Comparison of Offshore Wind Turbine Reliability

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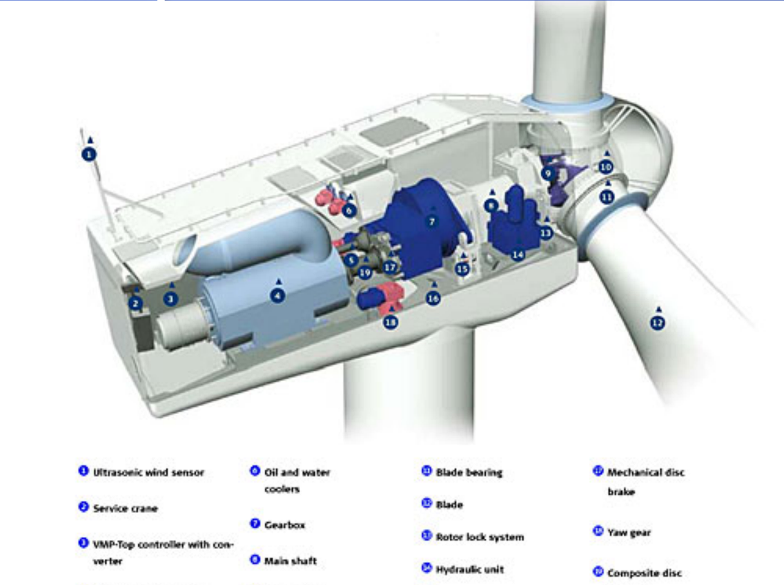
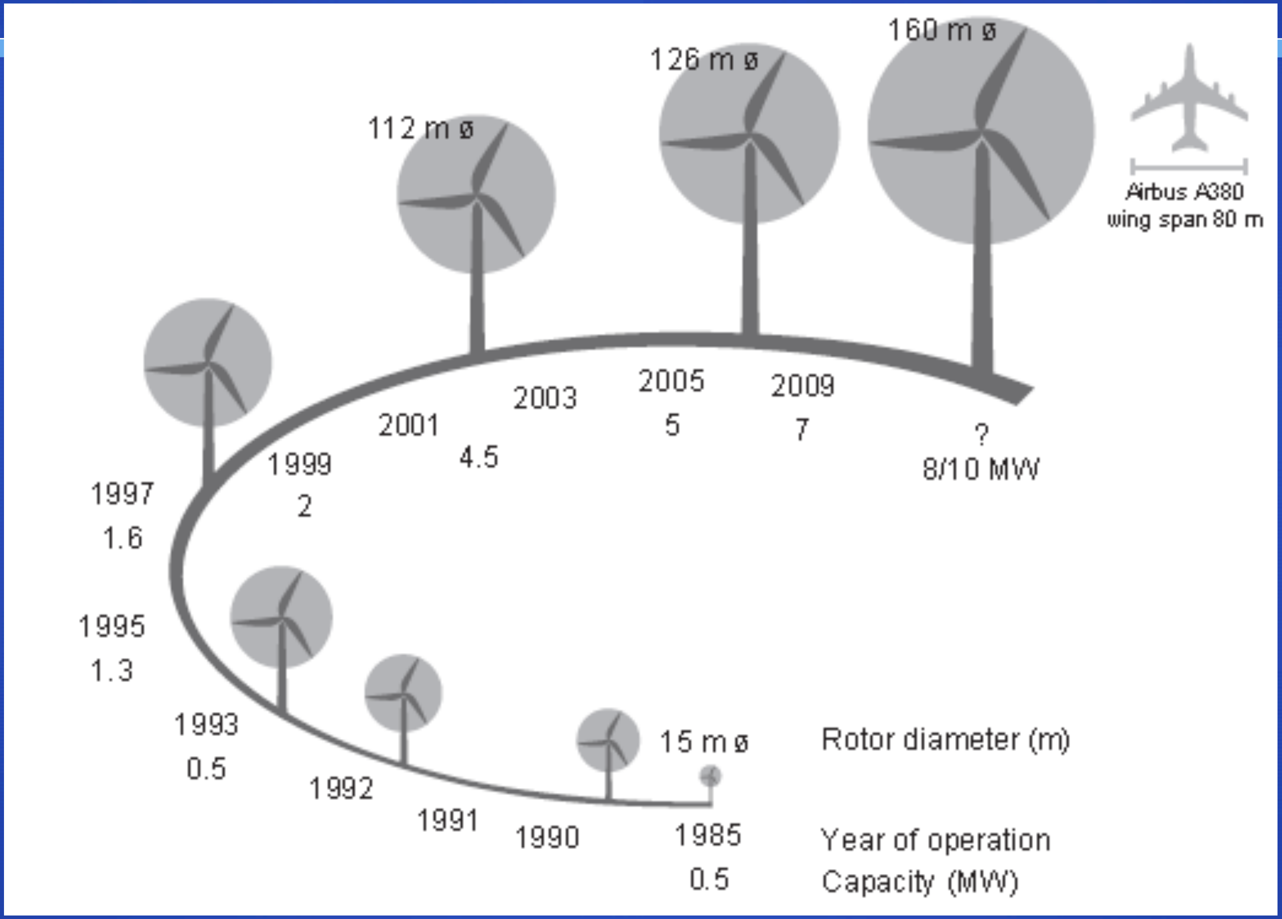
Outline

- General study of the failure rate and reliability of the several types of OWT architectures
- Comparison of the failure rate of assemblies in OWT drive train and electrical system
- Reliability issues of power electronics in power converters



Growth in size of Commercial WT Designs (from EWEA)



Off Shore Access is Difficult, and Costly: Require Minimum Maintenance and High Reliability

