Science & Research Abstract
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Title: Reliability of power converters in wind turbines: Results of a comprehensive field study

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Introduction

The power-converter system in wind turbines is a frequent source of failure and, as such, a driver of repair cost and downtime. As a basis for the development of effective countermeasures, it is crucial to understand the prevailing mechanisms and causes of converter failure in wind turbines. This is the main subject of a German research cluster carried out in a large consortium including wind-turbine and component manufacturers, operators and maintenance-service providers, Fraunhofer institutes and academia [1]. Using a field-experience based approach, the work builds on a systematic analysis of the comprehensive failure and operating data provided by the project partners, on directed field measurement campaigns and on post-mortem analysis of failed converter hardware to identify the main root causes of failure.

A previous paper of the authors [2] presented first results of statistical analyses carried out within this research cluster. It used a data subset covering 1269 wind-turbine operating years to identify the most frequently failing components and the main repair-cost drivers within the power-converter system.

This paper presents converter-specific failure statistics based on a substantially extended field-data basis provided by the partners of the research cluster, which now includes more than 4600 years of wind-turbine operation. The work is novel and unique due to

- the comprehensiveness, depth and actuality of the data basis, the analysis results of which are presented here for the first time,
- the focus on statistical analysis for the purpose of root-cause identification,
- the combined evaluation of failure and SCADA operating data, which allows to identify operating conditions promoting converter failure.

Data basis and approach

The data basis evaluated in this paper is described in Table 1.

Table 1: Data basis underlying the present work

Failure data	covers in total >1600 wind turbines • with doubly-fed induction generator (DFIG), electrically excited synchronous generator (EESG) and induction generator with full power converter (IG+FPC) as well as of single turbines with permanent-magnet synchronous generator (PMSG); • by 11 different manufacturers: DeWind, Enercon, Fuhrländer, Gamesa, General Electric, Kenersys, Nordex (incl. Südwind), Senvion (incl. REpower), Suzlon, Siemens, Vestas; • with nominal power in the range of: 600-3600 kW • commissioned during 1997…2015 (note: commissioning dates unknown in a number of cases) includes converter failure events from years: 2003-2015 length of the periods, from which failure data is available: several months to 12 years has different depths: data from most turbines (in total 3723 turbine operating years) covers failures of the complete converter system; in case of the other turbines (with in total 942 operating years), the data includes only failures of the converter-component category 'phase module'
SCADA data: 10min-averaged signals, status-logs	available for the majority of the above turbines

The converter-specific failure data is derived from maintenance reports including information on used spare parts as well as from turbine logbooks. Only faults requiring on-site repair and the consumption of material or spare parts are counted as failure events, i.e. faults remedied e.g. by a remote reset or by cleaning components are not included.

Based on the above information, failures are classified using the following converter component categories:

- phase module (including IGBT modules and corresponding driver boards, DC-link capacitors, busbars),
- converter control board,
- cooling system,
- main circuit breaker,
- grid-coupling contactor,
- other converter failures.

Average failure rates are considered in this analysis and are calculated as described in [2].

For the failure events of selected converter component categories, the date and time of failure as well as the operating conditions in the 10min interval preceding the failure are identified from the turbines' SCADA 10min data and/or status-logs.

Main body of abstract

The submitted paper will present and discuss the results outlined in the following.

Initial results published by the authors in [2] revealed that among the converter components, the phase-module stands out with respect to failure rate, resulting downtime and repair cost. Therefore, a particular focus in the present paper is set on phase-module failures.

(1) Converter failure rates of wind turbines with DFIG, EESG and IG+FPC

Figure 1 shows the average failure rates of turbines with doubly-fed induction generator and partially rated converter (DFIG + PRC), with electrically excited synchronous generator and full-power converter (EESG + FPC) and with induction generator and full-power converter (IG + FPC).

