Using Mixed Weibull Distributions to Estimate Financial Risk for Operations and Maintenance Activities

L.Bernardi, P.Deeney, D. Mikindani, P. Leahy, J.O'Brien

of University College Cork
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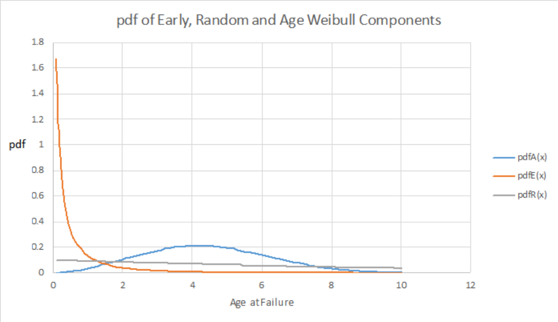
Overview

- Businesses are faced with financial risks from O&M activities and the situation is severe for power grid companies
- Why wind energy? decarbonisation, energy security,economic growth
- In Wind energy industry O&M costs account for 20%-25% percent of the total levelised cost per kWh produced
- This paper makes a methodological contribution by offering a way to to model and estimate risks using equipment failure rates (blades, generators, gear boxes)
- Three Weibull distributions are used to describe the actual data and estimation of parameters, followed monte carlo simulation to estimate actual number of failures
- The results inform operators and investors on which equipment pose great risks and the measures to take to maintain them.

The three Weibull distributions for Age related, Early and Random failures are displayed.



pdfA is the probability distribution function for age related failures as a function of the age of the component, pdfR for random failures and pdfE for early failures.

- Estimate k_A for the Age Weibull Component

We select a value of k_A the shape parameter, such that there is a 10% probability of failure before half the expected fail time, h. Solve:

$$1 - e^{-(h/\lambda)^{k_A}} = 0.1$$

when

$$h = \frac{\lambda\Gamma(1 + 1/k_A)}{2}$$

Solving numerically we find

$$k_A = 2.7801$$

- Estimate λ_A for the Age Weibull Component

For the scale parameter, λ_A of the Age component, select the largest non-zero mode, m, and solve

$$\lambda_A \left(\frac{k_A - 1}{k_A} \right)^{1/k_A} = m$$

using the value of k_A above.

- Early Failure

Early failures are caused by faulty equipment or faulty installation, therefore it is reasonable to assume that 95% of such fails occur within the first month of operation and that the mean time to failure is two weeks. Thus from CDF we have

$$1 - e^{-\left(\frac{1}{12\lambda_E}\right)^{k_E}} = 0.95$$

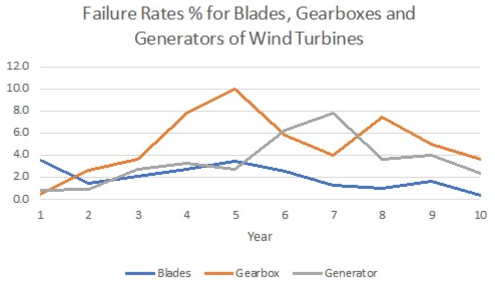
and from the mean we have

$$\lambda_E \Gamma(1 + \frac{1}{k_E}) = \frac{2}{52}$$

Solving numerically we find $\lambda_E = 3.9619x10^{-4}$ and $k_E = 0.2051$

- Random Failure

For a random distribution $k_R = 1$. In order to offer a contrasting distribution from the Age and Early components, we deliberately select λ_R so that the value of the pdf of for the Random component is reasonably constant. Thus we set $\lambda_R = 50$ so that the mean time to failure is 50 years, based on the expectation of how often one would expect a turbine to be hit by lightening, or suffer a random weather related event.



The plot is based on Lantz (2013).Generator and gearbox failure is not common when they are new, however it is not unusual for blades to fail when new. Note that blades do not seem to have a random failure component while generators and gearboxes do not seem to have an early component.