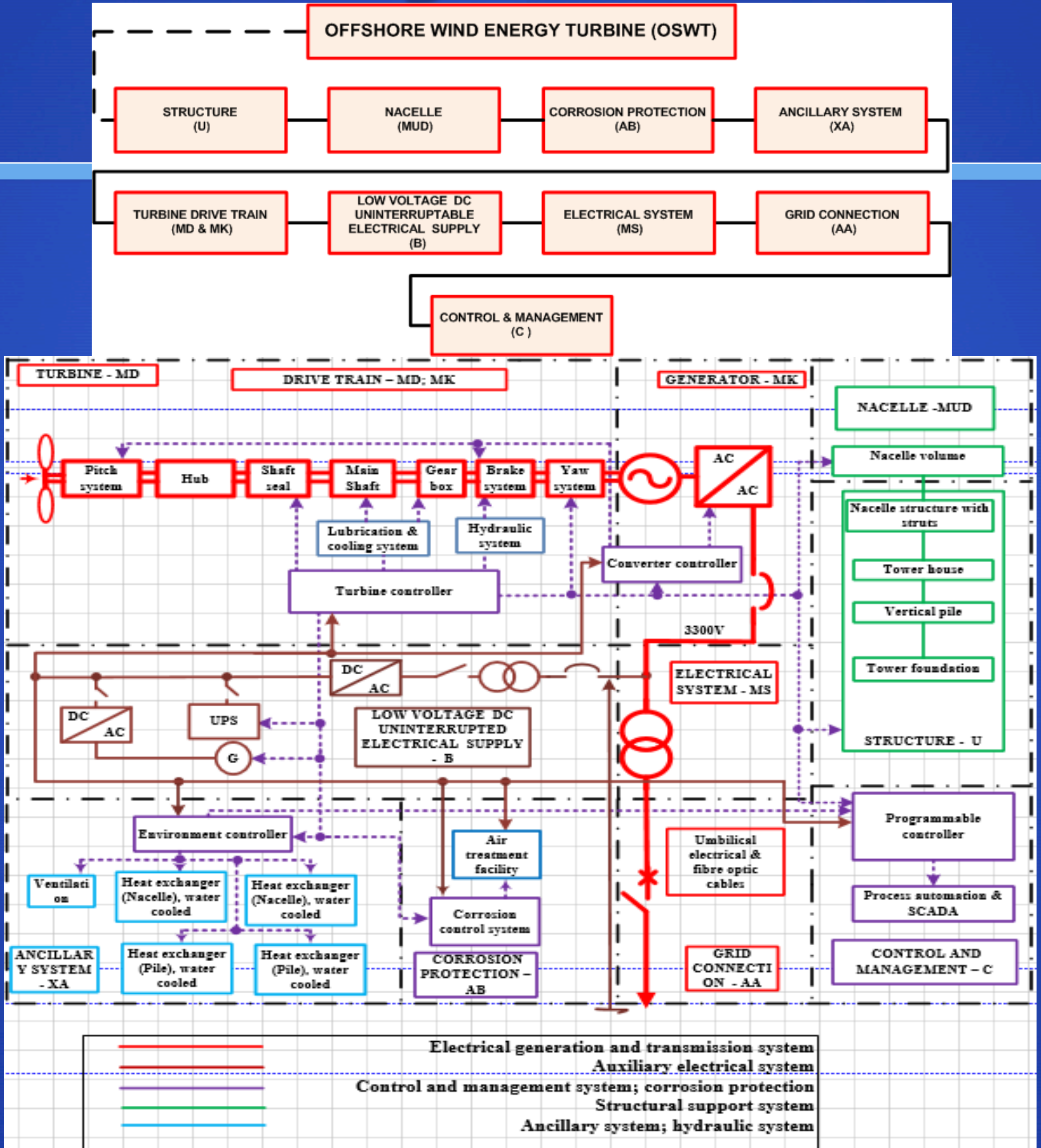
The "Marine Environment"

- The "marine environment" refers to the physical, chemical, and biological stressors acting on offshore wind turbines
- The primary concern is the effect of salt and moisture content, as sea water, sea air, or salt spray, on corrosion of WT components.
- This concern is partially mitigated by the practice of "normalizing the turbine internal atmospheric environment" by removing salt from all air inflows and providing a positive pressure
- There are, however, other physical and electrical stresses related to location offshore that can cause failures as well.
  - highly variable temperatures
  - powerful storms and lightning strikes.
- These can cause failures resulting from solder fatigue due to temperature cycling or due to the shock or vibration caused by high winds or waves during storms.

Main Issue is Reliability and Maintainability

- Develop reliability models for comparison of key technologies.
- Integrate Physics of Failure Models to Predict Reliability
- Assess life expectancy of wind turbine hardware under anticipated life cycle loading conditions and accelerated stress test conditions.
- Predict Effect of turbine degradation on grid performance

Schematic Diagram of Offshore WT



Reliability Comparison Models for Offshore Wind Turbines(OWT)

- 5 Types of WT architectures (Types1-4a) were chosen for reliability modelling using Reliability Block Diagrams and Parts Count Prediction technique, based on surrogate data from wind turbines, marine and other generic databases (OREDA, MIL-HDBK-217F, IEEE Gold Book, etc.)

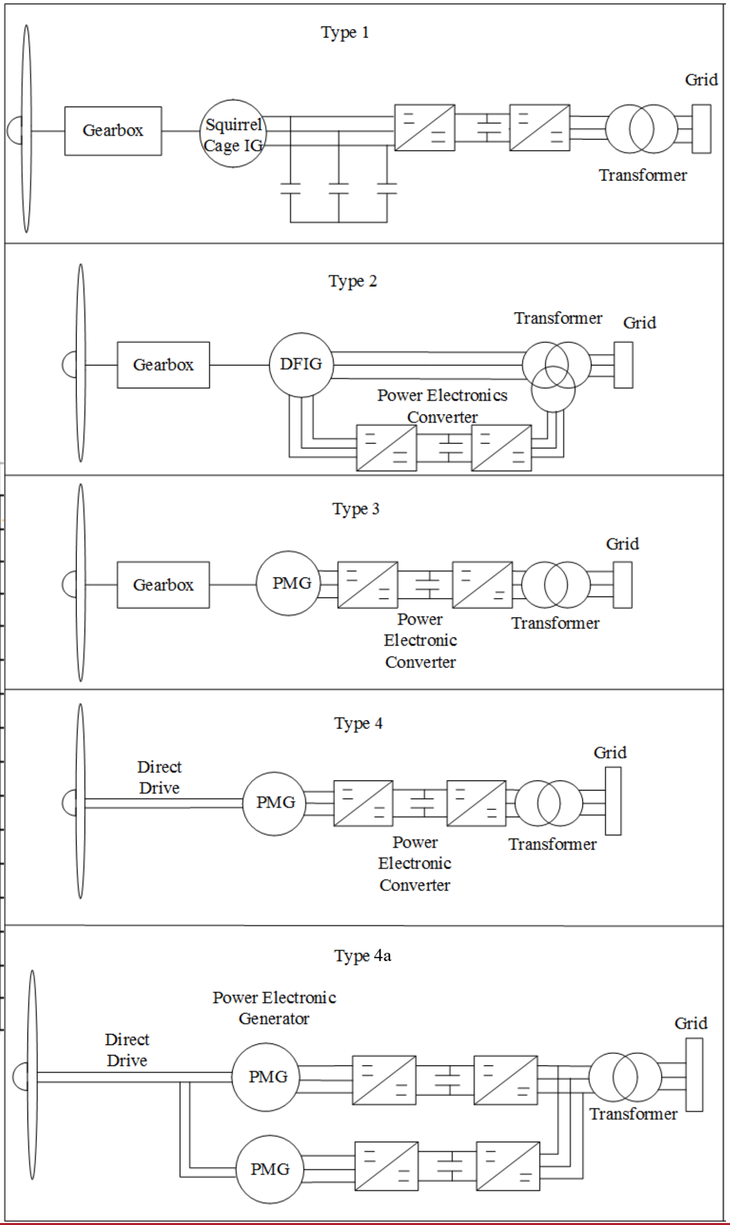


Table: Concept Types

Concept type	Drive train configuration	Manufacture	Turbine	Power MW
Type 1	GB + IG	Siemens	SWT-3.6-107	3.60
			SWT-3.6-120	3.60
			SWT-4.0-130	4.00
Type 2	GB +DFIG	Vestas	V90-3.0	3.00
		General Electric	GE 3.6	3.60
		Senvion	5M	5.00
			6.2M126	6.15
			6.2M152	6.15
Type 3	GB+PMG	Vestas	V112-3.3	3.30
			V164-8.0 MW® IEC S	8.00
		AREVA	M5000-116	5.00
			M5000-135	5.00
Type 4	PMG+Direct Drive	NORDEX	N150/6000	6.00
Type 4a	2 PMG*+Direct Drive	General Electric	GE 4.1-113	4.10
		Siemens	SWT-6.0-154	6.00