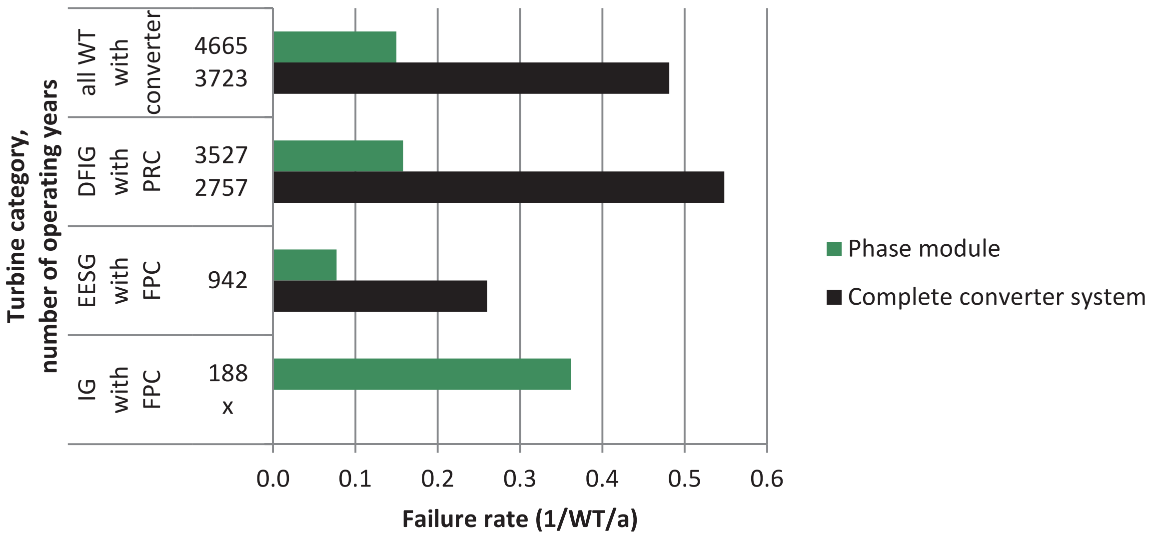

Fig. 1: Average converter failure rates of wind turbines with DFIG and partially rated converter (PRC), with EESG and full power converter (FPC) and with IG and FPC

On average, approx. 0.5 power-converter failures per wind turbine (WT) and year occurred in the fleet. Among these are 0.15 phase-module failures per WT and year.

The failure rates obtained for the fleets with DFIG, EESG and IG+FPC differ considerably: The EESG fleet shows a significantly lower failure rate both regarding the phase-module category and regarding the complete converter system. Turbines with IG+FPC are found to have the highest phase-module failure rate.

(2) Converter failure rates of DFIG-based wind turbines of different manufacturers

Turbines with DFIG constitute the largest portion in the data basis used for this work. This allows splitting the DFIG-based fleet is split into groups to allow a comparison of converter reliability in DFIG turbines of different manufacturers. The resulting diagram will be included in the final paper and the observed deviations between the groups will be discussed.

(3) Inter-turbine variability of failure rates

Major differences in converter failure rates are observed not only between groups of turbines with different designs as shown in the two preceding sections, but also between turbines within these groups and even between turbines of identical type. On this background, the distributions of turbine-individual failure rates are investigated in more detail.

Only phase-module failures are considered in this as well as in the subsequent analysis.

Figure 2 shows the distribution of turbine-individual phase-module failure rates in the group of DFIG-based WT. The full paper will additionally include the corresponding distributions obtained for the group of WT with EESG and IG+FPC, respectively. To exclude extreme failure rates resulting from short observation periods of turbines, only WT for which failure data from at least two years are available are taken into consideration in this analysis.