We introduce the Weibull combination $\vec{W}$ which is the approximation to the observed data for a component,

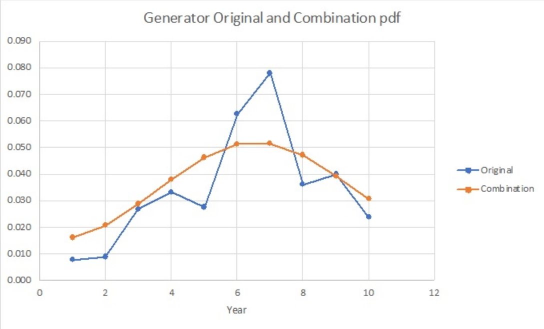
$$\vec{W} = a\vec{A} + e\vec{E} + r\vec{R},$$

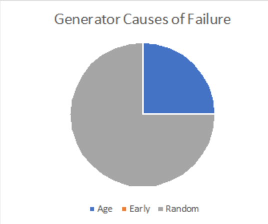
for some $a, e, r \geq 0$. We define $g(a, e, r)$, as the error between the observed data, D, and the sum of the three Weibull distributions:

$$g(a, e, r) = |a\vec{A} + e\vec{E} + r\vec{R} - \vec{D}|$$

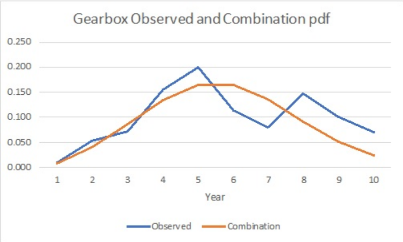
where the entries of $\vec{A}$ are the probabilities of failure for each year using a Weibull distribution for Age related failure, $\vec{E}$ is a vector for the Early Weibull and $\vec{R}$ is for the Random failures. $\vec{D}$ is the observed failure probability for each year and a, e, r are the proportions of the three distributions. The task is to find the values of these proportions which minimizes $g(a, e, r)$.

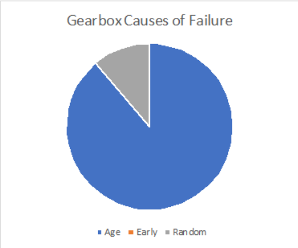
For the Generator we have $\lambda_A = 7.156$, $a = 0.25$, $e = 0$ and $r = 0.75$. The coefficients indicate that the strongest determinant of failure is random failure and there is no early component.



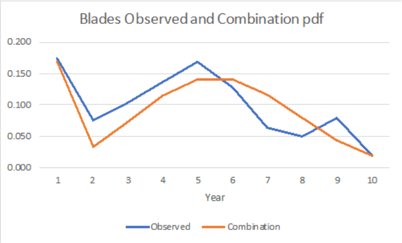


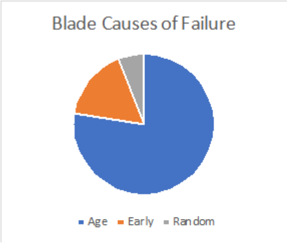
For the Gearbox we have $\lambda_A = 5.870$, $a = 0.89$, $e = 0$ and $r = 0.11$. The coefficients indicate that the strongest component of failure is age related with no influence from early failure.





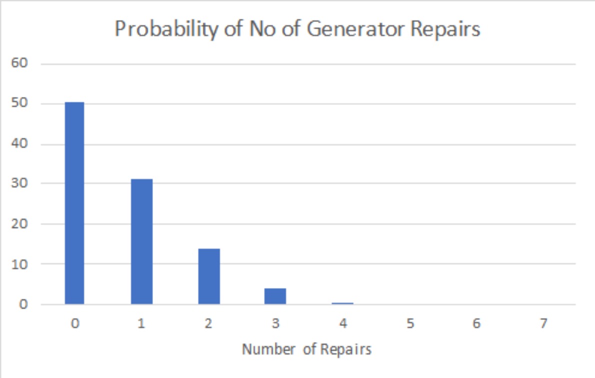
For the Blades we have $\lambda_A = 5.870$, $a = 0.78$, $e = 0.16$ and $r = 0.06$. The coefficients indicate that the strongest influence for failure is age with approximately equal and lesser influence from early and random fails.



