Power Electronics Reliability- A different view

Peter Tavner
Emeritus Professor, Durham University

*Beginning is easy - Continuing is hard*
Japanese Proverb
Overview

- What is reliability;
- What goes wrong with power electronics;
- How can we study power electronic reliability;
- The Bottom-Up Approach - Physics of Failure;
- The Top-Down Approach – Failure Modes & Effects;
- Top-Down in Action;
- A view from the wind farm.
The Bathtub Curve

Failure Intensity, $\lambda$

$\lambda_a = \left( \frac{\text{Total number of failures}}{\text{Turbine Population}} \right) / \text{Operating Period (years)}$

Most turbines lie here

$\lambda(t) = \rho \beta e^{-(\beta-1)t}$

Reference 15
The Bathtub Curve

Failure intensity $\lambda$

More rigorous sub-assembly pretesting
To remove Root Causes

Select more reliable components
Preventive maintenance
Reliability centred maintenance
Condition based maintenance
Detecting Root Causes early

Major sub-assembly Change-out
Based on Root Cause detection

Early Life ($\beta < 1$)

Useful Life ($\beta = 1$)

Wear-out Period ($\beta > 1$)

Time, $t$

Reference 15
Root Causes and Failure Modes
Example: Inverter H-Bridge Failure

Failure mode

Why?
Root Cause Analysis

Root Causes

How?
Physics of Failure Investigation

H-Bridge Failure

Die to Heatsink Failure

Device deterioration Due to temp

Excess Temp due to Switching Pattern

Control Regime

High Inverter Temperature

Poor Thermal Management
Power Electronic Unit Health

Fig. 1. Fault prognosis, diagnosis, and CM schemes [3]. The fault event causes the jump in health level shown.
Availability, Manufacturer’s or Inherent Operability

100% Operability

MTBF

MTTF

0% Operability

MTTR

Time

Reference 15
Availability, Operator’s or Technical

Operability

100% MTBF

Logistic delay time

0% MTTF

MTTR

Time

Reference 15
Availability & Reliability of a Converter

- Mean Time To Failure, $MTTF$
- Mean Time to Repair, or downtime $MTTR$
- Mean Time Between Failures,
  \[ MTBF \approx MTTF = \frac{1}{\lambda} \]
  \[ MTBF = MTTF + MTTR = \frac{1}{\lambda} + \frac{1}{\mu} \]
- Failure rate, $\lambda$  
  \[ \lambda = \frac{1}{MTBF} \]
- Repair rate, $\mu$  
  \[ \mu = \frac{1}{MTTR} \]
- Manufacturer’s or Inherent Availability, 
  \[ A = \frac{MTBF - MTTR}{MTBF} = 1 - \left( \frac{\lambda}{\mu} \right) \]
- Operator’s or Technical Availability, 
  \[ A = \frac{MTTF}{MTBF} < 1 - \left( \frac{\lambda}{\mu} \right) \]
The structure of Unreliability

1. Root Causes
   - Faulty design
   - Faulty materials
   - Bad Thermal Management
   - Poor maintenance

2. Physics of Failure Analysis
3. Monitoring Signals
4. Failure Modes And Effects Analysis, FMEA
5. Failure Location

How?
Pre-Testing during Prototype Development

Physics of Failure Analysis

Why?
Root Cause Analysis
Wind Turbine Nacelle

1. Nose cone  5. Generator
2. Pitch motor  6. Transformer
3. Hub  7. Hydraulic power pack
Types of Wind Turbine Converter Configuration

SCIG = Squirrel Cage Induction Generator
DFIG = Doubly Fed Induction Generator
PMSG = Permanent Magnet Synchronous Generator
WRSIG = Wound Rotor Synchronous Generator
Soft Starter

Induction generator

Soft starter

Capacitor bank

Contactor

Grid
Pitch Controller

Rectifier diode bridge

T set by switching frequency

Converter/SPA

2 IGBT

DC bus

2 quadrant chopper

Controller

Motor reversing switches

Series field

Relay timer

Encoder

Shunt field

Pitch gearbox

Battery (EPU)
Partially Rated DFIG Converter

Double fed induction generator

Bypass contactor

Main switch

Main WT transformer

Grid

Rotor

Stator

Crowbar

DC link

Rotor-side inverter

Grid-side inverter

Series contactor

Controller

Controller
Comparison of Partially-rated & Fully-rated Converter Failure Rates from the Literature
Failure Rate of WT Converters

Table 7.2: Reliability of Converters from Industrial Experience

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Failure rate, λ, Failures/assembly/yr</th>
<th>MTBF, hr</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Converter</td>
<td>0.0450-0.2000</td>
<td>43,800-195,000</td>
<td>Spinato et al [19]</td>
</tr>
</tbody>
</table>

LWK, E40 converter

LWK, E66 converter

LWK, TW1.5s converter

17
Summary of an FMEA study of Wind Turbine Converter Failure Rates

<table>
<thead>
<tr>
<th>Description</th>
<th>$\lambda_{tot}$ (failures/unit/yr)</th>
<th>$R_{(5yr)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Starter with 6 Thyristors &amp; Power Factor Correction Capacitors, Assembly Failure Rate Estimate based on Surrogate Data</td>
<td>0.063</td>
<td>94%</td>
</tr>
<tr>
<td>LV Partially Rated Converter (FRC) with 6 IGBT/Diodes per Inverter, Assembly Failure Rate Estimate based on Surrogate Data</td>
<td>0.121</td>
<td>88%</td>
</tr>
<tr>
<td>3-axis Pitch Converters with 2 IGBT/Diode Choppers per Converter, Assembly Failure Rate Estimate based on Surrogate Data</td>
<td>0.195</td>
<td>82%</td>
</tr>
<tr>
<td>MV Fully Rated Converter (FRC) with 12 IGCT/Diodes per Inverter in two Parallel PRC, Assembly Failure Rate Estimate based on Surrogate Data</td>
<td>0.402</td>
<td>67%</td>
</tr>
<tr>
<td>MV Fully Rated Converter (FRC) with 12 IGCT/Diodes per Inverter in one Single Channel, Assembly Failure Rate Estimate based on Surrogate Data</td>
<td>0.738</td>
<td>49%</td>
</tr>
</tbody>
</table>
Alarm Showers from a Partially Rated DFIG Converter
Root Causes of Power Electronic Failures according to Wolfgang

- Capacitors: 30%
- PCB: 26%
- Semiconductors: 21%
- Solder: 13%
- Others: 7%
- Connectors: 3%
- Others: 7%
Conclusions

- Power electronic reliability needs improvement
- There are many power electronic configurations
- Configuration is important to reliability
- Failure rate, $\lambda$, or $1/MTBF$, is important
- But downtime, $1/\mu$, or $MTTR$ is also important
- High $MTBF$ & Low $MTTR$ both raise power electronic cost but lower operational cost
- Failure rate of power electronic sub-assemblies can be improved by bottom-up Root Cause study, Physics of Failure
- But reliability can also be improved by understanding top-down Failure Location, Failure Modes & Effects Analysis, FMEA
Thank you