Towards 100% Renewables in the Faroe Islands: Wind and Energy Storage Integration

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***Abstract*— The Faroe Islands' national system operator SEV has deployed a 2.3 MW Lithium Ion (Li-Ion) Battery Energy Storage System (BESS) at the 11.7MW Húsahagi wind farm site. The BESS provides enhanced ramp rate control and frequency support, enabling wind power to safely cover 60% to 80% of instantaneous demand on the island grid.**

This paper is part of a continuing body of work examining the BESS's real-world performance on the island grid. This paper outlines the observed technical performance of the ramp rate control as well as the newly-implemented frequency support. An updated assessment of the increase in wind utilisation and resulting displacement of fossil fuel generation is presented, now based on two years of operation. SEV are currently studying the possible roles for BESS in the power system's transition to 100% renewables and this is also discussed.

This is of special significance for system operators looking to BESS technology as a means to maximise wind utilisation whilst ensuring system security.

Keywords – Battery energy storage, BESS, wind, ramp rate control, frequency support, isolated power system

I. Introduction

When increasing the penetration of inverter based generation such as wind and solar PV, measures must be taken so that the power system does not suffer from the lack of ancillary services normally provided by the fossil fuel power plants, such as short circuit, inertia and power reserves. Additionally, it must be ensured that the stability of the isolated power system is not compromised when increasing the share of variable renewable resources.

Rapid active power fluctuations from Wind Power Plants (WPPs), which can occur during high wind speeds, can be a challenge for power system operation. These power gradients (both positive and negative) must be balanced by a fast response from other power plants on the system. If this is not achievable, then the WPP output typically needs to be curtailed. However, this measure reduces the utilisation of the wind resource and is therefore undesirable.

Wind power fluctuations can also be mitigated by installing a storage device locally at the WPP which can provide Ramp Rate Control (RRC). The subject of this paper, the BESS at Húsahagi WPP, is designed to perform this function, thereby reducing the need for curtailment and increasing the wind resource utilisation.

The Húsahagi WPP, consisting of thirteen Wind Turbine Generators (WTGs) and a BESS, is owned and operated by SEV, the Faroe Islands' System Operator (SO). The WTGs have been in operation since 2014 and the BESS since 2016.

This paper is part of a continuing body of work on the BESS at Húsahagi WPP. Two previous papers, published in 2017, cover the design, commissioning, and technical results from the operation phase of the BESS [1] [2]. The purpose of this paper is to give additional context in relation to the Faroe Islands' power system, outline SEV's own perspectives on system operation with the BESS, as well as presenting updated economic and technical figures.

The paper begins with an overview of the Faroe Islands power system, where the Húsahagi WPP is installed. A profound shift towards renewable electricity is taking place in this power system, with a target of 100% renewable electricity by 2030.

The paper continues in section III with a technical description of the BESS, its RRC function, and a new Frequency Support function. An example of its response to a frequency event is shown.

A crucial aspect of the BESS is its potential to increase utilisation of the wind resource at Húsahagi WPP. This iscovered in section IV.

The outlook for renewables & storage technologies in the Faroe Islands' power system is discussed in section V and followed with the paper's conclusions.

II. Background

The Faroe Islands are an archipelago in the north Atlantic Ocean, between Iceland and Scotland, with no interconnectors to neighbouring countries and home to 50,000 inhabitants. The Faroe Islands have set high goals for renewable energy and have a clear goal of a 100% renewable electricity system in 2030 [6], taking into consideration an electrification of heating and transport on land. This will however require vast amounts of renewable energy to be integrated in to the power system in the upcoming years toward 2030 and the projected electricity demand is expected to double in the next 13 years, from 340 GWh in 2017 up to approximately 600 GWh in 2030 [6]. In 2017 the electricity demand grew by 5.3%, as shown in analysis for SEV's upcoming Annual Report (April 2018).

Hydro power has been the key resource in the Faroe Islands power system, with the first hydro power installation back in 1921, and hydro was the predominant resource until the early 1970s, when fossil fuel power plants were installed to accommodate the growth in demand.

