BEFORE THE HEARING COMMISSIONERS
AT PALMERSTON NORTH

IN THE MATTER	of the Resource Management Act 1991 (the Act)
AND	
IN THE MATTER	of a review by **PALMERSTON NORTH CITY COUNCIL** of the conditions of consent for Te Rere Hau Windfarm under section 128 of the Act

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STATEMENT OF EVIDENCE OF JAMIE STUART WALLACE ON BEHALF OF NZ WINDFARMS LIMITED

DATED 22 AUGUST 2017

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INTRODUCTION

1. My full name is Jamie Stuart Wallace.

2. I am currently employed by TRH Services Limited, a wholly owned subsidiary of NZ Windfarms Limited (NZ Windfarms), as a Development Engineer. I have held this position since 2013.

3. I completed a Bachelor of Engineering Degree in 2003 and a PhD in Mechanical Engineering in 2006, both at the University of Canterbury. I have been a member of the Institute of Professional Engineers New Zealand and a Charted Professional Engineer since 2010.

4. I have worked in the wind engineering industry for eight years, predominantly as Development Engineer for both turbine manufacturer Windflow Technology Limited (WTL) and operations and maintenance with NZ Windfarms.

5. At NZ Windfarms I have been heavily involved in turbine performance analysis, turbine mechanical and control software improvements, and operational and maintenance improvements such as job procedures and specialised tooling. I provide engineering and fault finding support to on-site staff and undertake development and improvement projects.

6. At WTL I led development of a software simulation model (using commercially available software 'Bladed') which enabled generation of turbine life load data, required to produce IEC 61400 certification design calculations. I worked closely with software authors Garrad Hassan to develop bespoke software features and abilities for the unique Windflow500 turbine model.

7. This included interfacing the simulation software with controller hardware and WTL control software (whereby the simulation software generated inputs, normally provided by a turbine, for the controller). This was a highly developmental process and gave me intimate knowledge of the unique control software running Windflow500 turbines.

8. I also accrued a unique level of understanding of all Windflow turbine systems, turbine operation and load events; I analysed, advised on and resolved countless faults with the operations team at Te Rere Hau (TRH).

9. I took responsibility for development of the hydraulic system in the turbines, one of the key and unique features of the Windflow500.

10. I oversaw IEC certification 'Type Testing' (proof testing) at the prototype Windflow500 turbine situated at Gebbies Pass near Christchurch, as well as numerous research and development projects to improve the prototype and subsequent turbines destined for Te Rere Hau. I also managed and undertook operation and maintenance of the Gebbies Pass turbine.

11. I oversaw fatigue testing, to failure, of a turbine blade, as required for IEC certification.

12. I am authorised to give this evidence on behalf of NZ Windfarms.

Purpose and scope of evidence

13. The purpose of this evidence is to provide an overview of how NZ Windfarms is reconfiguring how its wind turbines operate in response to site conditions.

14. This evidence will address the following matters:

    (a) How the turbines were previously operated;

    (b) What work NZ Windfarms has done to look at different modes of operation;

    (c) The changes made to date; and

    (d) Further changes NZ Windfarms is looking at making.

HOW TURBINES WERE PREVIOUSLY OPERATED

15. To conform with design limitations the wind turbines do not generate beyond a defined 'cut out' wind speed (30 m/s), and are prevented from running in the wake of another turbine, as is standard industry practice.

16. Turbulence Intensity (TI) is defined as the standard deviation of wind speed divided by the mean wind speed over some time period, and is a common and practical measure of how unsteady (or fluctuating) the longitudinal wind speed is. Often 10 minute averaging periods are evaluated as this adequately represents the typical frequency distribution of wind speed, which is stochastic in nature (i.e. unable to be predicted precisely).

17. Operational experience with a particular group of turbines at TRH led to development of 'Turbulence Intensity Curtailment', whereby eleven turbines' operation was restricted when excessive turbulence intensity was detected. This is invoked in wind speeds greater than 10.5 m/s, with hysteresis (to introduce lag) to remove the restriction if either the mean wind speed falls below 9.5 m/s, or TI falls to an acceptable level, for one minute.

18. Aside from the above limitations, until recently the operating strategy has been to keep turbines available and generating wherever possible. At times this clearly resulted in uneconomic running of turbines (e.g. particularly arduous wind conditions and/or low power price).