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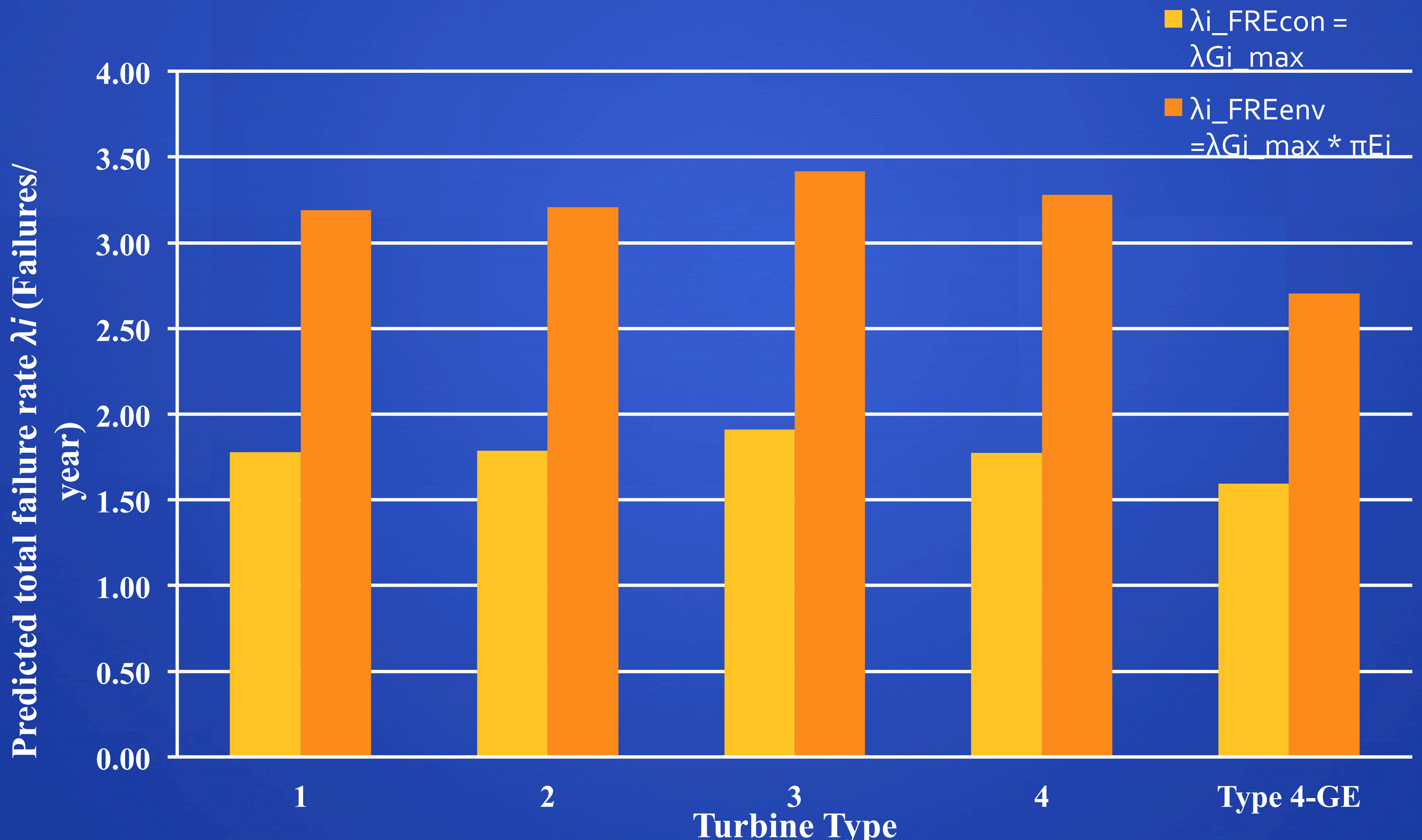
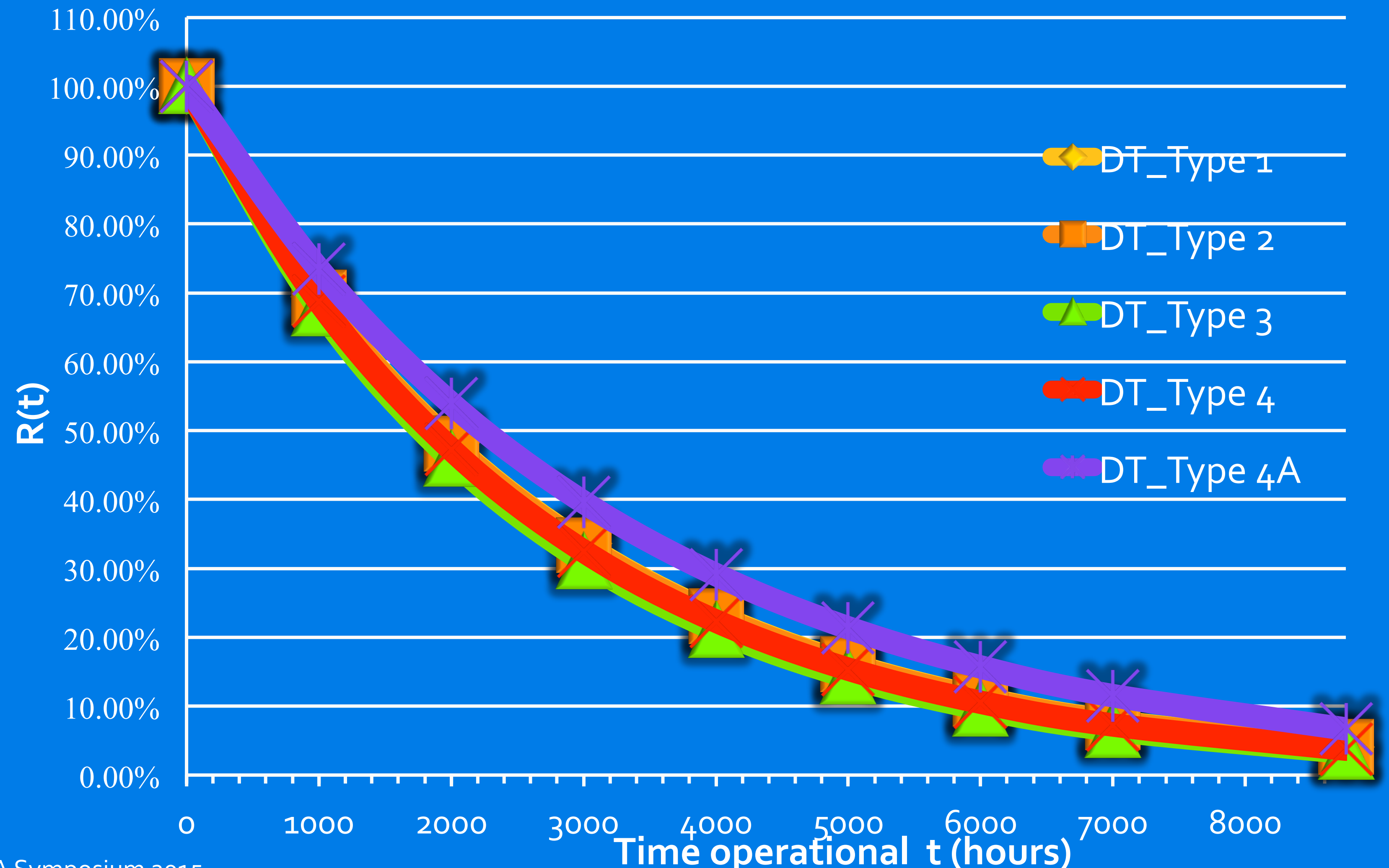