Fossil fuel power plants have been dominant in the power system for a number of years, but this is now changing. The share of renewable electricity has been steadily growing over the past years, mainly due to new wind power projects and a single new hydro power project. Notably, in 2015, 60% of electricity demand was covered by renewable energy. Demand growth over the coming years is expected to be met not by fossil fuels but by new renewable power plants.

Energy resources like wind, hydro and solar are available in the islands, and emerging technologies like wave and tidal energy also have great potential due to the islands' geographical situation. SEV anticipate that these energy resources, combined with energy storage technologies such as batteries (short term) and pumped hydro (long term), will be predominant players to reach the ambitious goal.

The Faroe Islands' power system consists of a number of non-interconnected grids. Húsahagi WPP is connected to the largest of these grids, the Main Grid. The Main Grid has the following data:

- Peak demand 2017: 55 MW
- Annual electricity demand 2017: 307 GWh
- Installed capacities / 2017 generation:
  - Hydro Power: 37 MW / 107 GWh
  - Wind Power: 18 MW / 60 GWh
  - Thermal: 50 MW / 140 GWh

III. Technical Overview of the BESS

The BESS at Húsahagi was installed on site in April 2016, and after an initial period of operational testing it was brought into full-time operation in August 2016.

A comprehensive technical description of the BESS is given in [2]. As mentioned above, the primary function of the BESS is Ramp Rate Control (RRC). This mitigates the fluctuating power output from the WECs by limiting the ramp rates of the WPP's power output to a fixed *dP/dt* setpoint. This is achieved by charging or discharging the battery in direct response to positive or negative ramping by the WTGs. The *dP/dt* setpoint is adjustable but typically set by SEV to 20kW/s.

The BESS is now also equipped with a Frequency Support function, further detailed in sections B and C below.

The new services provided by the BESS add to the existing system services from the WTGs and their controller: namely fault current injection (fault ride through), voltage droop control, and power-frequency response.

A. System description

A block diagram of Húsahagi Wind Farm is shown in Figure 1. The BESS itself consists of two battery containers and one inverter container ("SMART Container"), with technical specifications as per TABLE I.

The BESS has been integrated with the existing 11.7MW WPP, consisting of 13x ENERCON E-44 WTGs and their Farm Control Unit (FCU).

The SMART Container, an inverter unit supplied by ENERCON, is the electrical interface between the DC batteries and the AC grid.

The Local Energy Management System (L-EMS), also supplied by ENERCON, is the controller responsible for the closed-loop control of BESS charging and discharging. It has a remote interface with the SO's control centre, for exchange of setpoints and status signals.