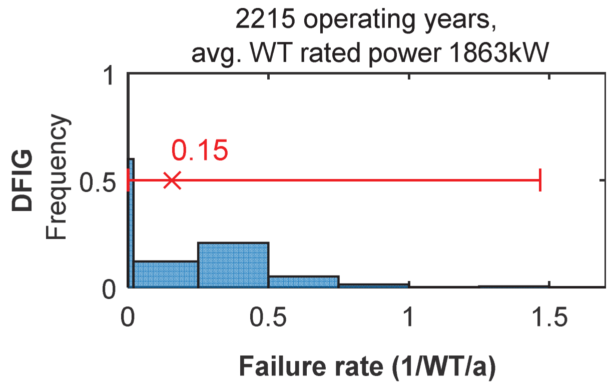

Fig. 2: Histograms of turbine-individual failure rates of the converter-component category ”phase module“, for wind turbines with DFIG (full paper: DFIG, EESG and IG+FPC); red marker: average failure rate, whiskers: range from minimum to maximum failure rate)

Besides the spread of the phase-module failure rates, Fig. 2 provides also information on the overall number of operating years underlying each of the three classes (DFIG, EESG, IG+FPC), as well as on the average rated power of the turbines in this class.

The full paper compares the failure-rate distributions and discusses them in view of differences in average nominal power and design of the three WT classes.

(4) Converter failure – a problem of aging fleets?

An important question in the context of this work is if high converter failure rates are an issue of older wind-turbine generations only or if this continues to be a problem in contemporary turbines.

To shed light on this question, the turbine population covered by the given data basis is separated into three groups: wind turbines commissioned (a) before 2005, (b) during 2005-2009 and (c) during 2010-2015. Turbines with unknown commissioning year are not included in this analysis.

The distribution of phase-modules failure rates along with their mean values are shown in Fig. 3. Again, only turbines with failure data from at least two years of operation are taken into consideration.

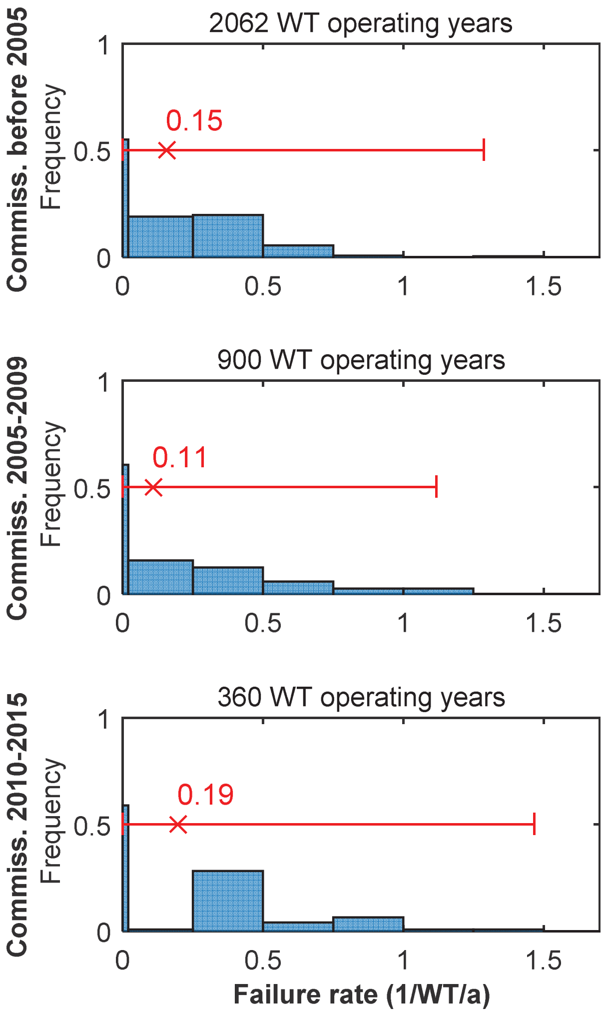

Fig. 3: Histograms of turbine-individual failure rates of the converter-component category "phase module", for turbines commissioned before 2005 (top), during 2005-2009 (middle) and during 2010-2015 (bottom)

In the paper, the results shown in Fig. 3 will be interpreted with respect to the development of converter reliability during the past 10-15 years, taking into account the average nominal power and converter rating in each group.

