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Machine and Converter Reliabilities in Wind Turbines

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Abstract

Electrical Machine/Converter combinations are used in a variety of applications, from powers of Watts to MegaWatts. Some applications, such as propulsion and generation, have high reliability & availability requirements. Modern large wind turbines incorporate variable pitch blades and a variable speed Generator, which feeds the Grid through a Converter and have a need for high reliability & availability. There are a number of configurations of generator and converter intended to provide optimum performance for present and future wind power. This paper describes an investigation into the reliabilities of Generators and Converters in such configurations and is based on failure data collected in Germany and Denmark. The paper draws conclusions about which configurations have the higher reliability and identifies the subassemblies of the turbines which require attention for the future design of high reliability wind turbines. Recommendations are made about how designers and operators of wind turbines can increase their reliability by the choice of Concept and the operating regime

1 Introduction

The application of Electrical Machine/Converter combinations to a variety of industrial applications is being extended and the reliability of those combinations is of great importance to the choice and design of new systems.

A modern large wind turbine incorporates a variable speed rotor and generator, which feeds the Grid through a Converter. There are a number of configurations or Concepts of generator and converter, which are the subject of a considerable literature to determine the best Concept for the future development of wind power. In general to date attention has been paid to the Concept which yields the lowest first cost or the highest energy harvest from the wind, for example see [1].

In this paper the relative reliabilities of two wind turbine Concepts are considered, using publicly available failure rate data.

The paper describes a preliminary investigation into the reliabilities of Generators and Converters in such Concepts and shows how the subassemblies which make up the Concept contribute to its reliability.

Data Sources: WindStats and Others

In previous work by the authors [2, 3] data from a quarterly public domain newsletter, WindStats (WS) [4] was analyzed to yield information about the historical trend of the failure rate of onshore wind turbines (WT). This survey includes results from up to 4000 turbines in Gemany and more than 1000 turbines in Denmark. Figure 1 summarizes the main results from those papers, comparing the failure rate of German and Danish populations of wind turbines, which are respectively shown with large squares and large dots.

On the far left of the diagram the failure rate for wind turbines in the USA in the late 1980s, taken from an EPRI survey see [5] is displayed.

On the same diagram the three horizontal lines show published failure rates for other generation systems. Starting from the top, the three lines represent respectively failure rates for diesel generator sets [6], combined gas steam turbines generators [7] and steam turbine generators [8].

This data is shown to demonstrate the very considerable improvement in wind turbine reliability, which has taken place over the last 20 years and to show that the reliability compares well with some competing power sources.

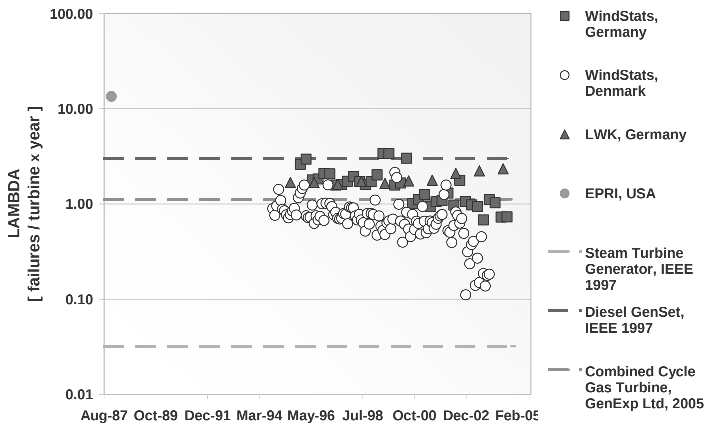

Figure 1: The failure rates of Onshore Wind Turbines taken from WindStats [4] and compared with other power sources.

Analysing Wind Turbine Concepts: LWK

The failure data from WS has one major disadvantage in that the data is aggregated for each reporting period for the entire population of wind turbines. So a comparison between different turbine configurations or Concepts is not possible. However, this comparison can be done by using another data source, in the public domain, from the Landwirtschaftskammer, Schleswig-Holstein, Germany, (LWK) [9]. This survey includes approximately 350-650 wind turbines of all sizes, where data is collected in a segregated form and the failures are reported for each WT Concept.

