Relevance of a Safety Factor for Wind Power Trading in Comparison with the Utilization of a Storage

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***Abstract*- In Germany renewable energy sources are paid by law with a constant amount for the supplied energy. Thus, the operators of such plants have no intention to take part at the energy market yet, but there exists possibilities to earn a better payment, so already some facilities act in the market and in the future this participation will be more and also necessary.**

This work analyses the opportunities for the participation at an energy exchange and at the control power market. To interact with the market, wind farms have to supply a constant power for a specified time. Due to the fluctuations of wind energy it is not possibly to guarantee a constant power based on wind forecasts. Thus, the wind farm cannot sell their maximal estimated energy but only a reduced value. The aim of the work is to figure out this specific "safety factor". Later on, the results are compared both technically and economically with the use of a storage unit, where the full amount of energy can be traded.

I. INTRODUCTION

Renewable energy is a constant growing part of the worldwide energy supply. In Germany the most important source is wind energy. In comparison to conventional power plants the most renewables have the main disadvantage of delivering fluctuating energy why they cannot be used to guarantee a steady supply.

In spite of this disadvantage, the renewable energy is extra supported because it is a sustainable and environment friendly energy form and an important alternative for future supply. In Germany this official support is regulated by law by the government through the Renewable Energy Sources Act (EEG) [1]. The owners of renewable production facilities get a priority feed-in into the grid, where the grid operator must take-over the energy and pay a fix refund for the generated energy. This payment is often higher than the average production cost in conventional power plants but sometimes lower than achievable prices at energy markets.

II. SAFETY FACTOR

To take part at an energy market the production facility has to provide a constant power for a specified time (e.g. 15 minutes or 1 hour). This is the so called "scheduled energy". Fluctuating energy sources like wind energy have not the ability to supply this scheduled energy because the forecast of the next day wind speed is not so accurate. The prediction of the produced energy is possible, but during the day the wind power may be not in the time when it is awaited. Due to wind delay the expected power may shift by one hour. Because of this forecast uncertainty, the wind farm owner cannot trade the whole produced wind energy. He has to insert a safety factor, by which the maximal possible wind power is reduced. By reducing the power, the wind farm owner is able to supply a (lower) scheduled power, but will not violate his supply contract in the case, that the wind power is another than predicted.

An example is shown in Fig. 1. Concerning to the wind forecast (blue line) the wind farm owner sells the wind energy in 1-hour-contracts (orange + grey bars) to a costumer. The height of power he uses is always the maximal possible power for this one hour, what is also the minimal wind power in this time. At the day of delivery the supplied wind power has another curve (red line), so a part of the sold energy can not be supplied and the before sold scheduled energy have to be reduced (grey bars). Thus, the wind farm owner has to pay a penalty because he cannot fulfill his contract.

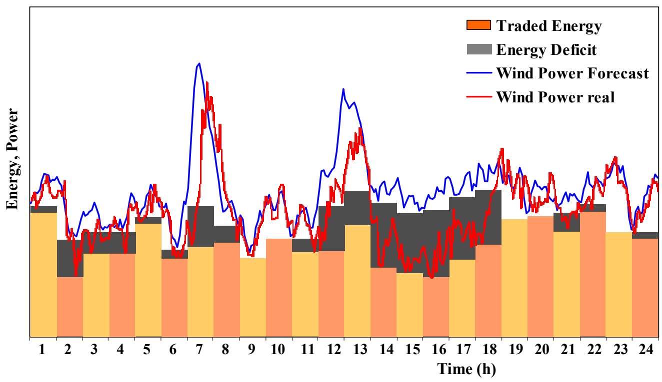

Figure 1. Example of energy deficit by trading the maximum power depending on the forecast compared to the real wind power

By this situation, the wind farm owner has to decide, whether it is cheaper for him to pay the penalty and sell the maximal possible scheduled energy or he reduces the scheduled energy by a safety factor (e.g. he sells only 80 % of the maximum). Doing the last option, he loses income because he cannot sell this energy to a better price, but on the other side he has not to pay penalties. This may work with an energy exchange, but at the control power market the supplier is pledged by contracts to be able to supply the scheduled power at 100 % of the time he offers.

