USING A BATTERY ENERGY STORAGE SYSTEM AND DEMAND RESPONSE CONTROL TO INCREASE WIND POWER PENETRATION IN AN ISLAND POWER SYSTEM

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ABSTRACT

This paper defines a study where the wind power generation in an island power system in Sweden with a rated power of 195 MW is increased by 5 MW. Analyses will proceed investigating whether a Demand Response Controller (DRC) for domestic loads and an industry can reduce the need of power transmission by the HVDC-link from the island to the adjacent grid at the mainland. Also a small Battery Energy Storage System (BESS) with rated power 1.7 MW (280 kWh) handling wind power forecasting errors, will be included. The aim of the studies is to show flexibility regarding domestic and industry power consumption and how it can be matched to the current wind power generation. The reason is due to transmission capacity limitations of the HVDC-link to the mainland. It is shown that it is technically feasible to reduce power export events by matching domestic and industry loads to the present power generation.

INTRODUCTION

The installed wind power capacity in the Swedish power system has increased rapidly during the last years, especially in the island power system located at the south east coast of Sweden, which will be the focus of this paper. In August 2011, the total installed capacity on the island was 118 MW, during 2010 the electricity produced was 0.2 TWh [1]. In recent years, many small wind farms have been replaced by larger ones, thereby increasing the total installed wind power capacity to approximately 170 MW. Hence, the installed capacity is approaching the maximum grid limit of 195 MW [2].

The challenges are to integrate additional wind power generation into the existing distribution network without making extensive investments. One issue that arises when the installed capacity exceeds 195 MW in the present network is that the transmission capacity of the HVDC-link becomes overloaded during hours of high generation and low consumption. These situations are defined as critical export hours. However, analyses will proceed investigating whether a DRC and a BESS can reduce the need of power transmission capacity by the HVDC-link from the island to the adjacent grid at the

mainland. Therefore, the main objective of the DRC and the BESS is to minimize/avoid occurrence of exporting events from the island to the mainland during maximum power transmission occasions. One way of dealing with the issue is to implement Demand Response (DR) on long-term (day-ahead) and short-term (within the operation hour) for domestic loads and industries. Hence, overall power consumption has to be increased during events of high wind power generation and low load situations. If the analyses turn out to be successful any grid reinforcements can be postponed to the future.

The aforementioned approach of this project regarding minimization of the exporting events is somewhat different compared to the traditional scope of DR when the purpose is to smooth out power consumption during the day by shaving consumption peaks and filling consumption valleys. Consequently the project constitutes a quite different application of DR and storage technologies in order to manage limitations and constrains in an island network. The presented studies will therefore play an important role in demonstrating possibilities introducing technologies to positively contribute to the overall system capacity improvement and specifically for increasing system capacity of hosting renewable energy sources.

GRID MODEL

A model representing the grid of the island containing the 70kV-grid, its connections to the mainland and the equivalent of the overlying grid has been established in the software tool *Power System Simulator for Engineering (PSS/E)*. To meet the requirements within this study, the wind power generation has been increased with 5 MW to fulfil the stated reference condition of 200 MW installed capacity. Furthermore, a BESS represented by a generation or consumption unit of active power has been modeled. Since the capacity of the BESS in fairly small a suitable application for the device is to handle forecasting errors regarding the additional 5 MW wind power generation. Assumptions regarding the forecasting error can be seen in [3]. Operation focus of the BESS is to absorb power from the grid during periods of high wind power generation and low load situations, in order to reduce the power export peaks to the mainland.

ANCILLARY SERVICES TOOLBOX

Approximations regarding the potential of the DR will be given by the optimization toolbox executed by MATLAB. The purpose of the AS toolbox is to communicate with flexibility tools to balance additional power generation in the existing network without overloading the export HVDC-link. The additional power generation is 5 MW where the installed capacity has been increased from 195 MW to 200 MW. The AS toolbox is a multi-agent model using long-term (LT) and short-term (ST) generation prognosis data as input. The ST generation prognosis is much more accurate than LT prognosis. For further description of the optimization toolbox, the flexibility tools and how these have been modeled, see [3] chapter 2.3.2, chapter 2.4.2 and chapter 3.

DEMAND SIDE MANAGEMENT

Traditionally, power producers ensure the power balance by either increasing or decreasing their generation according to demand. Demand side management on the other hand, consists of doing the complete opposite, i.e. to adjust consumption according to what is being produced. One increasingly popular example of demand side management is DR where consumers change their consumption behavior after receiving a DR signal. Examples of DR participants comprise households, industries and the public sector. A motivating incentive for the customers to engage in DR is the reduced electricity prices during periods of high wind power generation and will thus give economic benefits.