19. Operation in very high wind speeds (>25 m/s) or high TI (at a large range of wind speeds) is particularly abusive to turbines mechanically. This operation strategy resulted in high turbine availability and capacity factor, but also high component and labour costs for maintenance.

DIFFERENT MODES OF OPERATING

20. Each turbine is self-managing via its own programmable logic controller (PLC). The PLC's run a common programme which is unique to NZ Windfarms.

21. Each turbine measures wind speed and direction locally and can therefore respond in real time to changing conditions, as defined by the programme. The programme itself can be altered, as has been done to include Noise Curtailment functionality discussed later in this statement.

22. Oversight for automatic and manual intervention is provided by the Supervisory Control and Data Acquisition (SCADA) system. A large array of data is continuously exchanged between every turbine and SCADA, and enables setting changes (such as the bespoke conditions for curtailment on any turbine) as well as overarching control over whether a turbine is allowed to generate. In principle the SCADA software is almost limitless in capability; it is typically acquisition of valid input data (e.g. accurate forecasting or physical measurements that cannot be made by turbine systems, such as inflow angle) that limits functionality.

Work investigated or commissioned

23. Additional control of turbine operation based on TI, wind speed and power price has previously been considered but rules governing wind generators (disallowing output ramping in response to power price) has prevented implementation to date. However, as noted in John Worth's evidence, it is expected that these rules may change in early to mid-next year. Accordingly, I outline some of the strategies NZ Windfarms has investigated which could potentially be used if the rules do change:

(a) **Global TI Curtailment** - Application of existing TI curtailment to all turbines – based on 10 minute average wind speed and TI, each turbine evaluates local anemometry data and if wind speed and TI conditions fall outside pre-set limits for a pre-set duration, turbine operation is prohibited.

(b) **'3 Axis' Curtailment** – It is possible to feed power price data, as well as wind speed and TI, to a turbine controller allowing it to judge in real time whether it is economical to run each turbine. This would rely on provision of rules in the controller software defining what combination of inputs is economical.

(c) **'5 Axis' Curtailment** – Wind shear (the rate at which wind speed increases with elevation above ground level) and inflow angle (the gross angle at which incident wind meets a turbine rotor) are typically detrimental to wind turbines as they each cause uneven loading across the rotor, increasing fatigue damage. This is of particular concern at TRH due to the highly complex topography of the wind farm site. With more input data to the controller software to define further rules, additional sensitivity to inflow angle and shear could be applied to influence decision making on economic running of each turbine.

(d) **Noise Curtailment** – Controller software evaluates the mean wind speed and 10 minute mean wind direction to prevent individual turbine operation within pre-defined limitations such as time of day, and with wind speed, wind direction and time hysteresis.

24. Implementation of each of the curtailment options manifests in similar but unique ways and each requires that the following steps be taken:

(a) Clearly define the required functionality.

(b) Determine (and create) inputs required, on which to base an allow/disallow generation decision.

(c) Determine the form of those inputs, for example if the input is wind speed; is it an instantaneous measure or an average? If an average, of what duration?

(d) Determine the relationship between the inputs, such that any combination of inputs can be reduced to a binary decision.

(e) Define the above relationship with logic, such that any combination of inputs leads to a sensible binary decision, and every possible combination of situations (including faults and unexpected inputs) is accounted for.

(f) Define limits and hysteresis to ensure predictable decisions without flicker (prevent indecisiveness) in every possible situation.

(g) Implement the functionality in both individual turbine controllers and the overarching supervisory control software, including user configurable settings if appropriate.

25. In addition to the above, in order to implement:

(a) 'Noise' curtailment, NZ Windfarms has engaged with neighbours and worked with a sound engineer consultant to identify opportunities to reduce noise at neighbouring residences.

(b) '5 Axis' curtailment, NZ Windfarms has commissioned complex computational fluid dynamics (CFD) modelling to better understand the impacts of topography on each turbine. The analysis will inform the curtailment algorithm to aide decision making on economical running of individual turbines.

CHANGES MADE TO DATE

Low wind start-up behaviour

26. Each turbine independently monitors its locally measured wind speed and direction and continuously evaluates whether conditions are amenable to generating.

27. There are a multitude of conditions required to attempt a start-up, including the mean and instantaneous wind speeds being high enough for set periods.

28. The intent of the logical conditions is to ensure that there is sufficient, and sufficiently constant, wind for the turbine to accelerate and remain running and generating electricity. Start-ups can take from less than ten seconds to several minutes.