III. Simulation System

The basic simulation system consists of a wind farm with 250 MW and a storage system. These components were modeled in a simulation environment, which was designed for optimal operation planning of energy supply systems using a mixed integer linear programming (MILP) [2]. The required technical parameters of the wind energy farm and the storage system are implemented into the model, whereby it is secured that the facilities will run within their specifications. In this work the program uses the optimization to make decisions where the generated wind energy will be sold. For this purpose different payment sources exist, which each represents another customer (e.g. an energy exchange). For each scenario and their combination the optimization tries to find the best result by maximize the amount of coverage for the wind farm operator. Equation (1) shows the objective function.

$$OF = \sum_{i=1}^{I} \sum_{t=1}^{T} \left(R_{i,t} - C_{i,t} \right) \cdot x_{i,t} \xrightarrow{!} MAX \qquad (1)$$

R	revenues
C	costs
x	optimization variable
i, I	index of number of elements
t, T	index of time intervals

The simulation expects a "day-ahead" sale of energy with forecasts for wind & prices and makes a daily optimization with 96 time intervals of 15 minutes each for one complete year. The system uses also data from the next two days as input. Thus, the usage of the storage unit can be more optimized for a longer time period. In the case the prices are higher the next day, the optimization system maybe decides to store only energy to the storage at present day and sell it completely at the next day. As input for the components historical time-variant curves were used for price trends and wind speed. So it is guaranteed that the wind speed in the summer is corresponding to the energy market price in the summer.

IV. Basic Simulation Data

For the simulations, scenarios were devised in order to reproduce the energy market situation in Germany [3]. The main focus in this work was on the energy and control power market, but the model also included possibilities to participate at other markets, e.g. congestion management [4].

A. Energy Market

After the liberalization of the electrical grid the different European energy markets arose. This scenario is based on data from the European Energy Exchange (EEX). At the EEX suppliers and customers can trade at different markets, whereas in this work is considered only the spot market. There is the possibility to offer hour-bids (in this work called "Peak") with a minimum of 0.1 MW for 1 hour. The bidding is for the next day and following the daily load, the price between noon and afternoon is much higher than during night, so there can be a worthwhile energy shifting.

B. Control Power

To ensure a secure operation of the electrical grid, it is necessary to use control power for the regulation of energy and frequency fluctuations. There exist two types of control power: first is positive control power which demands extra energy feed into the grid (e.g. increased supply from power plants) and the second is negative control power which reduces the energy feed into the grid or increases the load (e.g. with pumped hydro storages). The different types of control power (primary, secondary, tertiary control power) are realized today mainly with large conventional power plants.

These simulations contain only tertiary control power (TC). After 15 minutes the TC has to be activated and takes place up to 1 hour. Suppliers have to deliver at least ± 15 MW and the bidding is for the next day. The transmission system operator purchases this power at a control power market, where accredited power plants are able to offer their power. Wind energy farms may also take part, because wind turbines are able to supply control power [5]. There exist already renewable energy sources which deliver control power. Besides hydropower, small and midsized power plants (wind, photovoltaics, combined heat and power) working together in generation pools to satisfy with the requirements.

The power plants get a fix amount of money only for providing the power ready (demand charge). The price depends on the demand at the power market; typically the negative control power is expensive during the night and cheap at the day, while it is reverse at the positive control power. The special interest at negative control power for wind farms is the possibility to sell the reserved energy also at a source without a contract, e.g. the EEG. As long as the negative control power is not required, the wind turbine can run on full power and sell the energy. Only at the time of demand, the turbine must throttle the output and loss the extra income.

C. Energy Storage

Energy storages are suited for making the energy supply independent of time. They can accept and deliver energy from the grid if there is a surplus or a shortage. Storages are not only used for this technical issue but also for economical purposes. During the night energy is charged into the storage and during the high demand at the daytime it is feed back into the grid, e.g. with pumped hydro storages. Thus, the expensive peak load energy can be avoided partly.