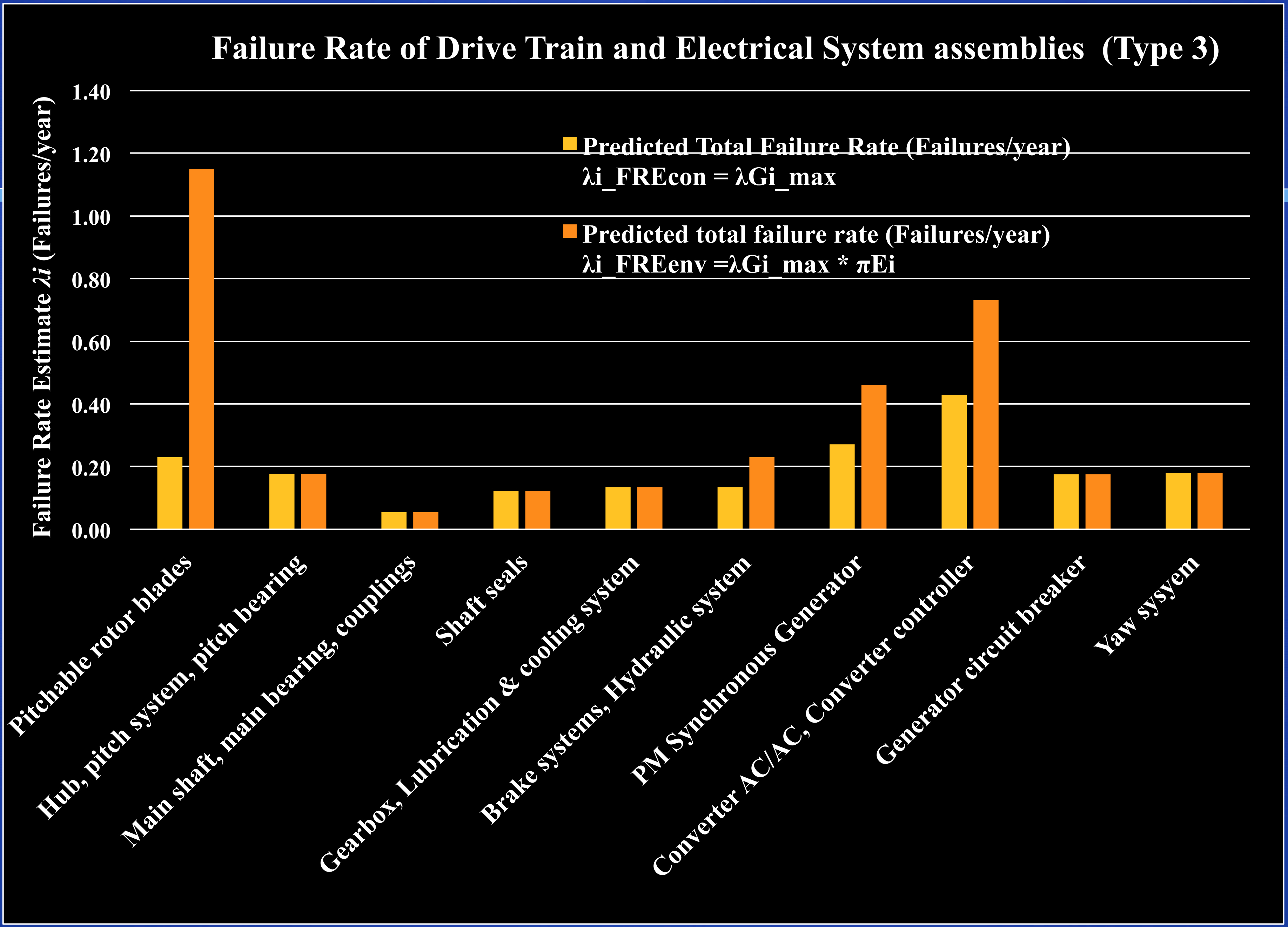
Predicted Total Failure Rate for Types 1-4a OWTs assuming no maintenance

