The Impact of Reliability on Wind Turbine Life Cycle Analysis

Joseph T. Foley
Massachusetts Institute of Technology
Cambridge, MA 02139
Email: foley@mit.edu

Timothy G. Gutowski
Massachusetts Institute of Technology
Cambridge, MA 02139
Email:gutowski@mit.edu

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I. Introduction

Wind turbine farms are an effective generator of electricity in windy parts of the world, with prices progressing to competitive levels. These prices become even more attractive as proposed renewable energy credits may significantly increase the cost of electricity from traditional sources.

On a size scale, large-scale wind generators have been generally considered to be more efficient. Unfortunately, large wind turbines have to contend with large forces. GE claims that the horizontal gearbox forces cause the most common failures, but the actual failure and performance are not easy to model. [1] As more of these generation farms go offshore and are less accessible, the issue of reliability becomes more critical.

II. Scope of Work

Here we address how this change in efficiency impacts life cycle analysis. A common question asked is, "What is the Return on Energy Investment for a Turbine?" To complete such an analysis requires knowing the amount of energy required to build, operate, and dispose of a turbine. [2]

The theoretical physical limit for a turbine's efficiency based upon fluid flow models is 58%. Building such a turbine would be impractical due to the physical limits of the current wind-foil technology [1]. Professor Paul Sclavonous gives an estimate of 35% for the efficiency as a much more typical number [3].

III. TurbSim: Simulator of Realistic Turbines

In [4], the challenge of estimating changes to a wind turbine in terms of its reliability and performance are discussed. Previous simulators that are freely available such as [5], assume that a wind turbine is always functioning. TurbSim, which was developed for this project, includes the factor of downtime and repair in its calculations. We chose the Vestas V90-2MW generator, as there is a reasonable amount of literature available.

A. Reliability

Our focus is on what the inclusion of unreliabile elements will do for generation efficiency and furthermore the life cycle analysis. A critical component for this simulation is a detailed reliability model of the wind turbine which is based upon data from [6], [7].

Tavner *et al.* [6] gives an excellent summary of Danish and Wind Turbine failures based upon WindStats, in particular the Mean Time Between Failure(MTBF). Hahn *et al.* [7] gives summary statistics on the Mean Time To Repair(MTTR) for German turbines. Making adjustments for terminology, we were able to build a poisson-process simulator for an individual wind turbine.

The TurbSim system creates a Perl object for each turbine with an entry for each subsystem. Upon initialization, the turbine uses the Poisson probability distribution function to choose times for when that subsystem will break. Upon entering a time that has a broken component, the MTTR parameters are used to generate a time for it to be repaired. In addition, the output of the turbine is set to a degraded mode depending upon the subsystem affected. This design was chosen to allow for easy modification of MTTR and MTBF parameters, enabling various what-if simulations for replacing components or processes.

B. Wind

The other major element in a simulation is accurate wind data. This is usually accomplished with a Weibull model based on wind surveys. In the absence of an easily available survey for the Boston area, we chose to use the NOAA's weather station data for the WQS station in the Blue Hills, adjusted for the change in height according to a logarithmic profile model as shown in Equation 1. $U(z)$ is the wind velocity at height z, U^* is friction velocity, k is von Karman's constant (0.4), and z_0 is the surface roughness length, a characterization of the ground terrain.

$$U(z) = \frac{U^*}{k} \ln\left(\frac{z}{z_0}\right) \tag{1}$$

Applying Equation 2 to two different heights allows us to estimate $U(z)$ at a desired height based upon the measured speed at a reference height z_r. [1]

$$U(z) = U(z_r)\left(\frac{\ln \frac{z}{z_0}}{\ln \frac{z_r}{z_0}}\right) \tag{2}$$

C. Power Curve

The power curve for the V90 is only freely available in document form. To approximate the power curve from this document, we traced the curve on graph paper and interpolated values. Optimally, we would get base power curve information from the manufacturer, unfortunately, such information is difficult to obtain. The power curve that was derived was examined against the V80-2MW generator and found to be similar enough to to be believable.

TABLE II
TURBSIM V90 LCA ENERGY RETURN ON INVESTMENT

	GREET	Nalukowe, etal
Life	0.05	0.07
Year	1.04	1.35
Month	12.53	16.17

D. Life Cycle Analysis

Since our end-goal is to complete a life-cycle analysis with this updated information, we chose to focus on the Vesta V90-2MW generator which is also used in [2]. In addition, we have processed the data using the GREET model originally developed at Argonne National Laboratory for detailed life cycle analysis of vehicles. [5]

Using these methods produces a number of different values for the total energy cost for the creation and use of V90 turbine. Using the GREET method gives an estimate of 21744 GJ for the 1530 ton unit. Nalukowe *et al.* used SimaPro to calculate 28062 GJ.

IV. RESULTS

The simulation base results break down to three base statistics:

Perf: assumes the turbine runs at full capacity for the entire duration.

Max: assumes that the turbine follows the given power curve for the wind parameter, but never breaks down.

Sim: the realistic turbine that occasionally breaks and is repaired.

In addition, there are derived statistics:

ν: (efficiency) simulated output divided by Perfect output.

WL: (Wind Loss) energy lost from non-ideal wind conditions; Maximum subtracted from Perfect.

BL: (Breakdown Loss) energy lost from non-functional (or degraded) internal turbine operation; Simulated subtracted from Maximum.

The these statistics are shown in Table I. Interestingely enough, the ratio of $\frac{BL}{\text{Max}}$ is 1.24%.

For our Energy Return on Investment, we compare this lifetime energy generation to the energy required to manufacture and operate the turbine(Table II).

V. CONCLUSION

Our analysis and simulation of a Vesta V90 wind turbine determined that reliability makes a small but noticable impact (1.24%) on its power generation output. Though this loss does not heavily increase the Energy Return on Investment (EROI), it does represent a significant loss over the lifetime of the turbine. TurbSim enables turbine manufacturers and windfarm operators to make reasonable estimations for the loss associated with downtime.

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TABLE I
TURBSIM V90 RESULTS FOR 20 YEAR SIMULATION

	Perf	Max	Sim	ν	WL	BL
	GJ	*GJ*	*GJ*	*%*	*GJ*	*GJ*
mean	3.51E8	1.17E8	1.15E8	33.4	2.34E8	1.45E6
std. dev.	0	0	174117	4.97E-4	8.58E-8	174117