On the basis of the failure data given by LWK a failure rate has been calculated, in the same way as was done for the WS data, using the Homogeneous Poisson Process, which assumes that the failure rate of turbines is sensibly constant with time. At first this process was done for the entire population in the survey, the results are plotted as large triangles on Figure 1.

It is interesting to compare the overall failure rate obtained from LWK with that from WS. It should be noted that on the average the LWK failure rate is closer to the failure rate of German wind turbines rather than the Danish ones. This is not surprising since LWK deals with German WTs of similar size and concept to those included in the German component of the WS survey, so it is likely that the two German populations would have comparable features.

On the other hand the decreasing trend in the failure rate, which was a remarkable conclusion from the WS data, is not shown in the LWK data, tending to increase in the last periods of the survey, 2003 & 4. This may be due to the fact that the LWK population of wind turbines is fixed, whereas the WS population is expanding. Thus ageing effects, which increase failure rates, will be more prominent in the LWK data.

Figure 2 illustrates this result more clearly over the survey period from 1994-2004. The squares and circles represent respectively the German and the Danish failure from WindStats and the triangles are for failure rates obtained from LWK in each recording period.

It should be noted that the recording intervals of the data in the three surveys is different as follows;

- Monthly for WS, Denmark,
- Quarterly for WS, Germany,
- Yearly for LWK, Germany.

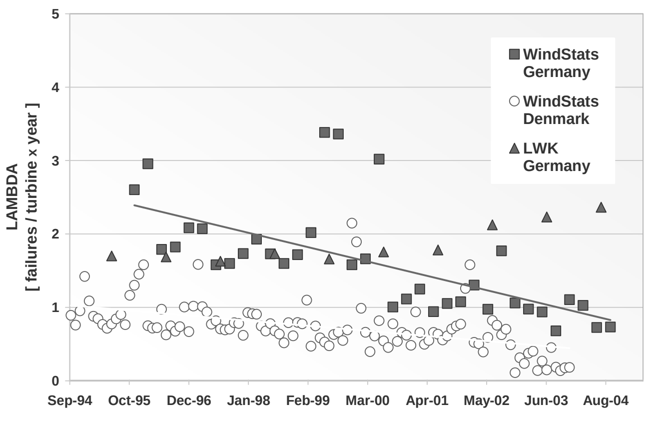

Figure 2: The failure rates of Onshore Wind Turbines taken from LWK [9] and compared with rate of onshore Wind Turbines taken from WS [4].

3.1 Definition of the Concepts

LWK data allows the comparison of three basic wind turbine Concepts:

- Fixed Speed Indirect Drive
- Variable Speed Indirect Drive.
- Variable Speed Direct Drive.

In particular the analysis has been carried out for two size groups of turbines with these characteristics, the first group of about 100 turbines of 3 models, rated 500-600 kW and the second group of about 35 turbines of 2 larger models, rated 800-1500 kW. Table 1 shows the models considered in the analysis, also reporting both the respective rating and type of drive.

Turbine Size Group	***Turbine Model***	***Rating, kW***	***Speed***
1	Tacke TW600 Vestas V39 500 Enercon E40	600 500 500	Fixed Variable Variable
2	Nordex N52/N54 Enercon E66	800/1000 1500	Fixed Variable

Table 1: Resume of Turbine Sizes

All the turbines have the same aerodynamic configuration, that is a three-bladed, upstream rotor, while substantially different technologies are involved in their power control, as shown in Table 2. The third column of Table 2 reports for each WT model the equivalent name of the Concept as defined in [10]

Turbine Model	***Power Control***	***Concept Name***
Tacke TW600	Stall control	Indirect Drive, Base Line Control
Vestas V39 500	Pitch control, hydraulic	Indirect Drive, Advanced Control
Enercon E40	Pitch control, electrical	Direct Drive
Nordex N52/N54	Stall control	Indirect Drive, Base Line
Enercon E66	Pitch control, electrical	Direct Drive