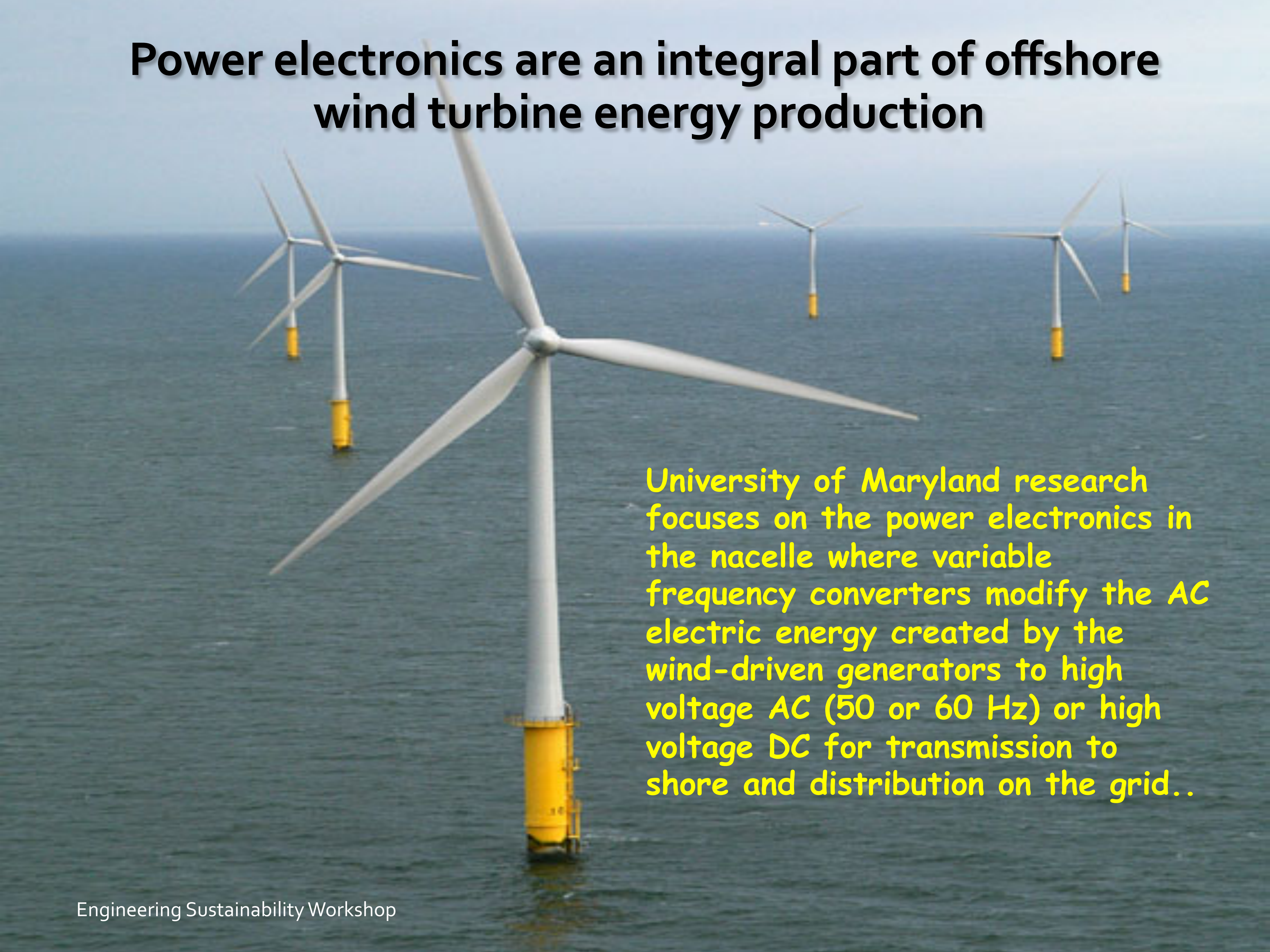


Reliability Survivor Function of Types 1-4a in 1 year assuming no maintenance



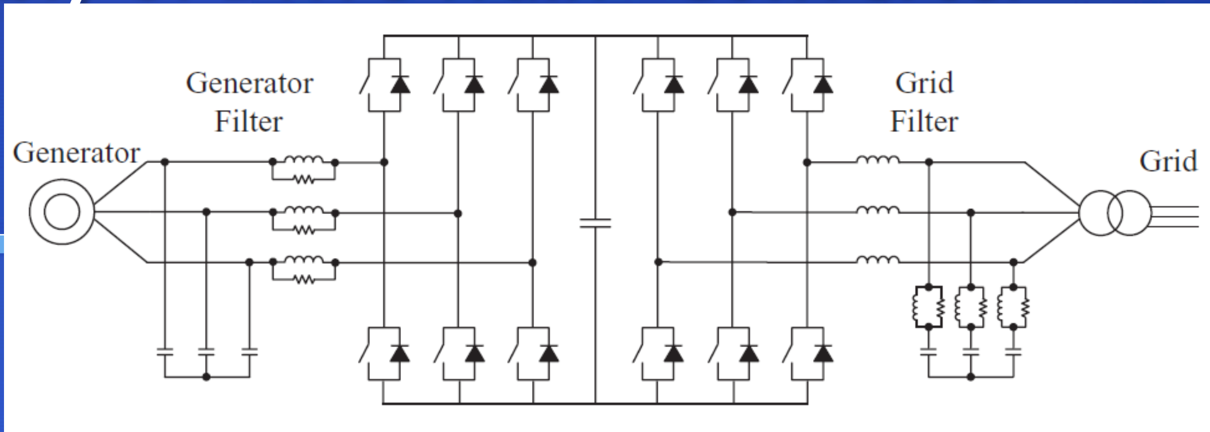

Failure Rate of Drive Train and Electrical System assemblies (Type 3)
Failure Rate Estimate λi (Failures/year)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Predicted Total Failure Rate (Failures/year)
λi_FREcon = λGi_max
Predicted total failure rate (Failures/year)
λi_FREenv =λGi_max * πEi
Pitchable rotor blades
Hub, pitch system, pitch bearing
Main shaft, main bearing, couplings
Shaft seals
Gearbox, Lubrication & cooling system
Brake systems, Hydraulic system
PM Synchronous Generator
Converter AC/AC, Converter controller
Generator circuit breaker
Yaw sysyem

Power electronics are an integral part of offshore wind turbine energy production



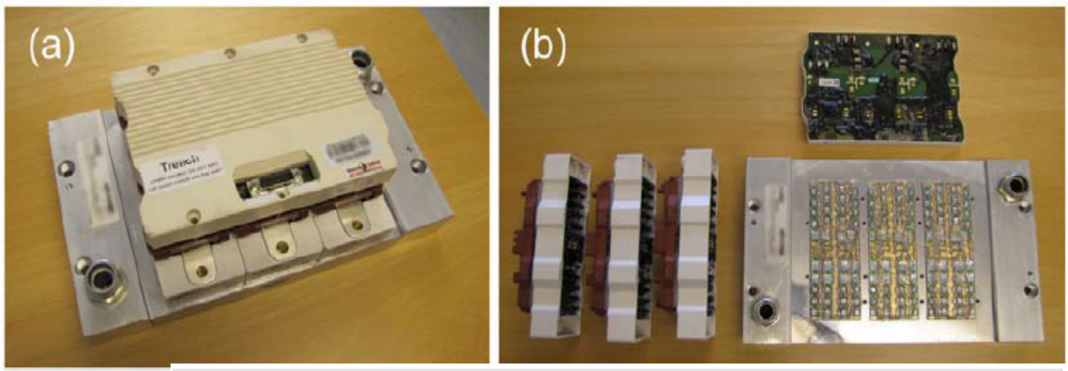
University of Maryland research focuses on the power electronics in the nacelle where variable frequency converters modify the AC electric energy created by the wind-driven generators to high voltage AC (50 or 60 Hz) or high voltage DC for transmission to shore and distribution on the grid..

