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Engineering Review

Ben Aketil Wind Farm

Ben Aketil Wind Energy Ltd.

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COMMERCIAL IN CONFIDENCE

Falck Renewables

PURE POWER TO GROW

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TNEI Services Ltd

Company Registration Number: 03891836 VAT Registration Number: 239 0146 20

Registered Address		
Bainbridge House	7th Floor	
86-90 London Road	West One	7th Floor
Manchester	Forth Banks	80 St.Vincent Street
M1 2PW	Newcastle upon Tyne	Glasgow
Tel:+44 (0)161 233 4800	NE1 1PA	G2 5UB
Fax:+44 (0)161 233 4801	Tel:+44 (0)191 211 1400	Tel: +44 (0)141 428 3180

TNEI Africa (Pty) Ltd

Registered: Mazars House, Rialto Rd, Grand Moorings Precinct, 7441 Century City, South Africa

Company Number: 2016/088929/07

1st Floor

Willowbridge Centre

Carl Cronje Drive

Cape Town

South Africa, 7530

Tel: +27 (0)21 974 6181

Executive Summary

TNEI Services Ltd has been commissioned by Falck Renewables Wind Ltd ("Falck") to undertake an engineering review of the operational Ben Aketil Wind Farm (the "Project"), located near Dunvegan, Skye, Scotland.

The Project comprises:

- Ben Aketil Wind Farm (10 wind turbine generators (WTGs) (planning permission reference 02/00275/FUL); and
- Ben Aketil Extension (2 WTGs) (planning permission reference 09/00115/FULSL).

Planning permission for both sites expires in 2033. Falck is applying to the Highland council to extended the Project's planning permissions for a further 7 years.

A Lifetime Assessment review, which assessed the condition of the wind turbines and their lifetime extension potential, was undertaken by Fichtner in December 2018. This report uses the findings of the Fichtner review, together with TNEI's engineering experience and professional judgement to determine the engineering implications of the proposed life extensions and the impact on the operational longevity of the WTGs.

Ben Aketil's commercial operation dates were January 2008 and December 2010, respectively. Both the 10 and the 2 turbine permissions comprise Enercon E70 WTGs, with 64 m high tower and rated capacity of 2.3MW.

The standard design life of a WTG is 20 years, however, the design life can be extended subject to site specific conditions. The Enercon E70 WTGs are design Class IA. With the exception of air density, it was determined that key wind condition parameters measured over 9 years of operation were below the Class IA certification values and thus greater potential for life extension and longevity Enercon have a strong OEM track record with over 13,000 WTGs installed worldwide, totalling more than 20GW of capacity. Enercon WTGs are direct drive, which eliminates the need for gearboxes and as such, associated failures. The WTGs are also variable pitch and variable speed which protects them from transition loads. Ben Aketil's availability of 93.65% indicates an operational period with relatively few issues.

An inspection of WTG 10, chosen as a representative worst-case, was undertaken in 2018. The inspection comprised a visual non-intrusive verification of key components, which identified only minor defects, typical of the WTGs age and environmental conditions, which can be readily rectified.

With no additional investment, over and above scheduled maintenance, the WTGs are expected to be able to operate for 24 years (up to 2032) from start up. Operation up to 2040 (i.e. 32 years from start-up) will require additional investment in key components.

A Life Extension Plan would be prepared and implemented by Falck, detailing component specific inspection and monitoring regimes, together with repair and replacement protocols. A number of identified component replacements and repairs can be readily undertaken, at low cost, with no additional plant (e.g. cranes) or materials. However, some component replacements will be more involved and would be carefully planned to ensure a safe and efficient operation. The plan would aim to replace all identified components ahead of their expected lifetime consumption and identify efficiencies by combining several component replacements. The plan would be aligned with the scheduled maintenance programme in order to ensure that relevant inspections and small component replacement are undertaken in the most efficient manner.

With the implementation of the Life Extension Plan the Wind Farm will be able to operate within its current parameters for an additional 7 years (up to 2040) with a low risk of main component failure.

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1 Introduction

TNEI Services Ltd ("TNEI") has been commissioned by Falck renewables Wind Ltd ("Falck") to undertake an engineering review of the operational Ben Aketil wind farm (the "Project"), located near Dunvegan, Skye, Scotland.

