Reliability in Medium Voltage Converters for Wind Turbines

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***Abstract* – In order to meet the demands of turbine integration into the wind park grids, advanced power converter technologies have successfully been developed by ABB. Along with the ongoing move from onshore to offshore wind installations, the system reliability, maintenance costs and product quality have come into focus to a far greater extent. Even the smallest service for offshore installations immediately results in very high costs. At the same time the loss of energy production due to servicing is a significant loss of profit, especially for the large wind parks, where failures can also affect the operation of other generators. Therefore, strong effort must be taken to achieve high reliability in the power electronics converter system of the wind turbine.**

In this paper, an approach to design of ABB multimegawatt MV wind power converter PCS 6000 for reliability is discussed.

I. INTRODUCTION

Today, energy produced by wind has the largest share of all renewable energy sources and the industry technology has already reached a high level of experience with respect to the development of new wind turbine concepts. To integrate wind turbines into high power wind parks and finally, to the main grids, advanced power electronics technologies were developed and designed for this special field of application [1-3].

Traditionally, the initial system cost, system efficiency, size and system reliability were the core decision factors with regards to preferred power electronics system solution. In particular, the focus has been on power electronics converter behavior during special grid conditions and faults, such as overvoltage, short-circuits, instability or loss of grid connection. Moving from onshore to offshore wind installations puts system reliability, maintenance costs and product quality in a new perspective. First of all, offshore installation maintenance is extremely expensive. Secondly, there is a loss of energy production during a stop due to a fault or maintenance resulting in the loss of profit. Therefore, a strong effort must be taken to achieve high reliability in power electronics converter systems. In this paper, the approach to reliability taken in the ABB PCS 6000 wind power converter development is discussed.

II. DESIGN FOR RELIABILITY

The right way to address product reliability is to approach it in a systematic way during the development process. Such a technique is known as "Design for Reliability" (DfR) [4]. Design for reliability is a fundamental part of an advanced development process and already starts at the concept phase. So, from the very beginning, key design decisions already consider aspects related to reliability requirements of the final product. DfR helps addressing complex product requirement specification including aspects as stress, environmental conditions, system operation under fault, etc. The target of DfR is to find and address design issues at the development phase as early as possible.

But DfR contains some more tools and practices that are executed during the design stages of the product development process.

One of the tools is Failure Modes and Effects Analysis (FMEA) [4]. Product and technical requirement specifications serve as an initial input to FMEA. The first part of FMEA deals with finding potential failures and estimating the risk of their occurrence. After this is done, the second part of FMEA identifies corrective actions to avoid or mitigate the failure.

Another practice is reliability prediction. Reliability prediction using commonly accepted standards such as, MIL-HDBK-217FN2 [5] or Telcordia, to estimate failure rate of an electronic system or system subassembly. But how can reliability prediction be used in the design process?

First of all, it allows comparing different designs, topologies and structures. Secondly, it provides valuable feedback to the designer on where attention should be focused. Additionally, once failure information is available, estimated values can be calibrated to provide estimates for field reliability in the future. However, the last one is typically very difficult to do due to high degree of uncertainty in field data.

Another very important aspect of DfR is Root Cause Analysis (RCA). In RCA, field failures are examined in order to determine the cause of failures and take adequate corrective measures to improve the product and, by that, system reliability. One of the techniques often used during RCA is to reproduce the failure in the laboratory environment. This helps to find true cause of failure and also suggests proper corrective actions. Root Cause Analysis gives insight into physics of failure and helps to address the problem systematically in the future. For example, based on RCA results, routine tests can be designed targeting failure modes of concern.

For PCS 6000 product development, the DfR process helped to tackle the following major points:

- Suitable technology and quality of components for the application
- Robustness to failure
- Critical system parts – improve operating conditions, redundancy
- Failure rate prediction
- Service & maintenance

III. DfR RESULTS IN PCS 6000 DEVELOPMENT

A. Suitable technology and quality of components for the application.

At the concept phase, the 3-level Neutral Point Clamped topology was selected (shown in Fig.1).

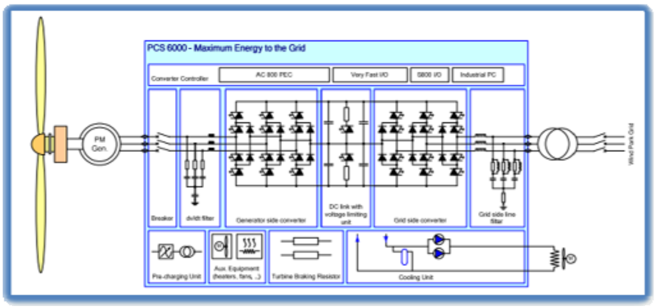

Fig.1. Structure of PCS 6000 converter

As power switches, IGCT press-pack devices (Integrated Gate Commutated Thyristor) are used. Unlike the case with IGBTs, the required application power levels can be reached without IGCT device paralleling nor a need for having IGCTs in series for voltage rating up to 4,16kV. As a consequence, low number of power devices has been achieved. The IGCT, as a device of choice, allowed reaching the power level required by the application without sacrificing reliability.