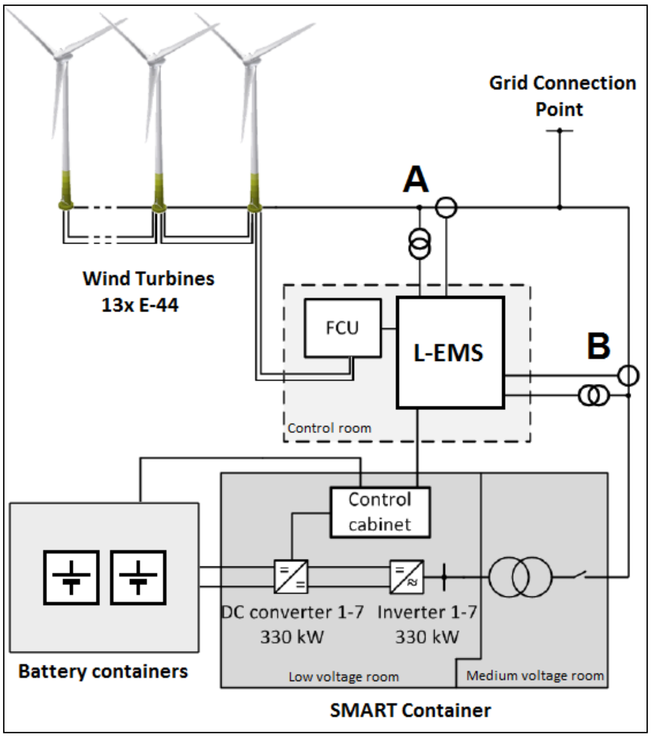

Figure 1. Húsahagi Wind Farm block diagram

TABLE I. BESS Technical Specifications

Battery containers: 2x SAFT Intensium Max® 20 HP	
Energy	707 kWh
Continuous discharge power	2400 kW
Continuous charge power	1500 kW
Inverter container: ENERCON SMART Container	
Apparent power	2300 kVA
AC Voltage	LV : 400V / MV: 20kV
DC Power	2400 kW

To comply with the battery's design limits, the L-EMS automatically adjusts its operation in real time to keep the BESS within a specified energy throughput limit, as well as upper and lower state of charge (SoC) limits.

The L-EMS's primary operating mode is Ramp Rate Control (RRC), whose operation is defined primarily by two adjustable parameters:

dP/dt_{set}	Power gradient setpoint (0-300 kW/s)
SoC_{set}	State of charge (SoC) setpoint (0-100%)

When RRC is active, the L-EMS acts to keep the WPP's overall power output within the specified range of $\pm dP/dt_{set}$.

Figure 2 illustrates the effect of the BESS on ramp rates at the WPP. The RRC is operating with a dP/dt_{set} setpoint of ±20kW/s. When the effect of the BESS is included (light blue bars) the ramp rate values within the setpoint are increased significantly, when compared with the output of the WTGs only (dark blue bars).

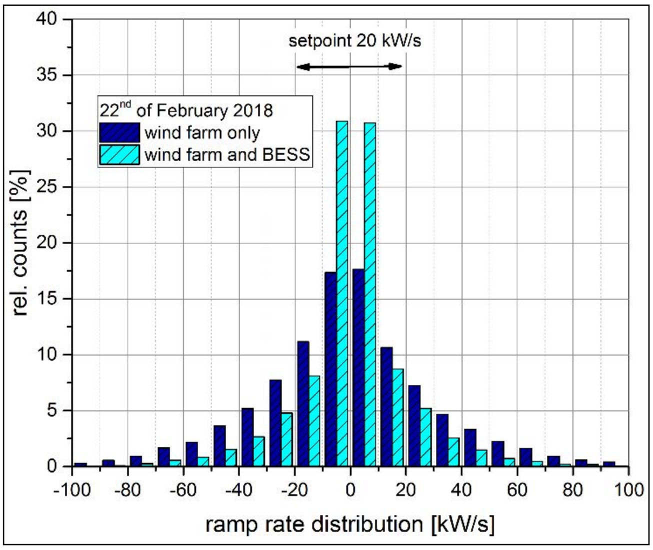

Figure 2. Ramp Rate distribution Husahagi Wind Farm, 22 February 2018

SEV control room staff have noted that, prior to the BESS installation, they would most often need to curtail the windfarm when the wind speed was within the range of 8-12m/s, or above 25m/s, and particularly during low load hours (see section IV below). It has been shown [2] that the BESS's Ramp Rate Control is most active during these times. This has helped to reduce curtailment (i.e. increase wind utilisation) as detailed in section IV below.

B. Frequency Support from the BESS

A Frequency Support function was added to the L-EMS in late 2017. This function acts to increase or decrease the BESS's active power value in response to frequency deviations on the power system. The Frequency Support function operates simultaneously with the RRC, and is thus an example of how a BESS can be used to provide multiple "stacked" system services.

When a frequency event is detected, a power set-point for the BESS is generated according to a preconfigured power-frequency (P(f)) curve, which is combined with the RRC function of the L-EMS. If the grid frequency changes abruptly, the Frequency Support function fully overrides the RRC, in order to maximise frequency support.

The actual frequency is used as reference, so that the controller reacts only to grid events (such as line or generator tripping) and not to long-term frequency deviations which could completely discharge the battery.