29. Although power output is low in such conditions, the annual distribution of wind speed results in a large number of hours which aggregate to significant generated volume over the whole farm; it is therefore impractical to simply raise the minimum requirements to a point where there is never a failure.

30. The nature of wind gusts, lulls and direction changes makes the start-up evaluation very challenging, and a turbine may attempt to start up but not experience enough wind to execute the start-up completely or to generate. This may be exacerbated by directional topographical dependence, whereby speed measurements can be affected variously in different wind directions.

31. Typical start up failure modes are:

    (a) Inability to accelerate to generating speed in set period (typically due to high turbulence, i.e. fluctuations in wind speed); and

    (b) Stagnating at a rotor frequency which coincides with the support tower natural frequency, which could lead to dangerous displacements and tower failure (typically due to lulls or wind shifts).

32. These eventualities have been allowed for in the controller software which will initiate a shut-down of the turbine, back to its standby condition.

33. Higher than usual aerodynamic noise emanates from the blades during transient start-up and shut-down events, particularly on shut down where the blades feather quickly to provide aerodynamic braking to bring the rotor to a stop. Shut-downs last approximately 4 to 15 seconds, with audible aerodynamic noise for just a few seconds.

34. During the first half of 2016 considerable effort was made to reduce failed start-up attempts (and the associated shut-down) in low wind. Parameters used by turbines in making the decision to generate were altered in response to trends evident from analysed failures – effectively to improve the turbines forecast of imminent wind conditions. These changes have significantly reduced failed start-up attempts and resulting shut downs in very low wind – conditions which some residents report to have noise impact.

Turbulence intensity curtailment

35. Turbulence intensity curtailment (considering wind speed and turbulence intensity) was originally developed to address excessive wear in a group of turbines experiencing exceptionally high TI. Each turbine measures local wind speed and TI and turbine controllers have pre-set rules defining which combinations are acceptable for generation and which are not. With the addition of limitations and hysteresis each controller determines in real time whether the turbine is allowed to generate or not.

36. In April 2017 this control strategy was applied to all turbines, reducing total run hours in a range of wind conditions.

Noise curtailment

37. In May 2017 I was asked by NZ Windfarms' Chief Executive Officer, John Worth, to investigate opportunities to reduce the wind farm's noise impact on neighbours.

38. A consultation process with neighbours was undertaken along with analysis of council complaint data. I collaborated with our consulting sound engineer in doing this, and to compare feedback against an acoustic model previously developed for the TRH wind farm.

39. The model guided identification of individual turbines, wind speeds and directions which, if curtailed, were expected to reduce the sound level at targeted receivers. This guidance

was fed back to me for implementation in turbine control software.

40. An algorithm enabling bespoke operating restrictions on individual turbines was developed. Implementation is achieved via both individual turbine controllers and the overarching SCADA system. Wind direction and speed is compared in real time against pre-determined values for each turbine. It is also necessary to build in limits, fault handling and hysteresis to ensure a correct response to every possible situation.

41. An initial pilot programme of noise curtailment was implemented in July 2017 specifically to test whether it had any noticeable impact on the noise level experienced by neighbours. To date one cycle of noise curtailment and feedback has been completed and further cycles are planned. As noted by Mr Worth, the process is intended to be ongoing, and will be refined over time.

FURTHER CHANGES

42. The following further changes are in varying stages of development.

3 Axis Curtailment

43. 3 Axis Curtailment, considering wind speed, TI and power price, is largely developed at time of writing. Operating experience and quantifiable historical data enabled the definition of a set of rules as to which combination of conditions is acceptable for generation and which are not. The rules are represented by mathematical equations which essentially represent a 3-D surface on which any point can be identified in real time, and equated to a binary decision on whether to generate or not.

44. Implementation is via both individual turbine controllers and the SCADA system and is expected to occur if NZ Windfarms successfully challenges market rules regarding curtailment based on power price, reducing total run hours in a range of wind conditions.

5 Axis Curtailment

45. 5 Axis Curtailment, considering wind speed, TI, price, inflow angle and wind shear, is under development. Complex CFD modelling is required to inform algorithm design and

curtailment decisions, which would result in additional rules in a similar but more complex fashion to 3 axis and noise curtailment. 5 Axis Curtailment will further reduce total run hours in a range of wind conditions.

Jamie Stuart Wallace

22 August 2017