For the simulations the storage is used both for technical and economic issues. It charges the wind energy when the price at the energy market is low and discharges when the price is high. The storage also assures a secure supply of the scheduled energy. According to the wind farm, a storage was chosen with a power of 100 MW and 800 MWh (redox flow battery).

D. Further Specifications

The running costs (operating and maintenance) of the storages were integrated into the optimization while fixed costs for the storage or other expenses (e.g. fees for participation at energy market) are not part of the optimization. They will be offset later with the simulation outputs to get the overall result. It is also assumed that the wind energy farm already exists, so its costs are not part of this work.

V. RESULTS

The safety factor was varied between 0 to 20 % according to the maximal possible power, as described in chapter II. With these different values, the various scenarios were simulated for one the same year to compare the results, according to violation of the scheduled energy and also to the income of the wind farm owner.

In Fig. 2, an example day of the day-ahead simulation is displayed. The wind power (*Wind*) will be sold between 7.00 and 21.00 to the energy exchange, supplying always a constant power block for one hour (*Peak1*, *Peak2*). In the morning, a four hour block of negative tertiary control power (*nTC1*) will be delivered, which will be provided by throttling the wind farm (*TnTC*). The rest of the energy will be sold via the EEG (*EEG*) with a payment of 80 €/MWh. It is obvious, that the optimization will sell as much energy as possible to the highest price, so the maximal power is always the maximal wind power, concerning to the wind forecast.

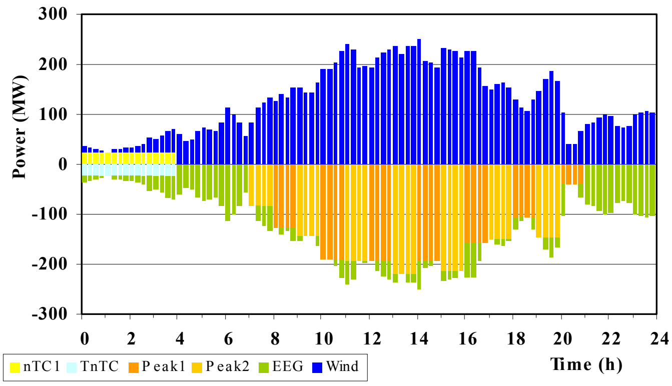

Figure 2. Optimized day-ahead sale of the wind energy without a safety factor

On the day of delivery, the wind speed differs from the predicted wind the day before, so the produced wind power does not fit the scheduled energy what was sold the simulation before to the day-ahead markets. In Fig. 3, the sold scheduled energy to the energy exchange (*PeakS*) and to the control power (*nTCp*) cannot be delivered (*PeakSh*, *nTCpH*). Therefore the missing energy has to be taken from other sources (*EnTCB*). In these cases, the wind farm owner has to pay a higher price to purchase this (balancing) energy (*BEPeak*) or has to pay penalties to the costumer, because he could not fulfill the contract. The rest of the energy is sold via the EEG like before, because the energy is feed directly into the grid without any contract like it is produced.

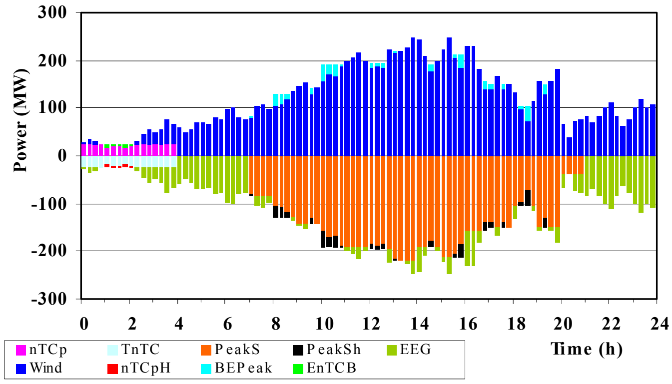

Figure 3. At day of delivery differences occur between supply and sale

If there will be a safety factor, then the amount of maximal possible power will be reduced. In Fig. 4 this value is reduced by 15 %, which can be seen in the purple (*PeakSF*) and dark green color (*nTCSF*). This energy can be sold also to the EEG the next day or it will be later throttled if necessary. With this "buffer" the wind farm owner can compensate differences between the wind forecast from the day-ahead optimization and the real wind. So on the day of delivery the missing energy (Fig. 5) is reduced, compared to Fig. 3.