If the BESS's SoC reaches its maximum limit, the P(f) curve will be adjusted automatically to prevent further import of active power (overfrequency response). Similarly, reaching the minimum SoC limit will cause underfrequency response to stop.

C. Frequency Support – operational results

Since installation of the Frequency Support function, SEV have also observed that the BESS is the fastest unit on the power system to react to fluctuations of frequency and active power. A frequency dip in March 2018, plotted in Figure 3, illustrates the BESS Frequency Support response. The frequency dip, plotted in black, occurred due to the tripping of a thermal generating unit. The BESS (plotted in red as *P.bess*) is seen to provide a step response of 2.1 MW in less than 400 ms.

Prior to the event the BESS had been exporting active power at approximately 0.2MW, and its RRC activity had been relatively low due to the flat wind output (*P.wtgs*, plotted in blue). The total WPP output (WTGs plus BESS) is also plotted in green as *P.wpp*.

When the frequency dip occurs, the BESS switches directly into frequency response mode, ramping up to its full 2.3MW active power output. This output is maintained until the frequency recovers after approximately 30s.

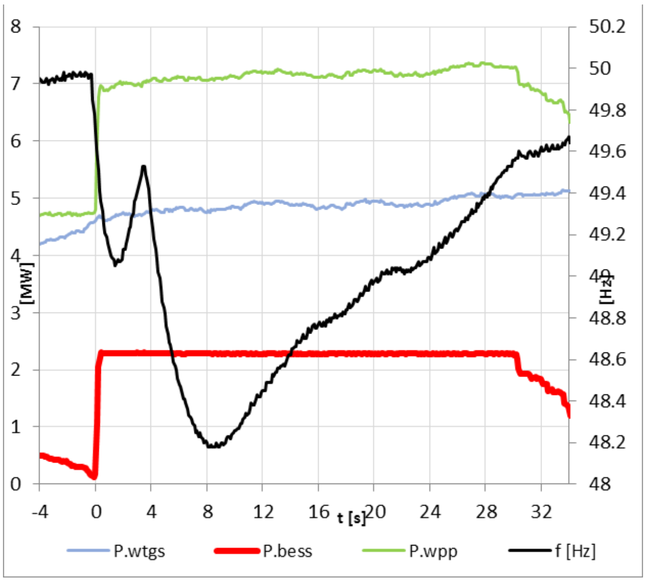

Figure 3. Frequency event and BESS response, 13 March 2018

IV. Utilisation of the Wind

With the BESS's Ramp Rate Control activated, it is possible to reduce the amount of curtailment needed due to fluctuating wind conditions. This increases the utilisation of wind energy at Húsahagi wind farm, displacing fossil fuel generation, and thus providing a basis for the financial viability of the combined wind/BESS system.

Prior to the BESS installation, it was necessary to curtail the wind farm in low load hours, where wind energy could in theory have provided more than 60-70% of the instantaneous load, to avoid compromising the grid stability in periods with fluctuating wind conditions.

It is possible to quantify the utilisation of the wind farm by comparing the Actual energy production to the Potential energy production. The latter is a theoretical signal calculated within the wind farm SCADA system, representing the possible energy production from the total wind farm based on the wind measurements in the different WECs, considering the different WEC availabilities etc.

Utilisation [%] = Actual energy production / Potential energy production

Since start of operation, these figures have been measured in the wind farm and BESS, and based on these figures it is possible to generate a chart as seen in Figure 4 below, where the increased utilisation is obvious over the operational time from October 2014 up to end of February 2018. An average utilisation of 81% is observed prior to the BESS installation in April 2016. Utilisation increases after the BESS is installed, with an average figure of 95% over the last twelve months, and 98% in the last two months.