Commercially available, the IGCT have current ratings between 520A and 5000A and blocking voltage capabilities from 4,5kV to 6,5kV. [6]. As a result, the PCS 6000 system reaches power level of 9MVA without device paralleling. IGCTs offer unsurpassed robustness to thermal cycling, in particular, in low-speed designs like for wind application. The big advantage in thermal cycling results from the press-pack design comparing to soldering and internal bonding based design of LV IGBT modules. Another advantageous characteristic is that the device does in fault conditions not show any desaturation effects and can then handle almost any system fault currents in a safe operating mode. This is also one reason why IGCTs are preferably used in ‘crowbar’ circuits.

ABB’s field experience shows, that IGCT short-circuit operation do not lead to the damage of neighboring components. This contributes to build high power density converters, what is a must for wind turbine application.

Fig.2. IGCT device used in PCS 6000

B. Robustness to failure

During PCS 6000 development, failure mode and effect analysis has been performed. The results were valuable and allowed to implement proper corrective actions in an early development stage.

During the product introduction phase, problems experienced in the field operation have been thoroughly studied with the help of Root Cause Analysis. When it was not possible to identify the cause of the problem from the field failure inspection, attempts were made to reproduce the failure in the laboratory. For example, a problem with overheating was reported from one of the test sites. Inspection showed that water-cooled resistor was damaged due to overheating. Initial analysis of failure did not reveal the source of the problem. Therefore, tests were done in the laboratory in order to reproduce the failure. The test showed that the cause of the problem was presence of air in the cooling pipes. This fact indicated that water-cooling system was not properly de-aerated after service. The identified problem was incorporated into training materials for service personal as a case study.

C. Critical system parts – improve operating conditions

Wind application requires converter operation at high ambient temperatures without power derating. So, it must be ensured that all system components are operating below their rated temperature. It is critical to monitor these limits during any changes in the product technology, manufacturing, assembly or supply chain. To enable reliable operation of the components in such a thermal conditions, derating was utilized in the design. In addition, more dissipating components on power and control hardware boards were taken care of by improving their thermal operating conditions. The same applies to component stresses during various operating modes such as, for example, grid side faults.

Another way to increase reliability is redundancy. Redundancy is an effective technique to counteract failures of the components during their lifetime. Concerning redundancy, two aspects have been considered.

First of all active redundancy was implemented for some of the electronic components on power and control hardware boards. In case one component fails, other components are able to take full loading conditions.

Secondly, redundancy was implemented for the pump in PCS 6000 cooling system. For converter reliable operation, such mechanical parts are one of the most critical ones. To be as compact as possible wind turbines require power converters with water cooling system and continuous operation of the water pump must be ensured. Therefore, redundancy has been implemented for the pump in PCS 6000 water-cooling system. The water-cooling unit consists of two pumps that are connected in parallel. Only one pump is working at a time, the other one is in standby mode. Non-return valves in the paralleled water circuit are used to avoid the hydraulic short circuit. In case one pump (or the pump motor) fails, the water flow stops. The detection of the pump failure is done via two differential pressure sensors. Once the pump failure is detected, the control logic starts the standby pump and brings back the water flow. If one pump is constantly working, while the other one is on stand-by, there will be unequal ageing of the pumps. To avoid this, the logic is programmed in such a way, that the pumps switch over regularly during normal operation.

To improve reliability, problematic ageing components have been avoided in the design. One good example is the absence of power fuses. Thus, problem of fuse ageing under continuous stress is avoided. Another example is that no encoder is needed in PCS 6000.

Vibration aspects have also been taken into account. In the development phase, vibration simulations and tests were conducted in order to ensure reliable field operation of the system assemblies.

Regarding the converter operating conditions in offshore wind applications, special attention have been paid to the impact of the high humidity level. To ensure operation of the system in such conditions, a special start-up sequence and a high protection level has been implemented for the cabinets.

D. Failure rate prediction

To evaluate circuit design alternatives for power and control hardware boards in PCS 6000, part stress method from MIL-HDBK-217-FN2 have been used. MIL-HDBK-217FN2 handbook offers reliability models for electronics components, where electrical and thermal stresses are considered. Also, quality aspects are taken into account during the calculation by using certain quality factors recommended. The latest revision of the handbook [5] was issued in 1995. In this respect, quality factors for commercial components are rather low, which results in very high failure rates calculated. When compared to field failure rates, results produced using MIL-HDBK-217FN2 have been found to be on extremely pessimistic side.

