TECHNICAL DIMENSIONING OF AN ENERGY STORAGE FOR A SWEDISH DISTRIBUTION COMPANY

Nicholas ETHERDEN
STRI AB – Sweden
nicholas.etherden@stri.se

Susanne ACKEBY
STRI AB – Sweden
susanne.ackeby@stri.se

Math H.J. BOLLEN
STRI AB – Sweden
math.bollen@stri.se

Lars OHLSSON
Falbygdens Energi – Sweden
lars.ohlsson@goteborgenergi.se

ABSTRACT

A grid-size energy-storage installation enables the removal of peak loads in the distribution system due to high amounts of wind production. In this paper the ability of a battery energy storage to increase the amount of wind power that can be connected to a distribution network is studied. It is found that about 40 % of overloading instances can be prevented with the storage. After this diminishing returns per unit of storage capacity occur and the overloading should instead be handled with curtailment. The extent to which the storage can minimise network losses was studied but the reduction in losses cannot compensate for the conversion losses in the storage installation.

INTRODUCTION

Energy storage can potentially allow for more production from renewable resources into existing electrical networks. Today the technology is under development and cost is still considerable with only a few minor trial installations made. Different applications have different requirements; energy is to be stored on different time scales and the amount of energy as well as the required power ratings will differ. The technology to be selected varies considerably with the intended application of the storage as shown in Figure 1.

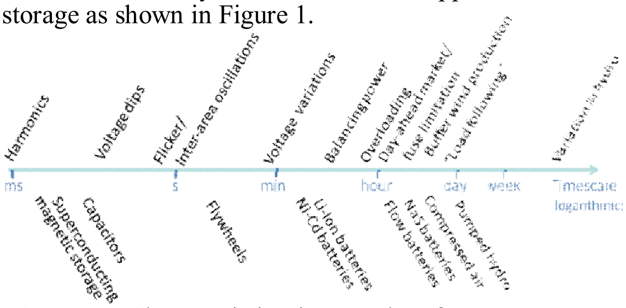

Figure 1. Characteristic time scale of energy storage applications, reproduced from [1]

Primary equipment in the electrical grid is typically designed for use during several decades. With life expectancy for batteries of only a few thousand charge and discharge cycles, it is not feasible to require more than a few cycles per day from a Battery Energy Storage System (BESS).

This paper addresses the dimensioning of a grid-side battery storage installation for avoiding overloading of the distribution grid due to wind power. A trade-off study has been done between the size of the storage installation and the amount of additional energy from wind-power installations, assuming that curtailment possibilities are in place to spill some of the wind-power production during grid congestion. An existing grid was used together with actual hourly values of consumption and production for this grid.

Two approaches have been compared for discharging the installation after it has been charged to avoid overload. One of those approaches is aimed at minimizing the losses in the grid. The study presented in this paper was part of a project that also covered regulatory aspects [2] and financial considerations [3] of the construction and operation of energy storage in the distribution network.

Wind-power producers in Sweden typically do not have balance responsibility for individual wind parks [2]. There is therefore no need for capacity firming of individual turbines. The application considered most feasible for a storage installation in Sweden was the removal of peak loads in the distribution system due to high amounts of net production (production much higher than consumption) or net consumption (consumption much higher than production). An energy-storage installation in the grid will allow the network operator to handle these peaks without the need to build additional lines, transformers, etc. This in turn allows the connection of more wind power to the grid, assuming that the transfer capacity (maximum loading) of the distribution grid is the limited factor, which is often the case for medium voltage distribution and sub-transmission networks.

Due to the strong variations in production with resources such as wind and sun, as well as the variations in consumption, peak loading of the grid only occurs during a small number of hours every year. The costs of energy-storage installations remain high, likely for the foreseeable future as well, so that it is important to make a trade-off between the size of the storage installation and the amount of additional energy from wind-power installations that can be transported by the distribution network.

HOSTING CAPACITY

The amount of wind power that is possible to connect in the network was studied by using the hosting capacity approach. The hosting capacity is defined as the maximum amount of new production or consumption that can be connected without endangering the reliability or quality for other customers [4]. The method has been applied to the dimensioning of energy storage in [5].

The hosting capacity varies with the studied phenomenon and associated performance index; which can be slow voltage changes, rapid voltage changes, overloading, harmonics, flicker, losses or the number of events in the network. Five different applications for energy storage where studied of which the limiting overloading case is described here.

The dimensioning study was done for three different location of the battery storage. All three connection points studied were in an existing distribution network in the western part of Sweden with annual transfer of 326 GWh. The locations represent connection to an urban 130/20 kV substation, a rural 40/10 kV substation, as well as further out in the 10 kV network in the vicinity of a wind park. The characteristic properties of the connection points are given in table 1.