The Project comprises two wind farm planning permissions:

- Ben Aketil wind farm, 10 wind turbine generators (WTGs) and associated infrastructure, consented in September 2006 (planning permission reference 02/00275/FUL); and
- Ben Aketil Extension, 2 WTGs and associated infrastructure, consented in February 2010 (planning permission reference 09/00115/FULSL).

For the purposes of this report references to 'Ben Aketil' shall mean both the 10 turbine development and the 2 turbine extension, unless otherwise specified.

Both planning permissions have an expiry date of 2033. Falck is applying to the Highland Council to extended the Project's planning permissions for a further 7 years ("life extension").

The purpose of this review is to determine the engineering implications of the proposed life extensions and the impact on the operational longevity of the WTGs.

A Lifetime Assessment review, which assessed the condition of the wind turbines and their lifetime extension potential, was undertaken by Fichtner in December 2018. This report uses the findings of the Fichtner review, together with TNEI's engineering experience and professional judgement to make an assessment of the Project's suitability for a 7 year life extension to both planning permissions.

This report identifies actions, which have been agreed with Falck, to be carried out which will minimise the risk of main component failure and allow the WTGs to operate within their existing parameters for the proposed life extensions.

2 Project Baseline Conditions

Ben Aketil's commercial operation date (COD), the date on which it first started exporting power to the grid, was January 2008. Ben Aketil Extension's COD was December 2010. Both projects comprise Enercon E70 WTGs, with 64 m high towers and generation capacity rated at 2.3MW per WTG. Monthly reports for the full duration of COD to June 2017 were available for Ben Aketil (i.e. no gaps in operational data).

2.1 Wind Conditions

WTGs are designed to withstand standard and regulated wind conditions. When these conditions are compared to actual site measured conditions, they are usually found to be conservative. The standard design life of a WTG is 20 years, however, this typical 'over design', means that the design life can be extended subject to site specific conditions.

The Enercon E70 WTGs deployed at Ben Aketil are Class IA. Table 2.1 below details a comparison between the Class IA design parameters and the parameters measured on site at Ben Aketil.

Table 2.1 Wind Conditions

Design Parameter	Class IA	Ben Aketil	Utilisation (%)
Annual Average Wind Speed (m/s)	10	8.95	89
Turbulence Intensity, Iu (%)	18	0.17	1
Inflow Angle (°)	8	2.22	28
Wind Shear α	0.2	0.18	90
Air Density (kg/m3)	1.225	1.226	100
Total Availability (%)	100	93.65	94

These wind conditions have the greatest impact on a WTGs operational lifespan, the less each parameter is utilised the less fatigue the WTG has been subjected to, and thus the more potential there is for life extension. With the exception of air density, it can be seen that all key parameters measured over the 9 years of operation are below the Class IA certification values.

2.2 WTG Technology

Enercon has a strong OEM track record with over 13,000 WTGs installed worldwide, totalling more than 20GW of capacity. Enercon WTGs are direct drive, which eliminates the need for gearboxes and as such, associated failures. The WTGs are also variable pitch and variable speed which protects them from transition loads.

Availability is the percentage over a given period that a WTG is available to generate power. availability is affected by scheduled and unscheduled maintenance, power system outages and control system faults. Availability figures do not take into account external factors such as grid availability and wind conditions. Ben Aketil's availability of 93.65% indicates an operational period with relatively few issues.

2.3 Visual Inspections

An inspection of WTG 10 at Ben Aketil was undertaken in November 2018. The turbine chosen was anticipated to be subject to the most onerous wind loading conditions and thus representative of the Project's worst-case scenario.

The inspection comprised a visual non-intrusive verification of:

- Foundation;
- Externals (Tower condition, door, and access steps);
- Internals (ladder, platform, welds, flanges, and bolts);
- Cables;
- Yaw gear;
- Hub and spinner;
- Brake and low speed shaft;
- Blade bearing;
- Main carrier;
- Pitch system;
- Drive train;
- Anemometer; and
- Rotor and Blades.

Overall, the WTG was categorised as 'Low', meaning minor irregularities were identified but which could be easily rectified and do not present any safety issues.

The internal foundations bolts were not inspected, this is considered most likely due to access being restricted to only HV Senior Authorised Persons (SAPs) to minimise safety risks. Due to the relatively good condition of the rest of the WTG and no obvious indications of bolt corrosion, fatigue, slackening or other defects, it is likely that bolts would be categorised as either OK or Low.