Demand response in households

DR is divided into active DR and remote DR. Active DR is the process where consumers actively change their consumption based on a DR signal and when customers engage in remote DR they sign up to let their consumption be controlled by an external entity. For example, it might be the control of appliances used for space heating or water heaters. The barriers of realization are considerably lower for remote DR than active DR since the consumer commitment is minimized. Moreover, remote DR offers a lot more reliability than active DR which is crucial from a power system stability perspective. This paper focuses on remote control for domestic loads.

Demand response in industries

In the studied power system, industries account for a high share of electricity consumption, having an industry participate in DR can help shift considerable loads. Industries offer mostly active DR solutions. It might for example involve power consumption which is possible to relocate during the day or week. The following examples illustrate a potential day-ahead DR strategy for an industry within the manufacturing business, which is an energy intensive company in the current power system [5]. The company performs stone quarry activity during day shifts, twice a week on weekdays. The stone crushing activity consumes 2.8 MW and the crushed stones are later sent for storage where they can remain for 4 days. During times when the production capacity is lagging the demand, the company can be issued permission from the county authorities for one extra weekday of rock quarry activity. If the company can be issued a similar permission for DR purposes then this power consumption activity can be utilized when shifting loads.

METHOD

This chapter contains a description of the cases that have been performed. One of PSS/E's main features, load-flow calculation, is frequently used in the studies representing the transmission requirements of the HVDC-link during different generation and load settings. By calculating the actual balance between power generation, losses in the system and power consumption, insight can be gained in how additional wind power may affect power transmission between the island and the Swedish mainland.

Defining scenarios

High wind power generation combined with low load situations are of interest for further analysis. A brief study has been performed mapping peak exporting events during 2012 and the result shows that the events are roughly evenly distributed over the year. Therefore, four simulation scenarios, one for each season, have been chosen. Also, the reason for defining one scenario for each season is that the seasonal variation has an influence on the consumption flexibility for residential consumers participating in DR. Periods for the simulation scenarios are presented in Table 1.

The simulation scenario chosen for each case are three consecutive days for the seasons of 2012. These periods are chosen at different times of experienced power export peaks. The simulation days for each case were carefully selected such that frequent and evenly distributed export peaks occur during the specified period. A new consumption curve during DR for each

Table 1. Defined simulation scenarios.

Season	Time period (yy-mm-dd)	Days
Winter	12-01-12 to 12-01-14	Thursday - Saturday
Spring	12-05-09 to 12-05-11	Wednesday - Friday
Summer	12-08-06 to 12-08-08	Monday - Wednesday
Autumn	12-10-06 to 12-10-08	Saturday - Monday

period is obtained by the optimization toolbox in MATLAB. Those consumption vectors are implemented in the PSS/E grid model together with a total generation of 200 MW to receive the transmission characteristics by the HVDC-link. Each season has a unique consumption and generation pattern as well as a typical outdoor temperature and solar radiation. Hence, there is an expected correlation between the seasons simulated and the space heating consumption.

In order to compare the transmission characteristics during the 200 MW scenarios corresponding results for the 195 MW scenario are established, giving four base cases. These scenarios represent the transmission characteristics of the HVDC-link when no additional wind power generation nor is the BESS installed. An evaluation comparing base case HVDC-transmission characteristics during all four periods and corresponding results when applying DR to the 200 MW scenarios is performed. The objective is to show that the power transmission of the HVDC-link is not increasing during critical export hours even though the installed wind power generation on the island is increased by 5 MW.

Applying demand response

The DR scenarios for the 200 MW case are divided into two parts, one part includes DR from only households and the other part includes DR from *both* households and the concrete industry. The stone crush industry activity will only participate in DR if there is an export problem prognosis during the first twelve hours throughout day shift weekdays. The simulation scenarios include at least one weekday where the industry could participate in DR.

Scaling power generation and consumption

Since the present measurement of wind power generation on the island is approximately 170 MW the generation data needs to be manipulated in order to receive the rating presented in this study, 195 MW and 200 MW wind power generation. Thus, in order to determine if the network can balance 5 MW additional generation one also has to provoke an export problem by scaling the hourly power consumption for the days simulated, since the original consumption data will not create an export problem. The scaling parameters mean to increase the hourly production to reach 195 MW at base case and thereafter 200 MW during the DR scenarios, but also decreasing the hourly consumption power such that the export margin increases and provokes an export problem combined with the manipulated power generation.

The consumption and generation characteristics are preserved by evenly scaling all values, giving a unique scaling parameter for generation and consumption each day simulated. Scaling parameter >1 are set for

generation and scaling parameters <1 are set for consumption. For further description of the scaling procedure see [6] chapter 4.4.1.