Table 2: Resume of Turbines Power Control and Concepts

3.2 Results

The failure rates for subassemblies of WTs have been calculated by applying a Homogeneous Poisson Process to each subassembly of each WT model. Since data are grouped yearly in LWK survey, the average failure rate coincides with the average of the failure rates in each year. The technological differences between WTs affect the distribution of the failure rate and a comparison of the subassemblies failure rate patterns is the core of the present research.

Figure 3 shows the results of the analysis made on the three smaller Group 1 WTs, where the subassemblies are sorted in descending order of the E40 failure rate.

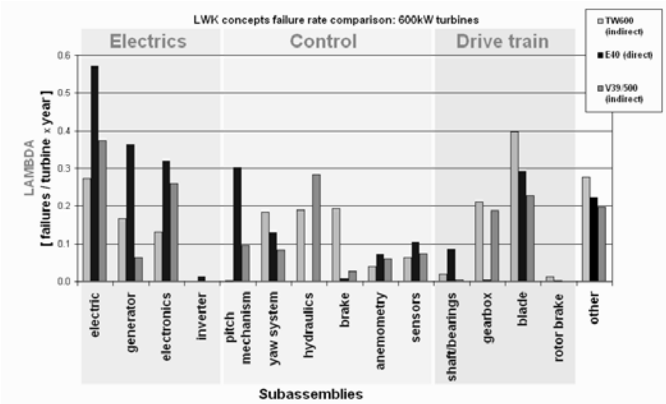

Figure 3: Comparison between failure rates of the Group 1, smaller WT Concepts

Figure 4 shows the results of a similar analysis made on the two larger Group 2 WT models, where the subassemblies are sorted in descending order of the E66 failure rate. In this case the statistical significance of the analysis is lower because Group 2 WTs have a much smaller population.

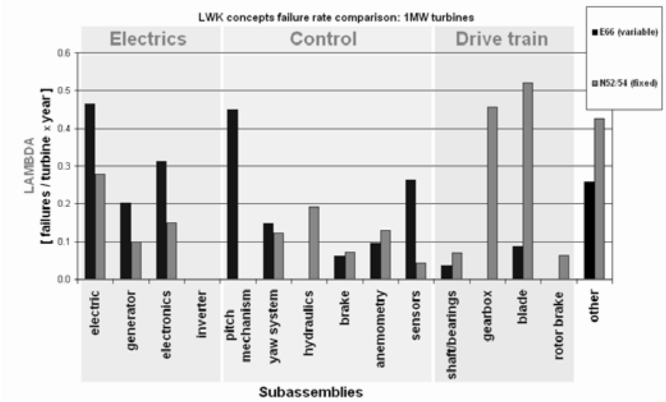

Figure 4 : Comparison between failure rates of the Group 2, larger, WT Concepts

Discussion

Three main observations can be made from Figure 3, Group 1 WTs:

1. Comparison between the failure rates of the gearbox in the Fixed Speed Concept with the failure rate of the inverter in the Direct Drive Concept. The comparison is striking, the failure rate of the inverter being consistently far smaller than of the gearbox. The advantage becomes overwhelming when one considers that the inverter is simpler to maintain.
2. In the Direct Drive concept the failure rate of the electronics is very significant. When the inverter and electronics are considered together their failure rate is considerably in excess of the gearbox. Therefore the advantage of eliminating the gearbox in the Direct Drive WT does not result in a lower overall failure rate than for an Indirect Drive WT. However, it will be certain that the Mean Time to Repair (MTTR) of electronics and inverter components will be shorter than for a gearbox.
3. The contribution of the electrical-related subassemblies to the overall failure rate for the Direct Drive Concept, which on the Enercon WTs includes both electrically-activated pitch and yaw mechanisms and no hydraulic plant, is shown to be significant.

