy amount of 5% due to additional feedings on other connecting points, the decrease in profits of the 3.2 MW wind turbines is approximately 14.400 € / year
- No network investments up to an installed feed in power of 7.5 MW is necessary

Future network investments, due to additional feedings into the MV grid and the LV grids, are not assignable to a single producer. If the amount of not feed in energy exceeds a certain level, e.g. 5%, it should be possible for the DSO

- to compensate the additional not feed in energy (payment to the producer)
- to determine the optimal strategy for investments in the network (e.g. change of the voltage control of the substation transformers, Smart Grids, network expansion …)

These future investment costs, which are triggered by the feeders, should be financed by the network users in the form of a construction costs contribution by the network connection of a generating plant. In any case, these additional costs have to be recognized in the system utilization rates. Additionally, the national regulation has to take into account changes in the network structure.

CONCLUSION

The probabilistic planning allows a better simulation of real network conditions and to estimate the amount of the probably not feed in energy. Due to this new assessment method we expect more than a 2 times higher generation capacity and higher number of stochastic feedings like on-shore wind turbines with minimal investment costs for the grid. The implementation of the new assessment method is only possible if suitable conditions are available and the producers accept a certain amount of energy not feed in. It must be possible to the DSO, to determine the strategy for future investments into the network (Smart Grids, network expansion ..) and thus to optimize the grid. The financing of these future investments should be supported via payment of construction cost contribution by the producers. This would make it possible to optimize the overall system (grid - generation) technically and economically and to connect a much higher proportion of wind turbines to the grid. However, this means turning away from the principle of full feeding at any time.

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