Table 1. *Dimensioning criteria of connection points.*

Storage location	Consumption [MWh/h] min	mean	max	HC limit (existing wind + additional new wind)
40/10 kV rural substation	0.5	3.1	6.8	12.25 +1.75 MW*
130/20 kV urban substation	2.7	7.5	46.5	16.8 + 50 MW**
Near wind park in 10 kV grid)	0.1	0.8	1.8	0*** + 1.3 MW*

* The HC limit refers to total rated power in the distribution grid, plus simulated extra contribution of wind power by power system analysis

** Theoretically calculated.

*** 12.25 MW wind generation exists today also for this substation but is not connected to the studied feeder.

MINIMIZING OVERLOADING

The amount of additional energy from wind-power installations delivered to the grid has been calculated as a function of storage size, when the amount of installed wind-power capacity exceeds the hosting capacity given in Table 1.

By studying how a storage installation effects the performance indexes associated with the hosting capacity limits suggestions on how to design and dimension energy storage are obtained. The studies have been done for a time period of 8 months using hourly data for production and consumption from the studied grid.

Storage algorithms to avoid overloading

The algorithm for storing and discharging energy to the BESS needs to be optimized for each application of the storage. In the first application, eliminating overloading, charging commences as soon as overloading occurs. The amount of energy to be stored is limited by either i) the remaining storage capacity, ii) charging power or iii) power flow reduction needed to avoid transformer overloading. The time of overloading is concentrated to certain periods. Once a period of overloading has ceased there is an increased probability for a new period of overloading to commence. With overloading occurring 5% of the time the probability for a second period of overloading to start in the following measured hour was 23%. The probability for a second period of overloading to occur within three hours was 36%. This is ten to twenty times the probability of an overloading to occur within the same time frame for a randomly selected hour without overloading. Thus it is a good strategy to empty the storage as quick as the grid and BESS can handle once overloading is over. This first approach to control dispatch is called "quick store/discharge". An alternative approach, aimed at minimizing the losses in the grid, is discussed later.

Optimal Dimensioning of storage

For the first and second connection point of Table 1 the transformers are limiting the hosting capacity. For the third connection point the overload in combination with overvoltage is limiting the possible amount of wind power production that can be connected to the grid. A large number of load flow calculations have been performed in a commercial power system simulation tool in order to identify the storage capacity and power rating for the battery storage installation. The installation studied in more detail was chosen to have a storage capacity of 4 MWh, in the knee point after which additional capacity gives smaller per unit increase of delivered energy to the grid. This implies that the storage is combined with curtailment of wind production ("spilled wind"). The knee point is shown for the first connection point of Table 1 in Figure 3.

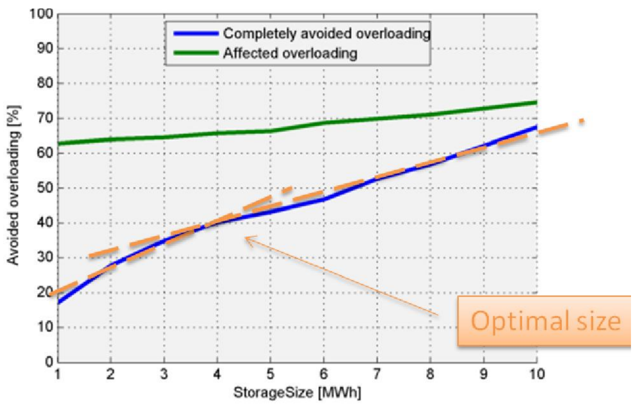

Figure 3. *Potential to avoid overloading with increased storage capacity.*

The total installed wind power capacity for the first connection point is currently 12 MW. Without battery storage, the hosting capacity is 14 MW, see Figure 4.

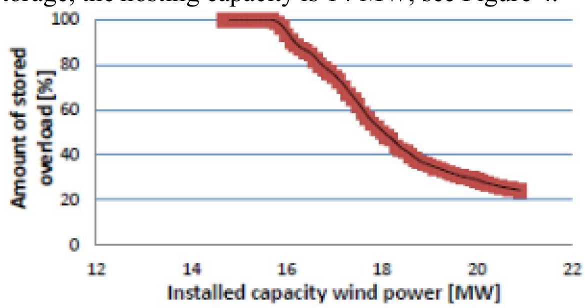

Figure 4. *Amount of overloading from wind power beyond the hosting capacity limit that can be avoided with storage. At connection point 1 it would be recommendable to install 19 MW wind capacity together*

with 4 MWh storage capacity and 4 MW charge/discharge capacity.