Critical Assembly of Drive Train--Converter

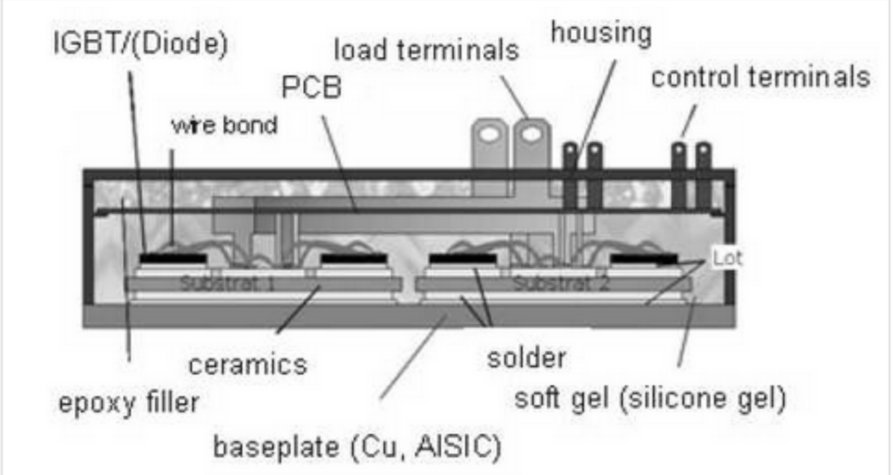


Back to back connected power module

Converter Module with driver board, connections, housing, and power electronic chips with heat sink.

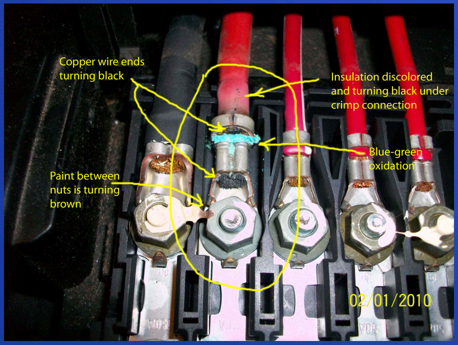


Failure Mechanisms: Corrosion of interconnects, Electrochemical migration, Bond wire liftoff and Solder Joint Fatigue



1. Corrosion of Interconnects

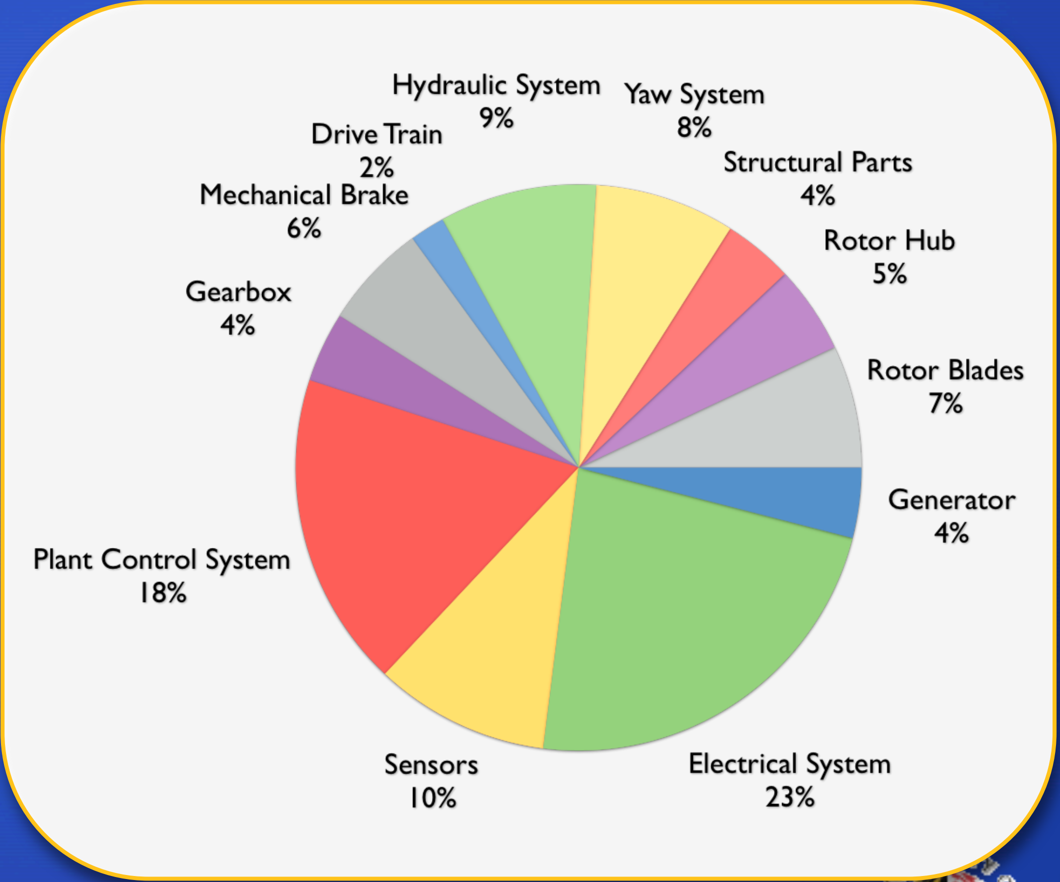
- Corrosion is the leading failure mechanism for offshore wind turbine
- Occurs everywhere in the wind turbine
- Multiple corrosion mechanisms active
  - General Corrosion
  - Crevice and Pitting
  - Stress Corrosion
  - Erosion / Corrosion



Assembly	Possible defects
Rotor blade	Surface damage, cracks, structural discontinuities
	Damage to the lightning protection system
Drive train	Leakages, corrosion
Nacelle and force- and moment-transmitting components	Corrosion, cracks
Hydraulic system, pneumatic system	Leakages, corrosion
Tower and foundation	Corrosion, cracks
Safety devices, sensors and braking systems	Damage, wear
Control system and electrics including transformer station and switchgear	Terminals, fastenings, function, corrosion, dirt