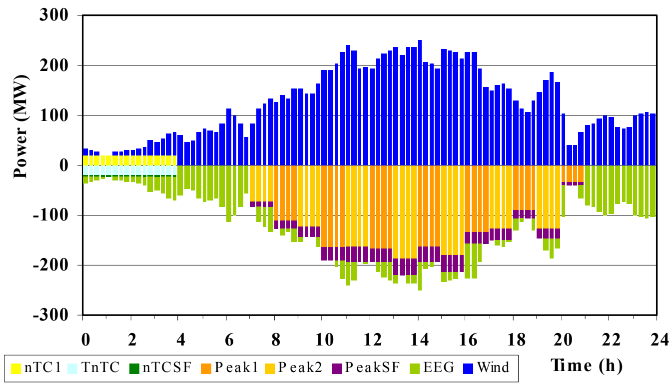

Figure 4. Optimized day-ahead sale of the wind energy with a safety factor of 15 %

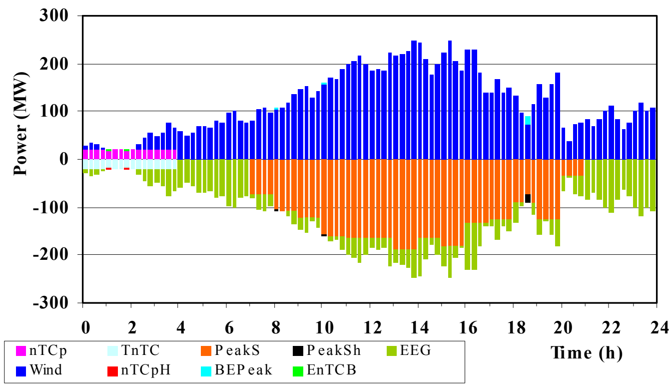

Figure 5. Supply with reduced violations due to the safety factor

In the case a storage is combined with the wind farm, a safety factor is not necessary because the storage will balance the difference between forecast and real wind. Furthermore the storage can increase the income of the owner because now it is possible to speculate on the market as described before. The same day as before is showed in Fig. 6. With the storage the optimization decide to buy energy in the morning (*EP*) and charge the storage (*Sc*). The storage is then discharged to maximize the energy which is delivered to the energy exchange (*Sd*) and it also supports the control power, which is increased in the morning and evening by the storage (*ScnTC*).

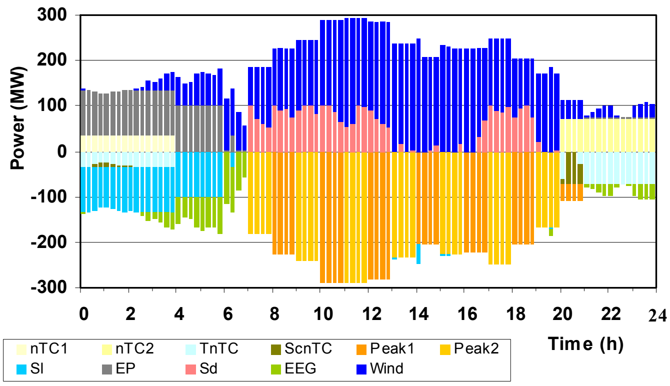

Figure 6. Day-ahead optimization including the storage

At the day of delivery (Fig. 7) the storage is able to manage the different wind speeds and no violation of the control power occurs, only balancing energy for energy exchange is needed.