In Figure 4 it can also be seen that for installed capacity above 15.8 MW the studied storage installation (4 MWh) can no longer store all extra wind power production that would cause overload without storage. The hosting capacity has been increased from 14 to 15.8 MW. Additional wind power, beyond this limit, can only be installed when regular curtailment of the production is accepted by both the network operator and the wind-park owner.

Table 2 shows the increase in amount of wind power that can be connected as a function of the storage size for the studied connection points. To increase the amount of energy from wind power transferred by the distribution grid by one third requires 4 MWh of storage capacity. To obtain a similar increase beyond that (from 34 to 60%) requires an additional 6 MWh; beyond that (from 60 to 100%) requires another 35 MWh. There is thus a "point-of-diminishing returns" beyond which additional storage capacity no longer gives as much increase in transferred wind energy. To store all additional wind production would require a storage capacity that was deemed unrealistic.

Table 2. *Increase of the hosting capacity for wind power with an energy storage that can avoid part or all of the overloading in the grid.*

Capacity	Power Charge	Discharge	Add. energy to grid	HC w. storage (orig. HC + add. wind capacity)
4 MWh	1,2 MW	0,2 MW	34 %	14 + 1,3 MW
10 MWh	3 MW	0,6 MW	60 %	14 + 2,9 MW
45 MWh	14 MW	3 MW	100 %	14 + 5 MW

MINIMIZING GRID LOSSES

In this study, preventing overloads is the main application of the installation; this is done in such a way that variations of the active power are minimized with the aim to keep network losses as low as possible. In addition to this a battery storage system may help to compensate for the conversion losses from the batteries by utilizing the continuous VAR compensation possible with the power electronic converters.

Storage algorithms to minimise losses

When the surplus energy in a period of overloading cannot be stored completely it can be desirable to minimize the maximum overloading (measured in amperes). This requires "shaving off" the highest portion of each peak that surpasses the hosting capacity limit. Without conversion losses the storage cycles will not affect the mean value of the power flow. In the second control algorithm the time of dispatch is optimized so as to minimize the maximum current during overloading and "fill" the deepest valley between peaks. This will reduce the deviation of the power flow from its mean value which in turn will decrease the transformer and line losses. By post-analysis of data the capacity of the storage is fitted as shown in Figure 2.

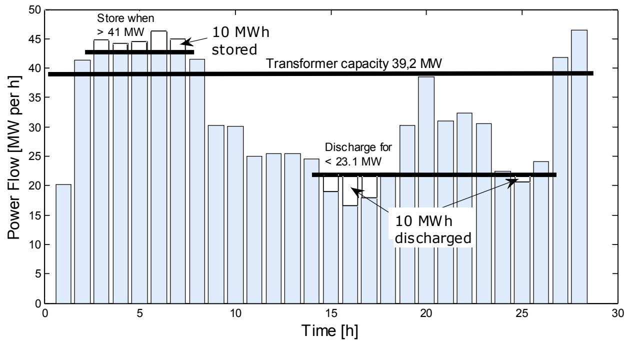

Figure 2 *Optimal charging and discharging to minimize losses of transmission line for a selection of hours. As the load flow profile is smoothed the average deviation from the mean will decrease, lowering the losses. The mean value itself is not influenced other than an increase due to conversion losses in the BESS.*

When the entire energy in the overloading period cannot be stored due to capacity or charging limitations the overloading is kept as small as possible. During discharge the entire period until the next overloading needs to be evaluated in order to discharge energy when the power flow is at its minimum.

This second approach to control dispatch is called "loss minimization. Such an algorithm is considerably more complex and for real time applications requires an accurate approximation of the loading and production in the next couple of hours. Several such algorithms have been developed [6, 7].

When approximating the future production and consumption it is important to have a good estimation of the error in forecast in order to reserve sufficient capacity in the BESS to ensure that the peak can be handled. The performance will decrease both with accuracy of future production and consumption estimation and with longer prognosis. In this study post analysis of data is performed in order to find the maximum amount of reduction in line losses that can be achieved. Performance of a real time algorithm is then to be evaluated against such a post analysis calculation.

Contribution to network losses

In the studied network the decrease in losses in overlying transformer and 40 kV line segment was less than the internal losses in the storage, see Table 3 and Figure 4. The continuous VAR compensation gives the largest contribution to minimizing network losses as it is used also during the majority of the hours when no active power is being dispatched.

Table 3. *Dimensioning of storage to minimize losses in overlying line when 19 MW of wind power is connected to connection point 1. Larger charge /discharge capacity gave no further reduction of losses for the studied grid.*

Capacity	Power		Avoided losses	Storage algorithm
	Charge	Discharge	[MWh/year]	
4 MWh	1,2 MW	0,2 MW	4.7 (4.2 % of total losses)	Only reactive power compensation
10 MWh	3 MW	0,6 MW	6.6 (5.9 %)	Quick discharge and reactive power comp.
45 MWh	14 MW	3 MW	7.9 (7.5 %)	Loss minimization and reactive power comp.