Failure Sites

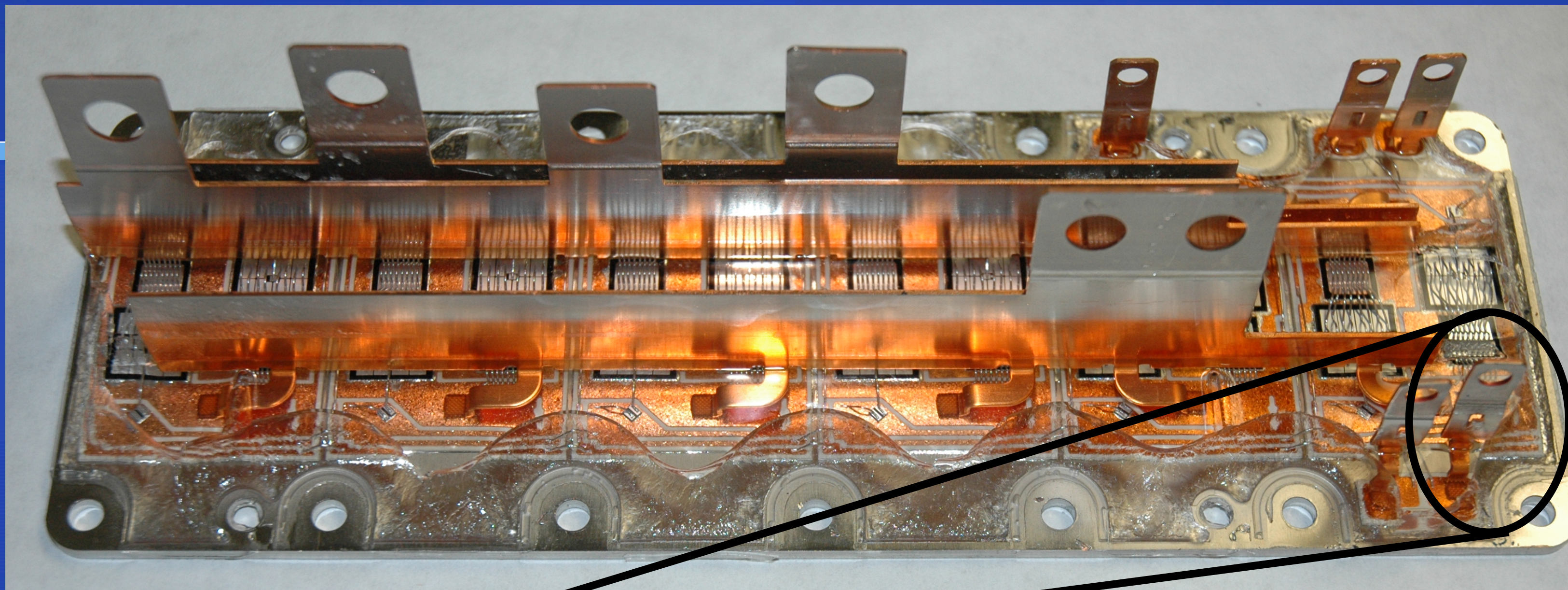
- Statistical failure studies indicate electronics are a major cause of unscheduled maintenance.
- Electronics have short repair times but harsh environmental conditions can make wind turbines inaccessible.
- Power Electronic Failures can propagate to the grid.

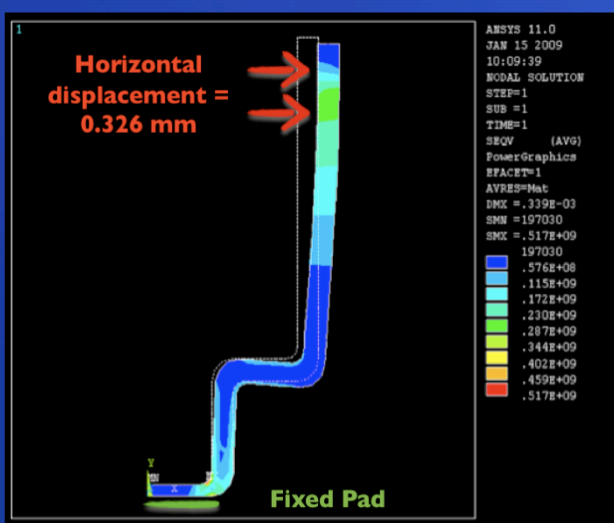


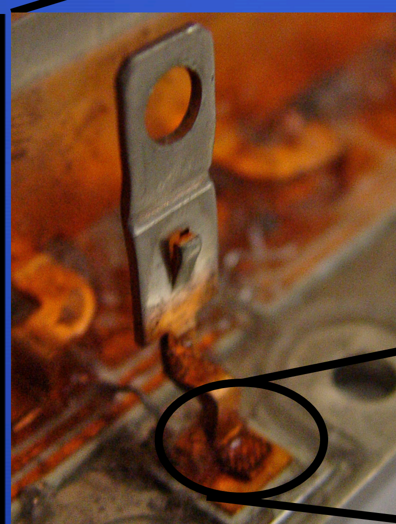
Corrosive Environments and Interconnect Corrosion: Copper Interconnects

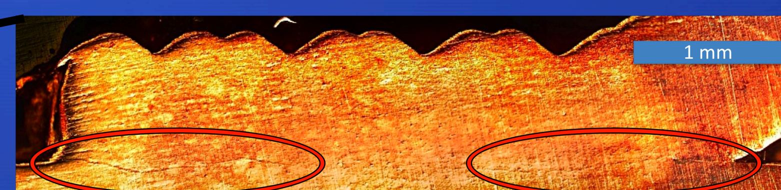
- Structures located over or within 2500 feet of a body of water containing chloride above 2000 ppm are considered to be marine structures.
- Marine environments are characterized by sodium chloride that is easily carried by sea spray, mist or fog.
- Temperature, relative humidity, and wet/dry time all effect the corrosion potential
- Corrosion of copper in the atmosphere results in a thin layer of corrosion, typically referred to as the patina.
- Higher concentrations of chlorides in marine air cause copper to acquire a patina sooner than other locations.
- The rate of copper corrosion layer formation varies in different environments:
  - Land ≈ 0.5 µm/year
  - Marine ≈ 1 µm/year

Copper Interconnect Corrosion in Power Converter



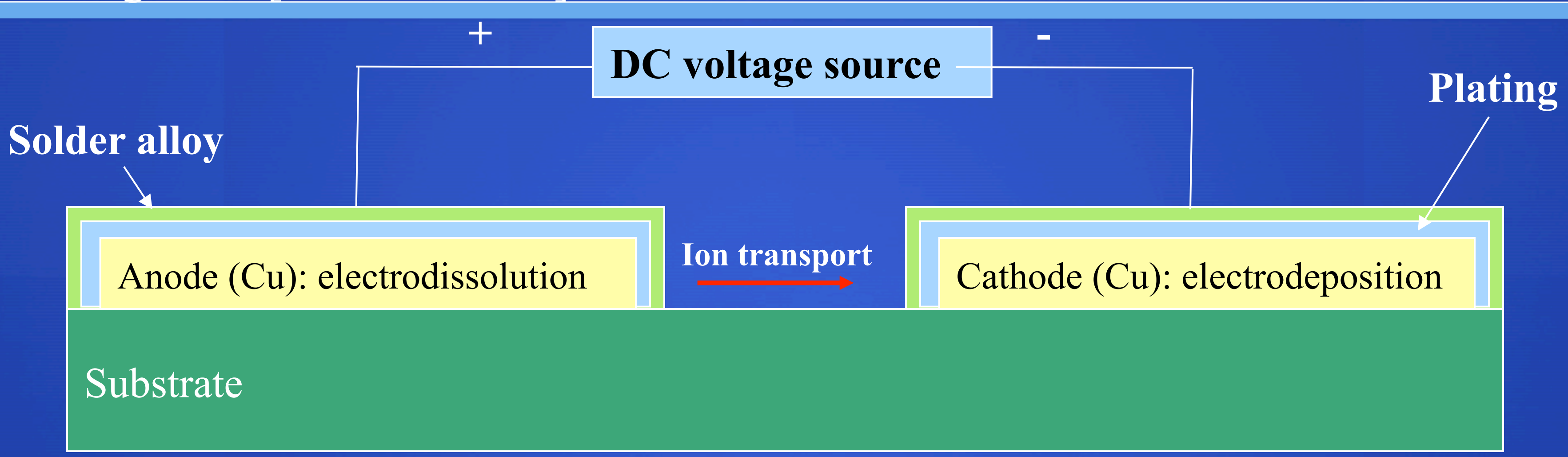






2. Electrochemical Migration

Electrochemical migration (ECM) is the growth of conductive metal filaments on or in a printed circuit board (PCB) under the influence of a DC voltage bias [IPC-TR-476A].



