PO.258

Flight Phase Control Strategies for Airborne Wind Energy Systems

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Abstract

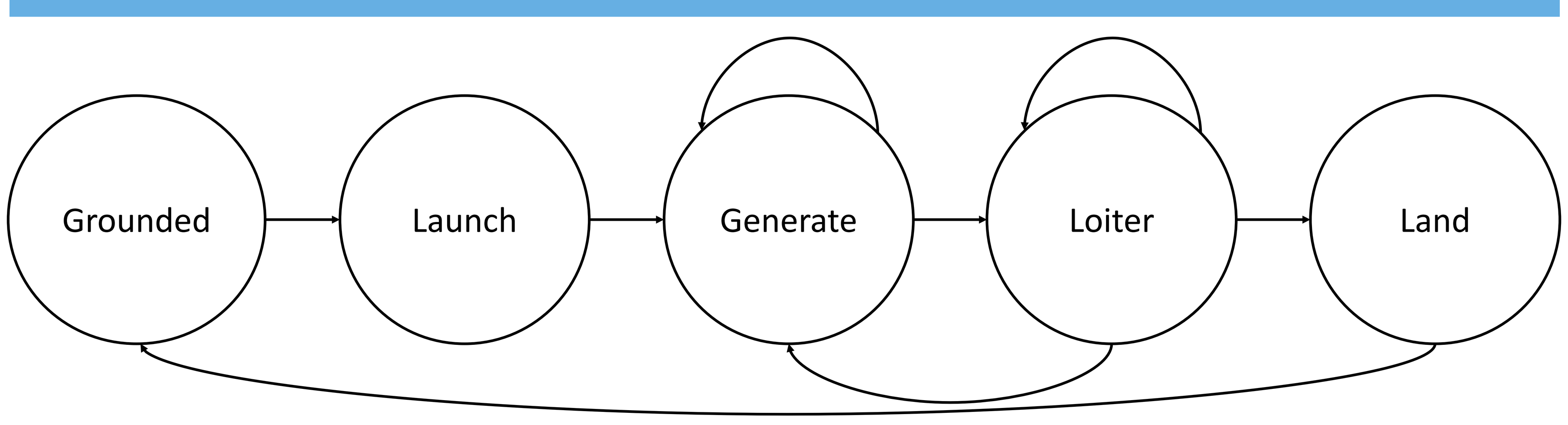
Traditional Danish concept wind turbines face many constraints when upscaling in order to access higher wind speeds, such as size, mechanical loading and weight. It is possible that some of these constraints could be circumvented through use of airborne wind energy systems (AWES).

With research into AWES becoming more prominent, the topic of launching and landing the system must be analysed in detail. Currently several concepts are being pursued with differing launch and land technologies. For all systems it is likely that minimising launch and land cycles will be a key objective due to increased energy costs and hardware risk in these phases.

This research focuses on a cross-wind ground-based generation system and discusses the problem of the launch and land policy with regards to the wind speed at operational height. The paper also discusses the use of an airborne powered loiter phase and a grounded waiting phase. A key consideration when analysing this problem is wind speed measurement uncertainty (including the degree of temporal averaging) and how to integrate this uncertainty into any launch & land policy.

The present research concerns cost-benefit analysis with respect to generated and consumed energy cost functions for each flight phase. It is found that for any given AWES there will be an optimum airborne loiter time after which a system should be landed. This avoids landings due to short-duration low wind periods.

Flight Phase Policy



An AWES will exist in one of several flight phases. For this research, they are considered to be Grounded, Launch, Generate, Loiter and Land. The transition between states is visualised above.

This research primarily focuses on the transition to and from the loiter phase with an emphasis on optimisation of the time spent loitering. The optimum loiter time will depend on the relative energy costs and yields of the flight phases.

Considering only the costs associated with loitering, launching and landing – or generally the parasitic costs – would suggest that there would be little benefit to implementing a loiter policy due to the increasing parasitic costs with increased loiter times. However, this does not account for the increased energy yield that could be determined due the implementation of an effective loiter policy.