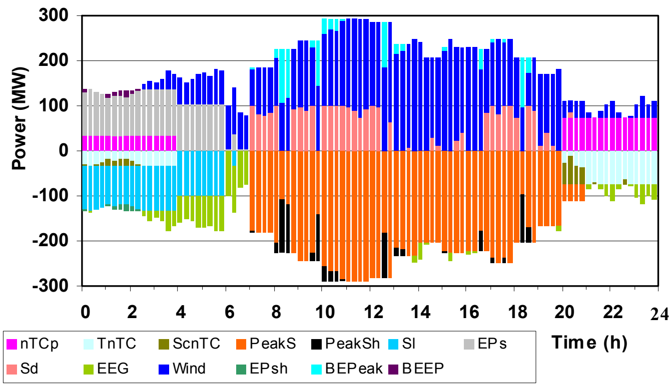

Figure 7. With a storage no violations occur and the income is increased

These simulations were made for each day of a chosen year for the different scenarios. At the end, the income/expenses of the wind farm owner including penalties and the annual storage capital costs (10 m€) have to be compared to give an answer to the question, which safety factor (SF) is necessary and whether the implementation of a storage is worthwhile. The results are shown in Table I. The first column shows the number of violations of the provided control power, because if there are violations, the wind farm is banished from further participations at this market. The next column is the results of the optimization for one year; the part of the penalty fees and balancing energy of the result and the last column shows the total income including storage costs if included.

TABLE I
OVERVIEW OF THE RESULTS FROM THE DIFFERENT SCENARIOS OF ONE YEAR

Scenario	Violations TC	Results in Euro		
		Optimization	Part of Penalty	End Result
SF = 0 %	74x	24 772 532	4 904 755	24 772 532
SF = 5 %	27x	28 178 166	1 222 412	28 178 166
SF = 10 %	9x	28 644 179	480 272	28 644 179
SF = 15 %	4x	28 582 357	254 864	28 582 357
SF = 20 %	1x	28 458 636	109 144	28 458 636
Storage & SF = 0 %	0	37 330 143	3 359 631	27 330 143

VI. CONCLUSION

This work showed, that it is essential to use a safety factor in the case, that the wind farm operator wants to participate at an energy market without a storage. Under some circumstances it is possible to allow violations of the scheduled energy, e.g. at the energy exchange. Nevertheless, the suppliers have to deliver the sold energy and so they have to buy it somewhere else (for higher prices) or have to pay penalties. At the control power market a non-compliance is not accepted, so in the case the wind farm is not able to supply the sold energy, it is locked out from further trade and cannot take part anymore at this market. Therefore it is necessary to include a safety factor (e.g. 20 %) to be on a safe side. However, including this factor will decrease the income of the wind farm because of selling less energy to the high price payment. An energy storage can handle this problem and is also able to increase the income by a better trading of the energy at the market. Thus, a storage has both technical and economical benefits for the system [6].

REFERENCES

[1] "Act Revising the Legislation on Renewable Energy Sources in the Electricity Sector and Amending Related Provisions (Renewable Energy Sources Act)", Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, in: *Federal Law Gazette 2008 I No. 49*, Bonn, 31 October 2008

[2] P. Hackländer, J.F. Verstege, "Accelerated MILP-Strategies for the Optimal Operation Planning of Energy Supply Systems", in *Operations Research Proceedings 2002*, Springer-Verlag, Berlin, Heidelberg (2003) pp. 259-264

[3] S. Völler, J.F. Verstege, "Investigation of new Payment Models for Wind Farms in Combination with Energy Storages", in Proceedings of *International Youth Conference on Energetics*, Budapest, Hungary, 2007

[4] A.F. Kaptue Kamga, S. Völler, J.F. Verstege, "Congestion Management with Energy Storages", accepted paper for CIGRÉ/IEEE PES Symposia *Integration of wide-scale Renewable Resources into the Power Delivery System*, Calgary, Canada, 2009

[5] A.-R. Al-Awaad, S. Völler, J.F. Verstege, "Contribution of Wind Power Plants to Frequency Control", accepted paper for *4th International Exergy, Energy and Environmental Symposium (IEEES-4)*, Sharjah, United Arabic Emirates, 2009

[6] S. Völler, A.-R. Al-Awaad, J.F. Verstege, "Benefits of Energy Storages for Wind Power Trading", *IEEE International Conference on Sustainable Energy Technologies (ICSET)*, Singapore, Republic of Singapore, 2008