RESULTS

In this chapter the results corresponding to the different seasons of the year is analysed from a base case and a DR perspective. The two transmission curves for each DR scenario and the base case are compared regarding the HVDC-transmission characteristics to the mainland. During base case the total installed wind power capacity is 195 MW and during DR scenarios the total installed wind power capacity is 200 MW.

Furthermore, curves demonstrating indoor and domestic hot water temperature per household for the LT and ST cluster are demonstrating the change in flexibility during each scenario. Thereafter, influence on cluster size when the industry is included in the DR scenario and characteristic for the BESS operation during the winter scenario is depicted. For further results covering change in cluster size and BESS operation for the reaming seasons, see [6] chapter 6.2 – 6.3.

Transmission characteristics

In Figure 1-Figure 4 power transmission during the four scenarios is illustrated. The solid curve represents the transmission limitation, the dashed/dotted line represents the base case while the dotted and dashed lines represent the two DR scenarios respectively. As can be observed in the legend for each figure, the industry is not included in the dotted lines.
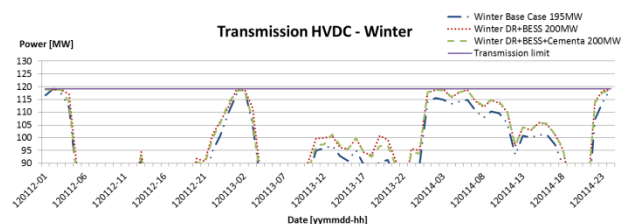

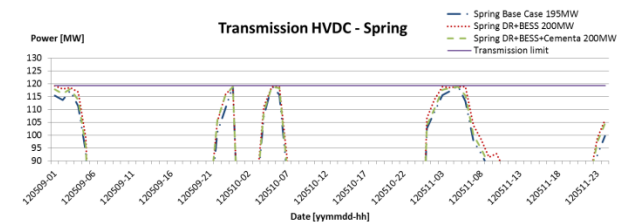**Figure 1. Transmission requirements during winter scenario.**

Figure 2. Transmission requirements during spring scenario.
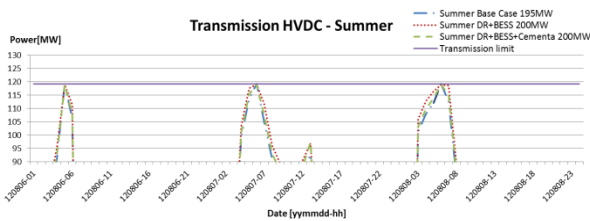
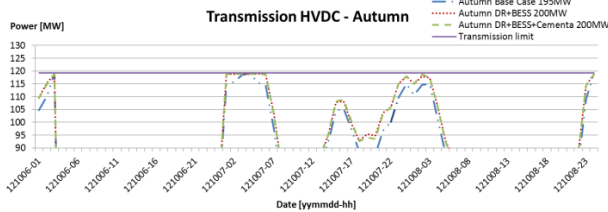**Figure 3. Transmission requirements during summer scenario.**

Figure 4. Transmission requirements during autumn scenario.

The optimized consumption curve increases during hours of export problem prognostics. The increase is a mix of activities from the DR clusters and the BESS. The load shifting phenomena is well observed, where the consumption increases during hours of export problem prognosis and decreases during hours when there is no danger of exceeding the transmission capacity. The ST cluster adjusts its consumption during persisting or new export problem hours that arise from the LT prognosis errors. Thus, the power to balance for the ST cluster becomes either greater, less or equal to what was previously predicted.

Indoor and water heater temperature changes

In Figure 5 - Figure 6 the indoor temperature change in time followed by the water tank temperature during all cases are presented for one household participating in LT or ST DR. The figures show how the constraints vary in time when the consumption has been optimized. There is a clear relation between the optimized consumption and the rise in temperatures at export problem hours. During the winter the solar radiation is very low as well as the outdoor temperature. This is why the indoor temperature curves during the winter scenario have a tendency of decreasing in time.

Industry influence on cluster size

Two simulations are presented in Figure 7. One without the industry nor any cluster size restrictions, i.e. the minimum LT and ST cluster size per day required to solve the export problems are used. The second simulation includes the participation of the industry, which only allows participation during weekdays. This is notated by (C) or (NC) if the industry is included respective excluded. The number of households participating in LT DR is depicted by the dark bar and

the light bar on top is indicating the number of ST DR households. Note that in reality the number of households per cluster will be fixed and therefore the worst case scenario will always be used as reference when deciding cluster size. It can be seen that participation of the industry is strongly affecting the LT cluster size.
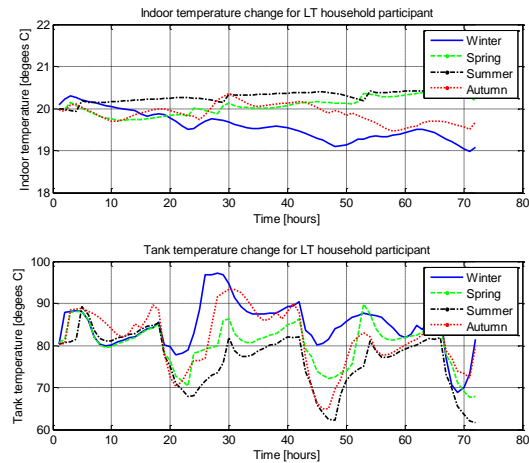