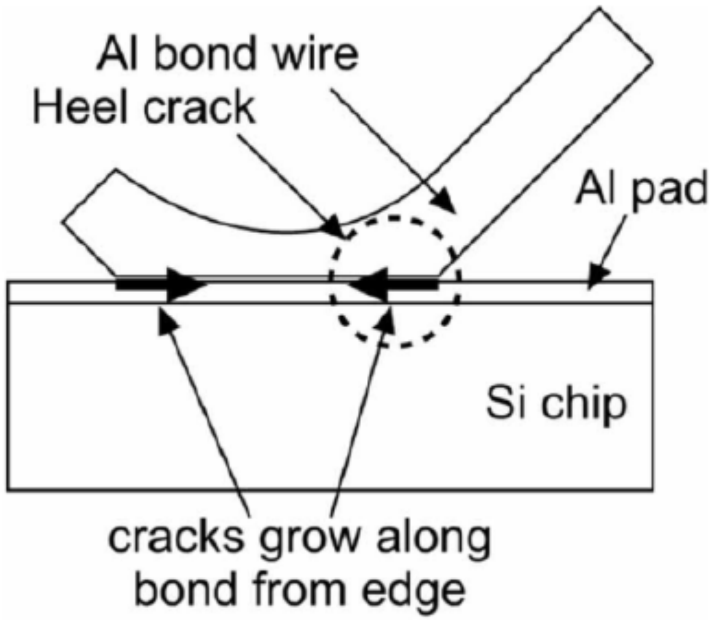
Necessary Conditions for ECM

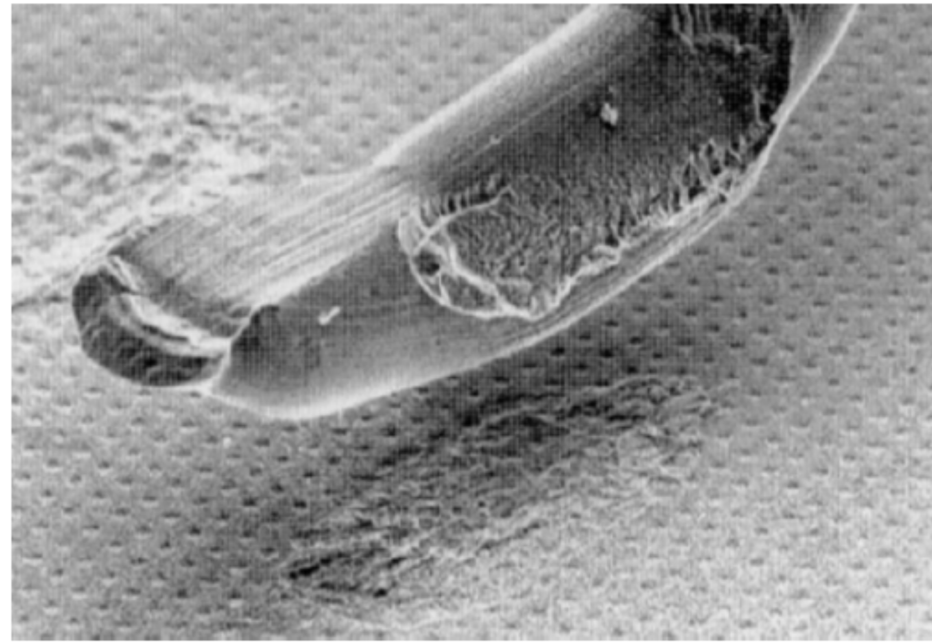
- **Electrical carriers (such as ions).**
- **A medium, usually water, to dissolve the ionic materials and sustain them in their mobile ionic state.**
- **Electrical potential between the electrodes to establish an ionic current in the liquid medium.**

Stages of ECM

- Path formation
- Electrodissolution
- Ionic transport
- Electrodeposition
- Filament growth

3. Bond wire lift-off

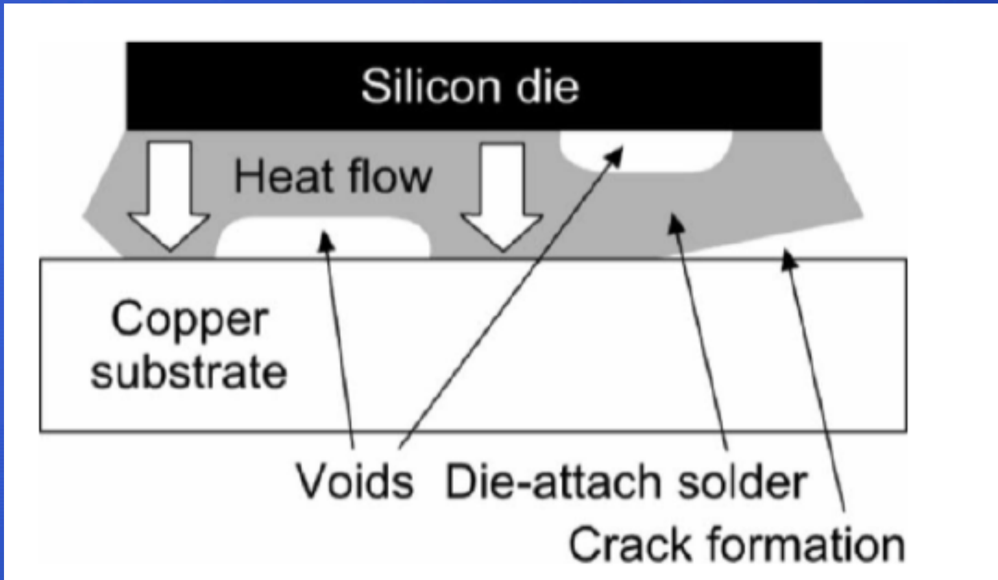




Bond wire lift-off is caused by cumulative damage due to crack growth at the interface between the chip and the bond wire, resulting from temperature swings in combination with the difference in thermal-expansion coefficients (CTE) of Si and bond wire material.

4. Solder Joint Fatigue

- The root cause for solder fatigue and cracking is also the CTE mismatch between adjacent materials while subject to power cycles. Frequently, the crack propagation starting from the edges of the solder contact area to the center, leading to an increasing delamination. Also, voids may form at the interface, exaggerating the delamination.



Conclusions: OSW Reliability Research

- Significant reliability problems remain
  - Off-shore possesses new challenges
  - Present investigations is a start in understanding the offshore environment and reliability of wind turbines.
- Future Work: Focus on corrosion and fatigue on Power Electronics.
- Apply techniques to make a better prediction of time to failure, failure rate and reliability
  - Baysian Analysis and Particle Filtering
  - Refined CALCE Physics of Failure Models

Thanks for your attention!