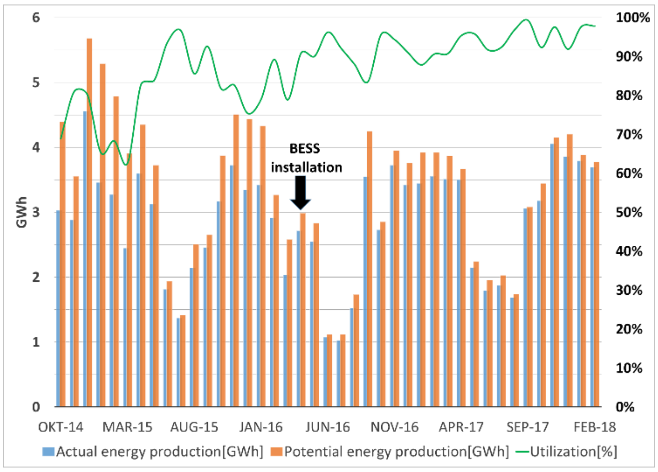

Figure 4. Utilisation of Húsahagi wind farm.

A. Simple Payback Period

Payback time, in this sense, wasn't possible to quantify when designing the project. At the time, the main criterion was that the size of the system would meet the ramp rate technical requirements, whilst remaining within a specified investment budget. Sizing studies carried out during the design phase [1] identified an acceptable balance between technical performance and battery costs. An increase in wind utilisation was anticipated, although 100% wind utilisation was not the aim.

The investment in a BESS was a technical prerequisite for installation of further wind on the islands, and therefore the project was considered as a necessary R&D activity.

With the project now in operation, it is possible to estimate this payback period, since the increased utilisation of the wind farm, or reduced curtailment, is displacing fossil fuel production and hence reducing oil consumption. To quantify the Simple Payback Period, we assume that the Húsahagi windfarm has a potential AEP of 40 GWh[1]. The average utilisation of the wind farm in the months prior to the BESS installation is calculated as 81%. After the installation of the BESS, this figure has increased to an average of 93% for the consecutive 22 months that the BESS have been in operation, or an increase of 12 percentage points.

The cost of each generated kWh produced by fossil fuel is 0.09€/kWh. With a total cost of approximately €2 million, the Simple Payback Period is calculated as approximately 4.5 years.

Other benefits, such as the added value of frequency regulation and the added value due to less spinning reserve running for the wind farm, could further shorten this payback period. It is difficult to quantify the added value of the reduced need for spinning reserve and the added frequency regulation capability, but in any case, even without considering these figures, the payback period is seen to be well within the 20 years design lifetime of the BESS.

V. FURTHER WORK AND OUTLOOK

The Faroe Islands' ambitious goal of 100% renewable electricity generation in 2030 will require extensive use of variable renewable energy sources as wind and PV, and later also tidal and wave energy, which will limit the share of controllable thermal generation which, as of today, provides a number of ancillary services that are essential to stable and secure power system operation.

Preliminary analysis has shown that there will be a need for 120-150MW of wind power and 80-100MW of solar PV installed by 2030 together with a Pumped Hydro energy system for long term storage and batteries for short term storage. This means that variable inverter-based generation will become dominant in the power system.

Today, batteries are the fastest unit to react to frequency and active power deviations in the Faroe Islands power system. For the future, SEV is now studying the effect of additional BESS capacity combined with synchronous condensers, which can provide additional ancillary services like "spinning" reserve, and support in N-1 contingency planning, Frequency Containment Reserve (FCR) and Restoration Reserve (FRR), short circuit power, and inertia.

VI. CONCLUSIONS

The BESS at Húsahagi WPP, now entering its third year of operation, has improved the wind utilisation, by lowering the need for curtailment and hence displacing fossil fuel generation. This results in an economic benefit, with an estimated payback period of 4.5 years. The BESS now also responds to frequency deviations, and in this way participates in the frequency regulation of the overall power system. The stacking of Ramp Rate Control and Frequency Support within the same BESS, managed by a single control system, helps to further support the system for a higher penetration of renewables.

For SEV, the BESS has also provided important data and know-how in relation to BESS capabilities and operations which will inform and add value to future investments and operation of the Faroe Islands' power system infrastructure.

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[1] Yield calculations for the Húsahagi site

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