The foundations, external tower conditions, ladder, door frame, and yaw system were all categorised as low, with all other components categorised as OK (meaning no irregularities were identified).

2.3.1 Foundations

A small crack was observed in the foundation surface. Likely to be a result of inadequate curing after casting of the concrete. Due to its location adjacent the tower, its condition could be exacerbated over time due to thermal expansion and bending. With the application of simple remedial works and ongoing monitoring, there will be a low risk of any structural issues arising over the proposed extended operational lifespan.

2.3.2 External Tower

Minor corrosion (rust) patches were observed on the external surface of the tower. The corrosion is considered to be caused by sub-standard paint application during manufacturing. With the application of simple remedial works and ongoing monitoring, there will be a low risk of any structural issues arising over the proposed extended operational lifespan.

2.3.3 Ladder and Door Frame

Similar to the tower, small areas of corrosion were identified on the external access steps and around the door frame, most likely a result of substandard manufacturing. With the application of simple

remedial works and ongoing monitoring, there will be a low risk of any structural issues arising over the proposed extended operational lifespan.

2.3.4 Yaw System

Small areas of corrosion were identified on the bolts of the yaw lubrication system. As with other components, the corrosion is considered to be a result of substandard paint application during the manufacturing process. With the application of simple remedial works and ongoing monitoring, there will be a low risk of any structural issues arising over the proposed extended operational lifespan.

3 Project Life Extension

3.1 Life Extension Potential

With no additional investment, over and above regular scheduled maintenance, the Ben Aketil WTGs are expected to be able to operate for 24 years from start up. Some individual WTG components' life spans exceed this duration but the WTGs overall life spans are generally limited by the adapters, blades, top tower and yaw bearing supports.

Therefore, operation up to 2032 is considered to be feasible, with no additional investment. Operation up to 2040 (i.e. 32 years from start-up) is also feasible with additional investment in the adapters; blades; ring, main carrier, yaw bearing & supports; tower, hub and foundation. Operation beyond 2040, will require further investment in the pitch actuators and supports and the pitch bearing, but is feasible.

All additional maintenance actions are readily achievable using existing site infrastructure (e.g. roads, hardstandings etc) without the need for construction activities and as such would not result in any significant environmental effects.

3.2 Life Extension Uncertainty

The level of uncertainty in the lifetime extension modelling, performed in accordance with the Failure Modes and Effects Analysis (FMEA), is determined by monitoring and scoring projects against 240 key parameters. The parameters take into account, the Project's general data (e.g. site layout), site specific measured wind data, operational data (fault logs, maintenance etc), WTG geometrical data, and the calculations process (i.e. uncertainties in the process and tools/software used). Each parameter is scored with regards to its criticality (i.e. its importance compared to other parameters), source (e.g. directly measured, indirectly measured, estimated or generic) and scenario selection (e.g. use of measured values for mean vs. maximum). The lifetime assessment for Ben Aketil has a 20% level of uncertainty, putting into the Medium category. Section 3.3 below, details how the modelling uncertainty will be addressed.

3.3 Life Extension Plan

In order to realise the life extension potential summarised in Section 3.1, a Life Extension Plan (LEP) for the Project would be implemented by Falck. Table 3.1 summarises the actions to be undertaken on WTG components, the component life consumption (i.e. lifetime replacement) and the optimal scheduling of works. These remedial actions and timings would be incorporated into the LEP. It should be noted that the level of uncertainty detailed in Section 3.2 will be addressed in the LEP through component specific inspection and monitoring regimes and replacement of components in advance of their life consumption. Furthermore, components with a life consumption greater than 32 years, shall be included to allow for analysis uncertainty.

Table 3.1 WTG Component Remedial Works

Component	Remedial Actions	Life Consumption (years)	Scheduling
Blade pitch bearing hub bolted connection	Replace blade bolts in the sector +/- 45° from the blade edges; this can be done without uninstalling the blades	24	Prior to component life consumption in combination with other works to reduce downtime and operational costs (e.g. root over-lamination, pitch bearing replacement)
Composite blade root and edges reinforcement	Installation of composite over lamination reinforcement on damaged edges.	24 – 25 (root and lower sections) 28 – 37 (mid sections) 40 (tip)	Prior to component life consumption in combination with other works to reduce downtime and operational costs (e.g. blade bolts replacement, pitch bearing replacement)
Pitch bearing	Replacement of pitch bearings	37	Prior to component life consumption in combination with other works to reduce downtime and operational costs (e.g. blade over laminations, pitch bearing replacement)
Pitch actuators and supports	Implement management plan to detect, measures and monitor appearance of cracks. Plan to details repairs/reinforcements to supports. Actuators to be replaced completely.	35	In accordance with management plan and prior to component life consumption
Hub	Implement management plan to inspect and monitor for cracks. Plan to detail crack repair / reinforcements rather than component replacement.	27	In accordance with management plan and prior to component life consumption