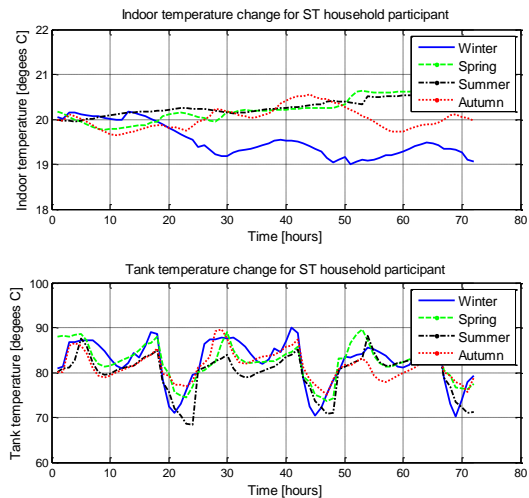**Figure 5. Indoor and water tank temperature changes for LT household.**

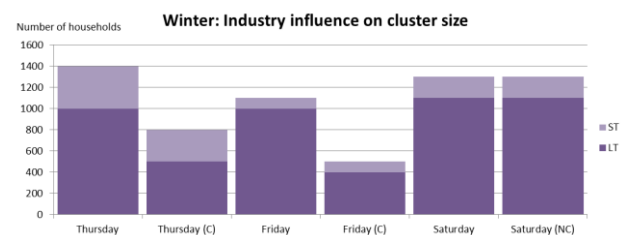**Figure 6. Indoor and water tank temperature changes for ST household.**

Figure 7. Industry influence on cluster size.

BESS operation

The hourly BESS charge/discharge level and required wind curtailment during the winter scenario including the industry is presented in Figure 8. Since the BESS reaches its maximum energy storage capacity level due to significant prognosis error, curtailment of wind power generation of approximately 0.015 MWh is needed for one of the hour simulated. To avoid curtailment, a BESS with higher energy storage capacity could be installed. When evaluating the investment of higher storage capacity one has to take into consideration that wind power curtailment was only required for the winter scenario simulated. Furthermore, note that the BESS handles wind power generation prognosis errors after the hourly optimization by the ST cluster. Hence, increasing LT or ST cluster will not exclude any wind curtailment in this case.
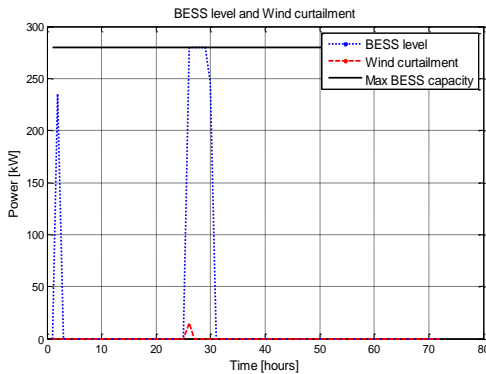

Figure 8. BESS level and wind curtailment when the industry is included.

CONCLUSIONS

According to results gained in this study it is possible to reduce power export events by matching residential and industry loads to the present power generation. Wind curtailment of 0.015 MWh was only requested throughout one hour during the winter scenario.

Indoor temperature curves during the winter scenario have a tendency of decreasing in time as well as the flexibility. I.e. the cluster size has to be increased if running the optimization algorithms during a longer period than three days. The persistence can be changed by increasing or decreasing the amount of households and industries.

When the industry is participating during DR events the cluster size can be significantly reduced. On weekdays during the winter scenario the total cluster size could be reduced from 1400 to 800 households the first day and from 1100 to 500 households the second day.

The results in this report are based on no possibilities for the occupants in the households to reject the DR signals. In reality, one has to take this into consideration when dimension the size of each cluster. In a real implementation, the number of households must probably be expanded compared to the theoretical cluster size given in this study.

It should be noted that space heating is included in the DR flexibility during the summer scenario. That is probably not realistic, because space heating is often turned off during summer month due to high outdoor temperature. Thus, only heating of domestic hot water will contribute to the DR flexibility during June to August. That will increase the cluster size required to solve the optimization algorithms.

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