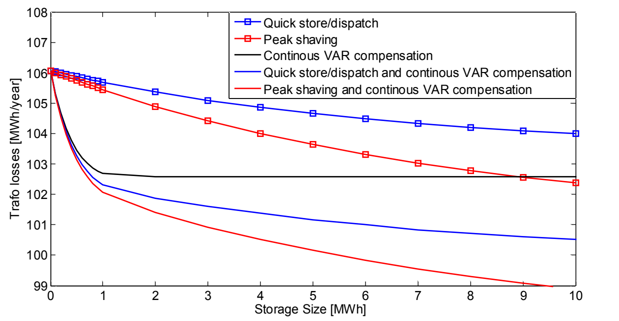

Figure 4. *Line losses as function of storage size*

The contribution to the storage losses from different components of the BESS can be found in Figure 5.

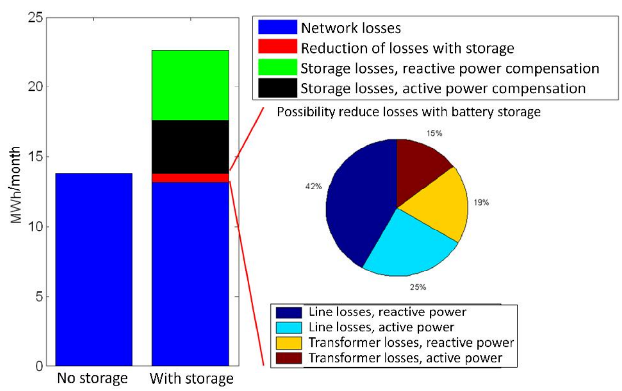

Figure 5. *Losses in the studied part of the 40 kV network with and without battery energy storage. Insert shows the composition of the line loses from the storage. These losses come short of compensating for the losses of the energy conversion and power electronics. Losses for a multilevel converter according to [8]*

CONCLUSIONS

Battery storage in the distribution grid allows for an increase of the amount of wind power that can be connected. The increase is however limited when the regular use of curtailment is not considered as a design option.

Totally avoiding overload in the grid, without any need for curtailment, would require excessive amounts of energy storage, most of which would only seldom be used. Therefore a combination of energy storage and curtailment will be required in any practical application of energy storage. The trade-off therefore becomes one between storage capacity and amount of curtailment.

It is found that about 40 % of overloading instances are suitable to handle with a Battery Energy Storage System. After this, diminishing returns per unit of storage capacity occur and the overloading should instead be handled with curtailment.

The impact of a battery storage system on the hosting capacity and on the amount of energy delivered to the grid is highly dependent on the characteristics and power flow of an electrical grid,

ACKNOWLEDGEMNT

The work was undertaken as a joint project between STRI AB and the regional distribution operator, Falbygdens Energi (a subsidiary of Göteborg Energi). The work was funded equally by Göteborg Energi, the largest publicly owned utility in Sweden and Elforsk, Swedish Electrical Utilities' R & D Company.

REFERENCES

[1] N. Etherden, 2012, "*Increasing the Hosting Capacity of Distributed Energy Resources Using Storage and Communication"* Licentiate thesis, Luleå University of Technology [available on-line]

[2] S. Ackeby, L. Ohlsson, N. Etherden, 2013, "*Regulatory aspects of energy storage in Sweden*", CIRED, paper 586

[3] M. Lindén, J. Helbrink, 2013, "Smart grid – the business case potential", CIRED, paper 1181

[4] M.H.J. Bollen, F. Hassan 2011 "*Integration of Distributed Generation in the Power System*, Hoboken: John Wiley & Sons, Inc., USA

[5] N. Etherden, M.H.J. Bollen, 2013 "*Dimensioning of Energy Storage for Increased Integration of Wind Power*", IEEE Trans. on Sustainable Energy, in press

[6] Y. Hida, R. Yokoyama, J. Shimizukawa, K. Iba, K. Tanaka and T. Seki, 2010, "*Load following operation of NAS battery by setting statistic margins to avoid risks*" in Power and Energy Society General Meeting.

[7] N. Ding, Y. Besanger, F. Wurtz, G. Antoine and P. Deschamps, 2011, "*Time series method for short-term load forecasting using smart metering in distribution systems*" IEEE PowerTech.

[8] Zhang, Y., Adam, G. P., Lim, T. C., Finney, S. J., Williams, B. W, 2010, "*Voltage source converter in high voltage applications: Multilevel versus two-level converters,*" 9th IET Int. Conf. on AC and DC Power Transmission.