Component	Remedial Actions	Life Consumption (years)	Scheduling
Ring (rotor/generator bearing)	Inspections using endoscopes and grease analysis. Replacement of ring.	25	In accordance with inspection regime and prior to component life consumption. In combination with other works to reduce downtime and operational costs (e.g. maintenance of blades requiring removal of rotor)
Main Carrier (base frame)	Implement management plan to inspect, monitor and replace bolts. Plan to also monitor, inspect and repair any cracking instead of full component replacement.	25	In accordance with management plan and prior to component life consumption
Yaw bearing	Replacement of tracks, balls, teeth and actuator components dependent upon results of ongoing inspections	26	In accordance with management plan and prior to component life consumption. Can be done in combination with other works to reduce downtime and operational costs (e.g. actions which may require use of cranes)
Yaw bearing supports and tower top	Implement management plan to inspect, monitor and replace bolts. Plan to also monitor, inspect and repair any cracking	24	In accordance with management plan and prior to component life consumption
Towers	Implement management plan to inspect and monitor body, joints and bolts for cracks. Plan to detail repair protocol and reinforcement works for body and joints. Bolts to be replaced.	24 (top) 25 (middle) 26 (bottom)	In accordance with management plan and prior to component life consumption. Can be done without use of cranes.

Component	Remedial Actions	Life Consumption (years)	Scheduling
Foundation	Implement management plan to inspect and monitor for cracks. Plan to detail crack repair / reinforcements rather than foundation modification.	26	In accordance with management plan and prior to component life consumption

4 Summary

The WTGs at Ben Aketil Wind Farm have undergone a thorough component assessment, supported by a representative visual inspection, to determine their operational life span and potential for life extension.

4.1 Conclusions

It has been determined that the WTGs have not been subjected to their maximum design loadings, thus component utilisation is low. Visual inspections have identified a number of minor defects that are considered typical for WTGs of their age and environmental conditions. All defects can be readily addressed with minimal disruption and cost.

A 240-point FMEA, taking into account general site data, wind conditions, operational conditions, WTG geometry and calculation process, has been undertaken for the Project and has determined a 20% (medium) level of uncertainty in the life extension modelling, which is considered reasonable for the scope of works undertaken.

Subject to typical ad-hoc and scheduled maintenance, and repair of the minor defects identified during the visual inspections, it is anticipated that the WTGs have an operational life of 24 years (with 20% uncertainty level). Given the Project COD of 2008 (original Ben Aketil site), WTGs can operate until 2032 without substantial component repair or replacement. The two WTGs for the Ben Aketil Extension site can operate until 2034.

To facilitate the 7-year planning permission extensions, resulting in consent expiration in 2040, the WTGs will be required to operate for 32 years. In order for WTGs to safely and efficiently operate for this period, a number of key components will require specific inspection and monitoring plans implemented with eventual repair or replacement before their respective life consumption periods. A number of component replacements and repairs can be readily undertaken, at low cost, with no additional plant (e.g. cranes) or materials. However, some component replacements will be more involved and would be carefully planned to ensure a safe and efficient operation.

4.2 Actions

A Life Extension Plan, as described in Section 3.3 would be prepared and implemented by Falck. The plan would detail component specific inspection and monitoring regimes, together with repair and replacement protocols.

The plan would aim to replace all identified components ahead of their expected lifetime consumption, to account for analysis uncertainty. The plan will identify efficiencies, reduce costs and maximise WTG availability by identifying those components which can be replaced in conjunction with others. Modelling uncertainty will also be accounted for through inspection and monitoring regimes which will facilitate the detection of early deterioration.

The Life Extension Plan would be aligned with the scheduled maintenance programme in order to ensure that relevant inspections and small component replacement are undertaken in the most efficient manner.