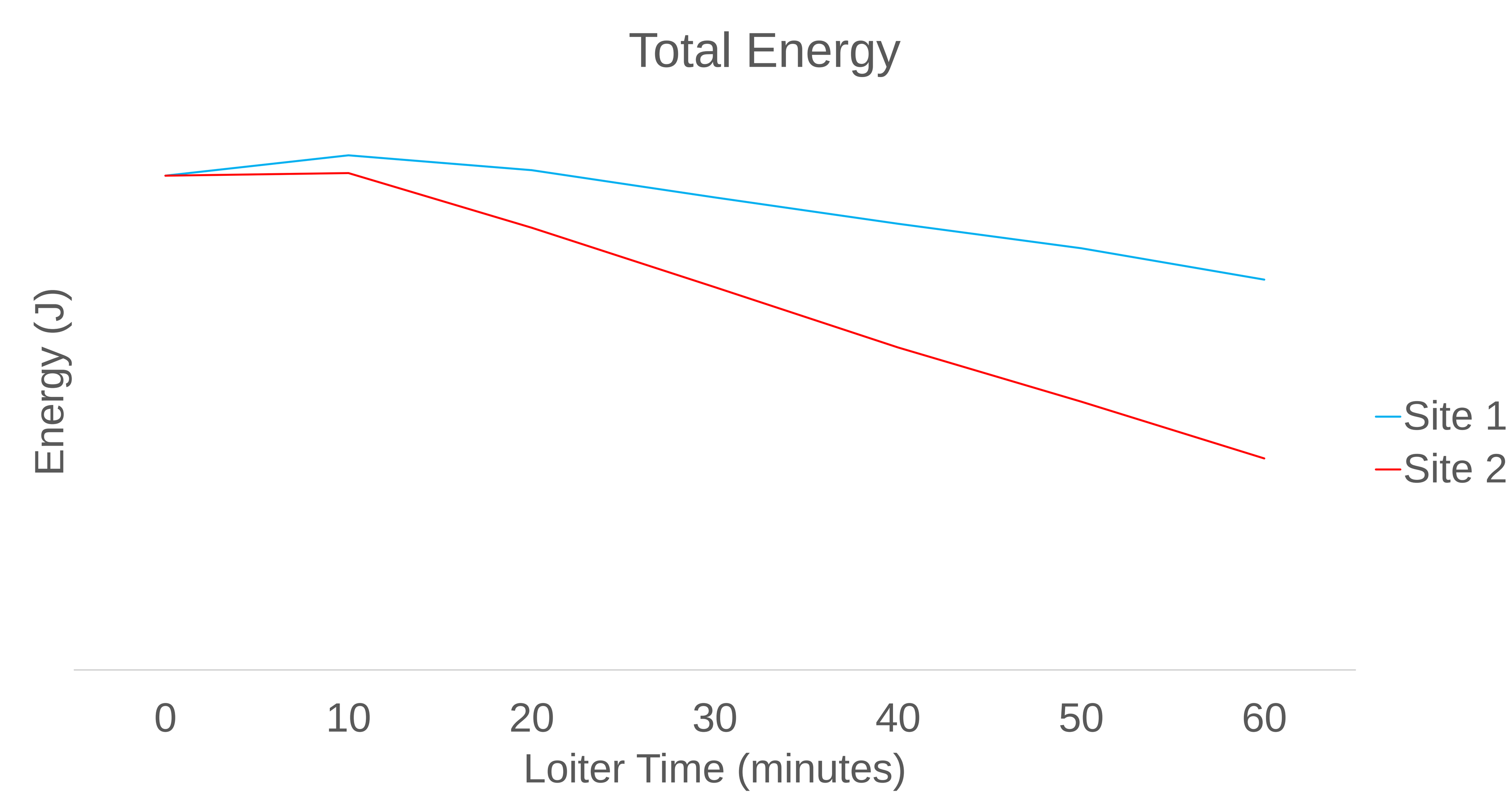
Maximum Loiter Time

$$\frac{E_{Land} + E_{Launch}}{P_{Loiter}} = t_{Loiter}$$

In order to evaluate the maximum loiter time the energy cost of launching, landing and loitering the system must be considered. In the above equation E is energy, P is power and t is time taken to complete the act of landing, launching, loitering and grounding the system.