For PCS 6000, calculations have been performed using the part stress method under ‘Ground Benign’ environment conditions and a system ambient temperature of 40 degrees. These conditions are much milder than the ones existing in wind application. However, the results obtained in such a way correlate better with field experience. Moreover, for the same reason, unity quality factor was used for commercial off-the-shelf components. Quality factor of 1 also reflects component technology advancement. Relex software was used to automate the reliability prediction calculations.

In Fig.3 total failure rates for different component types on IGCT gate driver board are shown (MIL-HDBK-FN2, T=40°C, GB, quality factor 1 is taken for commercial off-the-shelf components).

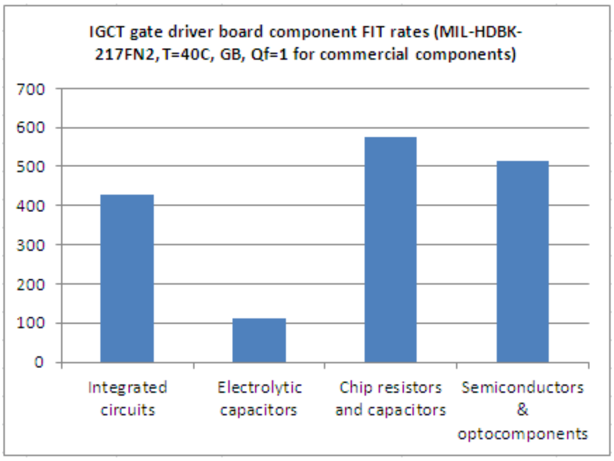

Fig.3. Exemplary breakdown of IGCT gate driver board component failure rates (MIL-HDBK-FN2, T=40°C) The quality factor of 1 is used for all components

Fig.4 shows the breakdown of system failure rates into categories.

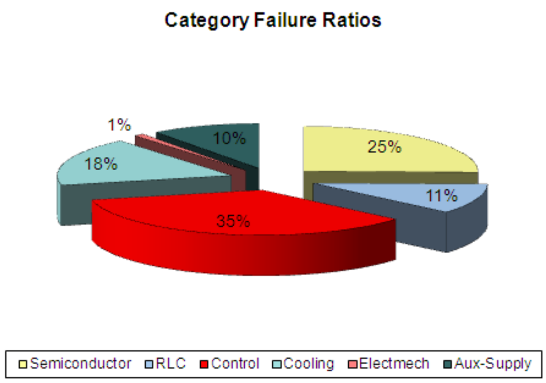

Fig. 4. Breakdown of predicted failure rates into categories (in %)

Sometimes the IGCT gate driver board is mentioned as a reliability concern due to large number of components and complexity. But in fact, the gate driver circuit is simple. It mainly contains a certain amount of capacitors to provide peaks of charge during gate control. A serious effort has been invested in the capacitor design for reliability on the IGCT gate unit. The result can be seen in Fig.3. Part stress method calculation has showed, that total failure rate of capacitors is only a small portion of total IGCT gate driver board failure rate.

Breakdown of total predicted failure rate into categories proved very helpful. This information complemented total predicted failure rate values and provided valuable feedback to the design team. This has been found to be true both for on the board and on the system level. For example, on the board level failure rates has been split into categories such as auxiliary power supply, sensing arrangements, protection, local intelligence, etc. This allowed to trade-off cost and complexity aspects between various functions in respect to reliability.

E. Service & maintenance

During DfR, important aspects of maintenance and service have been addressed. Constraints imposed by converter position inside the wind tower have been taken into account. Also, limitations imposed on service time, especially, in offshore application, have been considered.

To ensure safety of service personnel, each cabinet has an earthing switch and safety interlock.

Power electronics building block (PEBB) concept used in PCS 6000 has a very good serviceability. The latest triple-stack PEBB solution (as shown in Fig.5) utilized in PCS 6000 enables high power density without sacrificing service and maintenance aspects.

Fig.5. PCS 6000 power cabinet: converter realized using IGCT high density triple stack

IGCTs can be exchanged fast and in a convenient way, without disconnecting bus bars or cooling pipes. The stack can be opened easily by discharging a spring, spreading the heat sinks with a tool and finally removing the IGCT [7].

Cabinet design is done in such a way that access for individual components replacement during service is provided. Moreover, most components are transportable by a single person by boat or helicopter if needed.

Finally, control hardware and software concept allows remote access for off-site troubleshooting as well as software update. This enables reduction of maintenance cost and helps to ensure high availability.

IV. CONCLUSION

Becoming a core decision factor for wind application, reliability demands its place in the design process. Designing reliability into PCS 6000 proved to very rewarding exercise that allowed achieving high reliability product for the very demanding field. Low number of components and improved operating conditions for critical systems parts allowed to achieve high converter reliability. FMEA proved to be useful tool to identify potential failure modes. Reliability prediction provided valuable feedback into design.

The authors gratefully acknowledge the work of Wind Group, Turgi, ABB Switzerland in PCS 6000 converter development and support for this paper preparation.

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