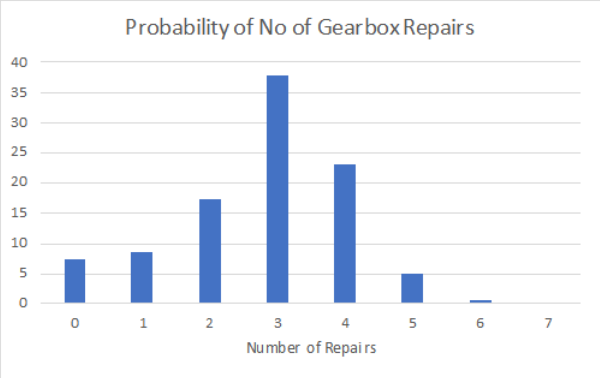


Using a Monte Carlo simulation we estimate the numbers of repairs required for Generators, Gearboxes and Blades over a 20 year period, assuming the combination of the three Weibull distributions are valid for this length of time, which is the usual lifespan of an onshore wind turbine.

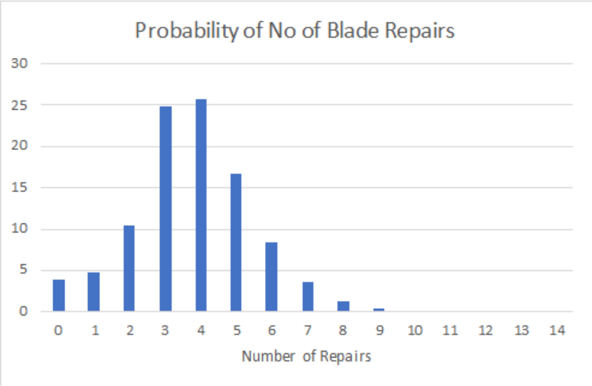
We see that there is an evens chance of not needing any Generator repairs at all, and there is a 4.5% probability that there will be more than two repairs.



The most probable number of Gearbox repairs is 3, and the probability of needing more than 4 repairs is 5.6%. As seen in the figure the risk of 7 repairs is very low.



The most likely number of Blade repairs is 3 or 4, the probability of needing more than 6 repairs is 5.5%.



Parameter	Generator	Gearbox	Blade
a	0.23	0.89	0.78
e	0	0	0.16
r	0.76	0.11	0.06
Lifetime Results			
Mean No of Fails	0.73	2.79	3.77
Modal No of Fails	0	3	4
Median No of Fails	0	3	4
Expectation of 95 - 100%	3.04	5.12	7.57
Cost of One Repair €1,000s	190	528	305
Expected Tail Loss (95%) €1,000s	577	2,705	2,315

- Generators Fail Randomly - Invest in Quality
- Gearboxes Wear Out with Age - Invest in Maintenance
- Blades Wear Out and Fail Early -Get a good warranty, Invest in Maintenance and Check Quality on Delivery and Installation
- Generators can give nasty surprises
- Gearboxes are the highest risk,
- Don't forget there are three blades

Thank you

Questions?

peter.deeney@ucc.ie
dorcas.mikandani@umail.ucc.ie

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Questions from IAFA

- The possibility of including Offshore wind turbines to the analysis
- wind energy can supply all the electricity demanded therefore it is important to research on the economic efficiency in both offshore and onshore wind projects.
- Possibility of feeding the data to NPV calculation
- Adding more components (currently we just have three)
- Extremely weather effects as a factor on the study
- Possibility of studying specific manufacturer effects in the failure rates, and financial advice to investors
- the effects location have on the failure rates