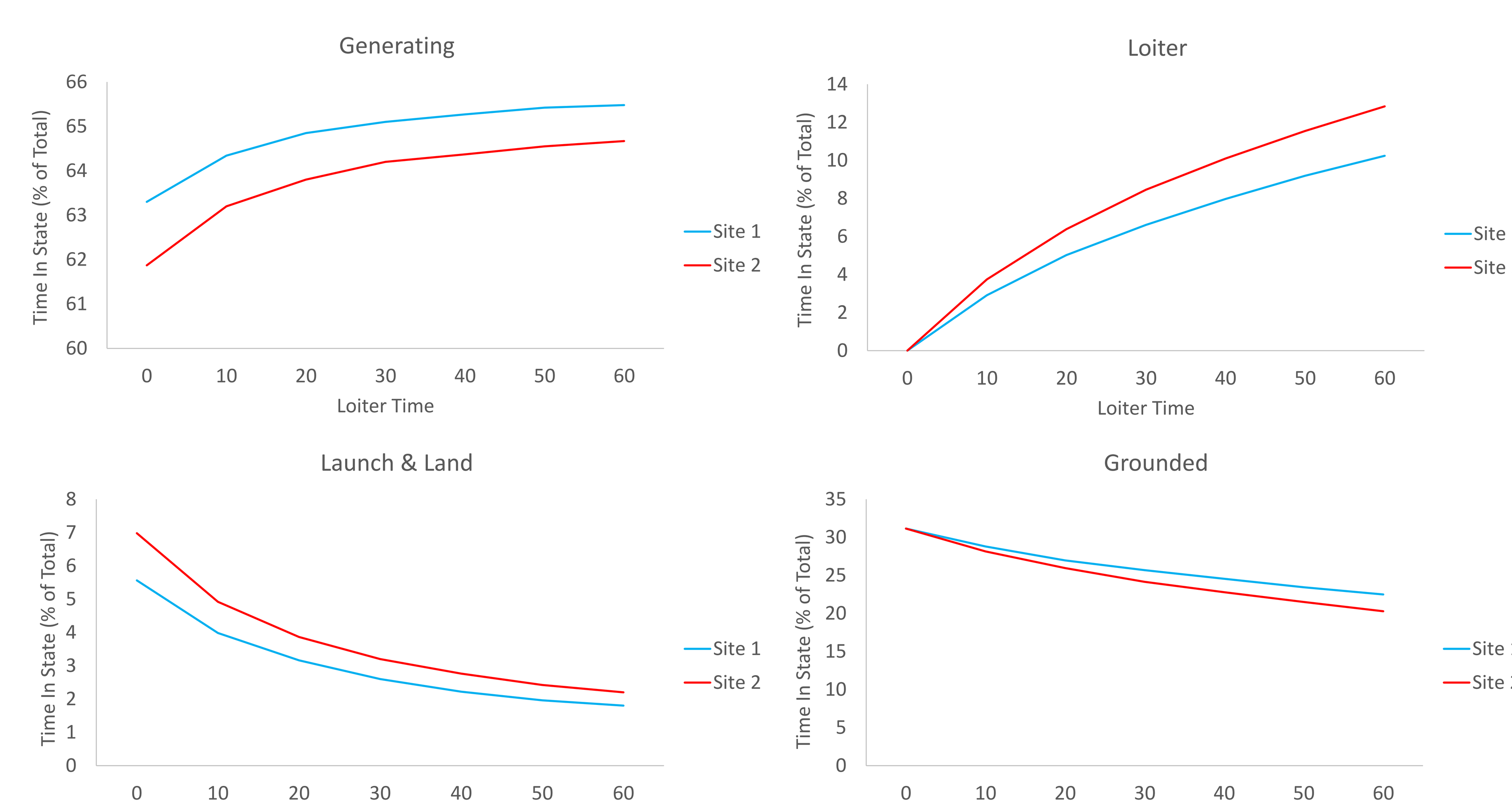
Analysis

The annual energy yield for two sites was calculated for a range of loiter times – 0-60 minutes – and was offset against the parasitic energy.



It can be seen that for both sites 1 and 2 the peak loiter time occurs at 10 minutes after which the total energy output for the system over 12 months diminishes. However this result relies upon factors such as the cost of launch, land and loiter and could change with changing estimations of these costs as well as with the size and output of the AWES.

The effect of changing the predetermined loiter time on the time spent airborne (generating and loitering) and grounded (grounded, launching and landing) was also assessed.



Conclusions

This paper has set out to investigate the airborne loiter policy that will be implemented by ground generating airborne wind energy systems. Equations have been presented to theoretically calculate the maximum amount of time that should be spent loitering by an AWES.

Through analysis of historical wind speed data at several sites the flight phase control strategy was evaluated. Whilst an optimal loiter time appeared to have been established the reasons that this may change for other systems in different environments have been highlighted.

Investigation into the behaviour of the system given changes in the predetermined loiter time was conducted. It was confirmed that the system behaves as expected.

To optimise the loiter time of any given ground generating airborne wind energy system weather prediction tools must be implemented to allow the system to make better informed decisions about the time spent loitering or waiting on the ground.

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