According to the analysis, the price to be paid by the Direct Drive WTs for the reduction of failure rate by the elimination of the gearbox is a substantial increase of the failure rate of all electrical-related subassemblies.

The main observation from Figure 4, Group 2 WTs is that in this size range the overall failure rates of Direct Drive and Indirect Drive WTs are very similar, with the Direct Drive WTs having a slightly higher failure rate, but this cannot be considered statistically significant.

Particular mention, however, must be made of the generator in Group 2 Direct Drive WTs whose failure rate is at least double that for generators of the Indirect Drive WTs.

The Direct Drive machine is a wound-rotor, Synchronous Generator with a large number of poles, whereas the Indirect Drive machine is a High Slip Induction Generator with 4 to 6 switchable poles.

The lack of detailed information about the nature of the failures recorded only allows us to speculate about the cause of this higher failure rate but they could be due to:

- The lower level of industrial standardization in the Direct Drive Synchronous Generator, because manufacture is on a smaller scale compared to the Induction Generator. This may negatively affect the reliability of the Direct Drive Synchronous Generator.
- The larger diameter of the Direct Drive Synchronous Generator and greater length of its stator and rotor windings, compared to the Induction Generator. This, associated with the difficulty of adequately sealing windings on larger machines against external agents, could statistically increase the probability of winding defects.

Both these observations require further investigation.

A warning must be sounded about the statistical significance of the data since the approximate population size of the LWK survey considered in this paper is considerably smaller than that presented earlier from WS data. The population sizes are summarised as follows:

- Windstats [1 & 2] approximately 4000 German turbines in total.
- Windstats [1 & 2] approximately 1000 Danish turbines in total.
- LWK [this paper] approximately 350-650 German turbines in total.
- LWK [this paper] Group 1, smaller German turbines, 500-600 kW, approximately 100 turbines in total.
- LWK [this paper] Group 2, larger German turbines, 800-1500 kW, approximately 35 turbines in total.

However, the comparison of LWK and WS data in Figure 1 does show that some confidence can be placed in the smaller LWK dataset.

Conclusions

The conclusions of this preliminary study of failure rates in WTs of various concepts using the LWK dataset [1], albeit with a smaller population size, are:

- Direct Drive WTs do not appear to have a lower failure rate than Indirect Drive WTs.
- The failure rates of gearboxes in Indirect Drive WTs are much greater than the failure rate of Inverters in Indirect Drive WTs.
- However, the aggregate failure rates of inverters and electronics in Direct Drive WTs are greater than the failure rate of gearboxes in Indirect Drive WTs.
- The price paid by Direct Drive WTs for the reduction of failure rate by the elimination of the gearbox is a substantial increase of the failure rate of all electrical-related subassemblies.
- It is known that the MTTR of electronic subassemblies is lower than the MTTR of gearboxes so this suggests that despite these results Direct Drive WTs may achieve a higher availability than Indirect Drive WTs.
- In larger Direct Drive WTs the failure rate for generators is at least double that of the Indirect Drive WTs. The Direct Drive machine is a wound-rotor, Synchronous Generator with a large number of pole pairs, whereas the Indirect Drive machine is a High Slip Induction Generator with 4 to 6 switchable poles. The reasons for this disparity in failure rates is not known but should be investigated

Recommendations

The lessons for the development of large wind turbines are as follows:

- There should be a greater understanding of the interaction of the predicted reliability of a WT Concept with its first cost and energy harvest, as described in [1].
- There is an issue associated with the reliability of large diameter Direct Drive generators which requires further investigation before conclusions can be reached.
- The benefits of Direct Drive over Indirect Drive are not clear cut, because the elimination of the gearbox in the Direct Drive WT incurs higher electronics and inverter failure rates. However, these higher failure rates are mitigated by a lower MTTR for electronic subassemblies and therefore potentially a higher availability.
- Consideration should be given to improving the reliability of electrical-related subassemblies, perhaps by the application of condition monitoring.

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