(5) <u>Operating-condition dependence of converter failure susceptibility</u>

In the context of root-cause analysis, an interesting question is in which load range the wind turbines were operating in the moment of converter (phase-module) failure.

Thus for each phase-module failure, for which the exact timestamp of failure could be identified, the active power of the wind turbine at the onset of failure is derived from the SCADA operating history of the affected turbine.

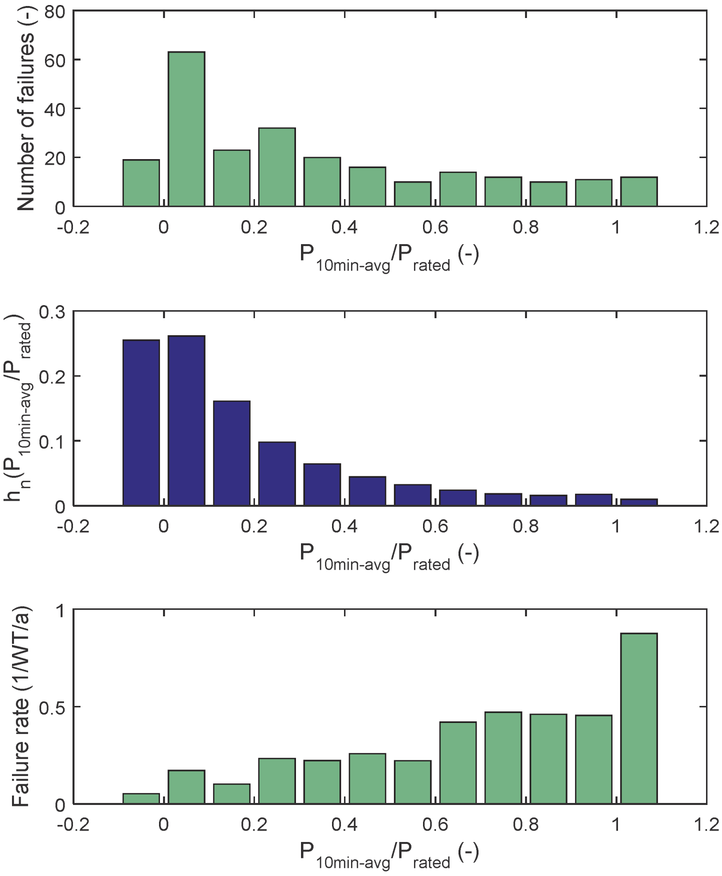

Fig. 4: Distribution of converter (phase-module) failures of a fleet of DFIG-based turbines over active power (top); distribution of operating time over active-power bins, derived from 10min-averaged SCADA operating histories (middle); resulting failure rates (i.e. number of failures per year of operation in this load range) over bins of active power (bottom)

The full paper will explain the used analysis method in more details and discuss the results, which reveal valuable details about which operating conditions promote converter failure. Besides the results shown in Fig. 4, the paper will also include the corresponding results obtained from turbine fleets with EESG as well as with IG+FPC.

Conclusions

Paper presents the status quo of converter reliability in wind turbines and shows detailed results for different groups of turbines. On average, approx. 0.5 converter failures occur per wind turbine and year, among these approx. 0.15 phase-module failures.

A systematic assessment of turbines of different ages reveals that converter reliability has not generally improved during the past 10-15 years, which stresses the continued urgent need for effective reliability-enhancing measures for the power converter.

An evaluation of the operating points preceding converter failure identifies operating conditions afflicted with a higher risk of converter failure. The fact that an increased susceptibility to converter failure is found in different operating points for different turbine types points to dissimilar prevailing failure mechanisms.

Learning objectives

The main objectives of this talk / paper are:

- disseminating state-of-the-art converter reliability data for a variety of wind-turbine types
- underlining the continued need for effective converter reliability improvement also in contemporary turbine generations
- stressing the importance of a field-experience based approach to the problem
- showing the influence of the operating point on converter failure behaviour

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