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Fatigue Reliability-Based Inspection and Maintenance Planning of Gearbox Components in Wind Turbine Drivetrains

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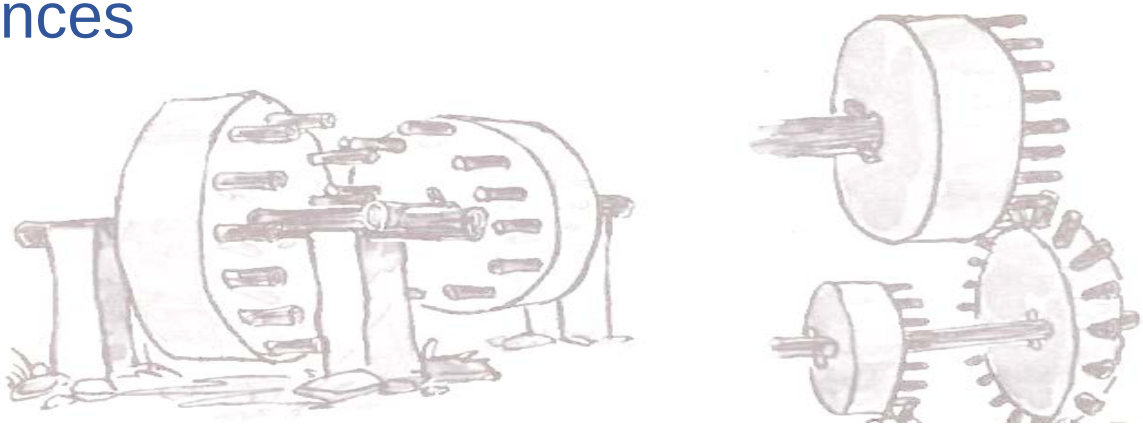


Introduction

Maintenance, in general terms, is classified into [1]:

- **Corrective** actions.

The corrective action is taken when the failure of components is occurred and the system is partly broken down.

- Precautionary- or **preventive** - actions.

The preventive maintenance action is on routine schedule to repair or replace components before they fail [2].

Introduction

- **Preventive** maintenance in Wind Turbines:

The preventive maintenance of wind turbine gearboxes is often carried every 6 months for each wind turbine, normally within a day, and a major check-up is performed every 3 years [3].

- What is included in gearbox routine inspection?

Oil sampling for particle counting, oil filter checking, observing the possible oil leakage from housing or pipes and identifying any unusual noise from the gearbox [3]. The oil sampling even in offshore wind turbines equipped with condition monitoring systems is often offline.

Introduction

If the result indicates high debris in the oil, unusual noise or leakage, further internal visual inspection by other means such as **endoprobe** or **fiberscope** with camera is then performed [3].

In the endoprobe or fiberscope inspection, the maintenance inspector should examine all gears and bearings, one by one in order to find the source of noise or debris in the oil. Any knowledge of impending failure can reduce cost dramatically and can help the maintenance team to plan. [4]

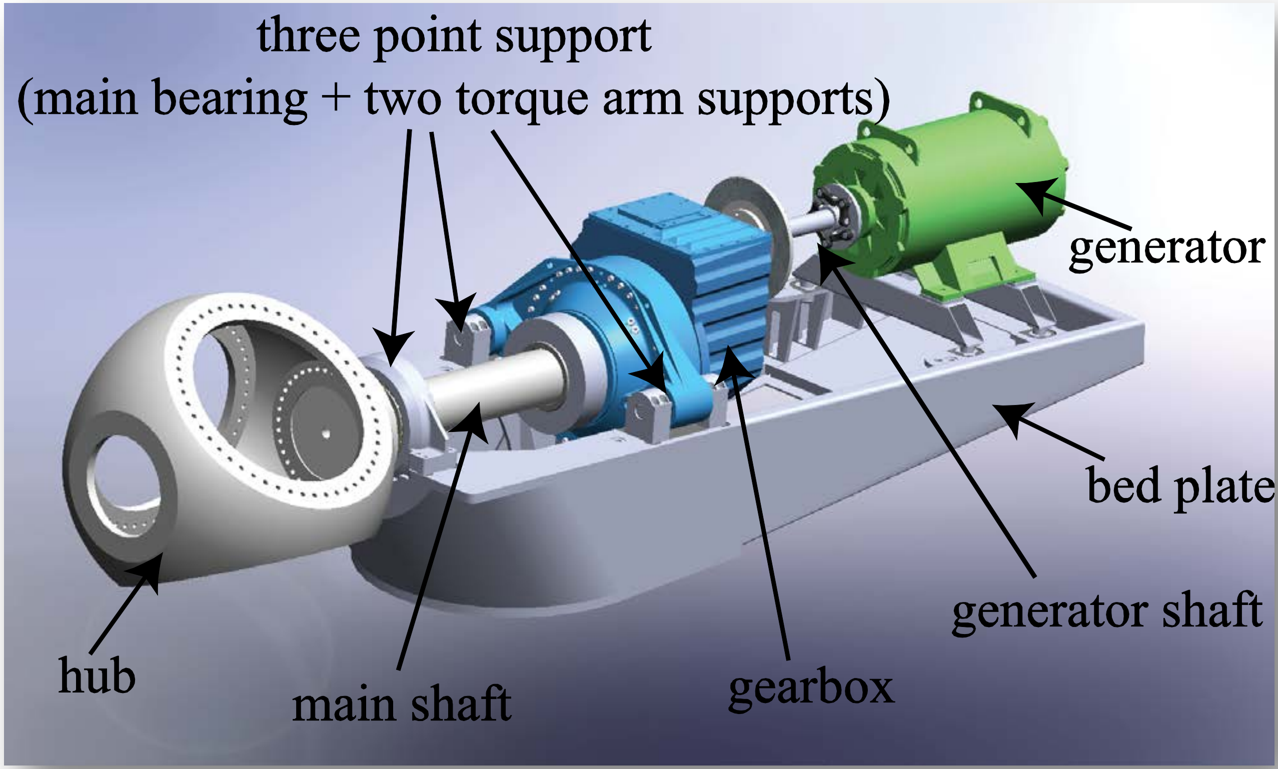
Objectives

The main aim of this paper is:

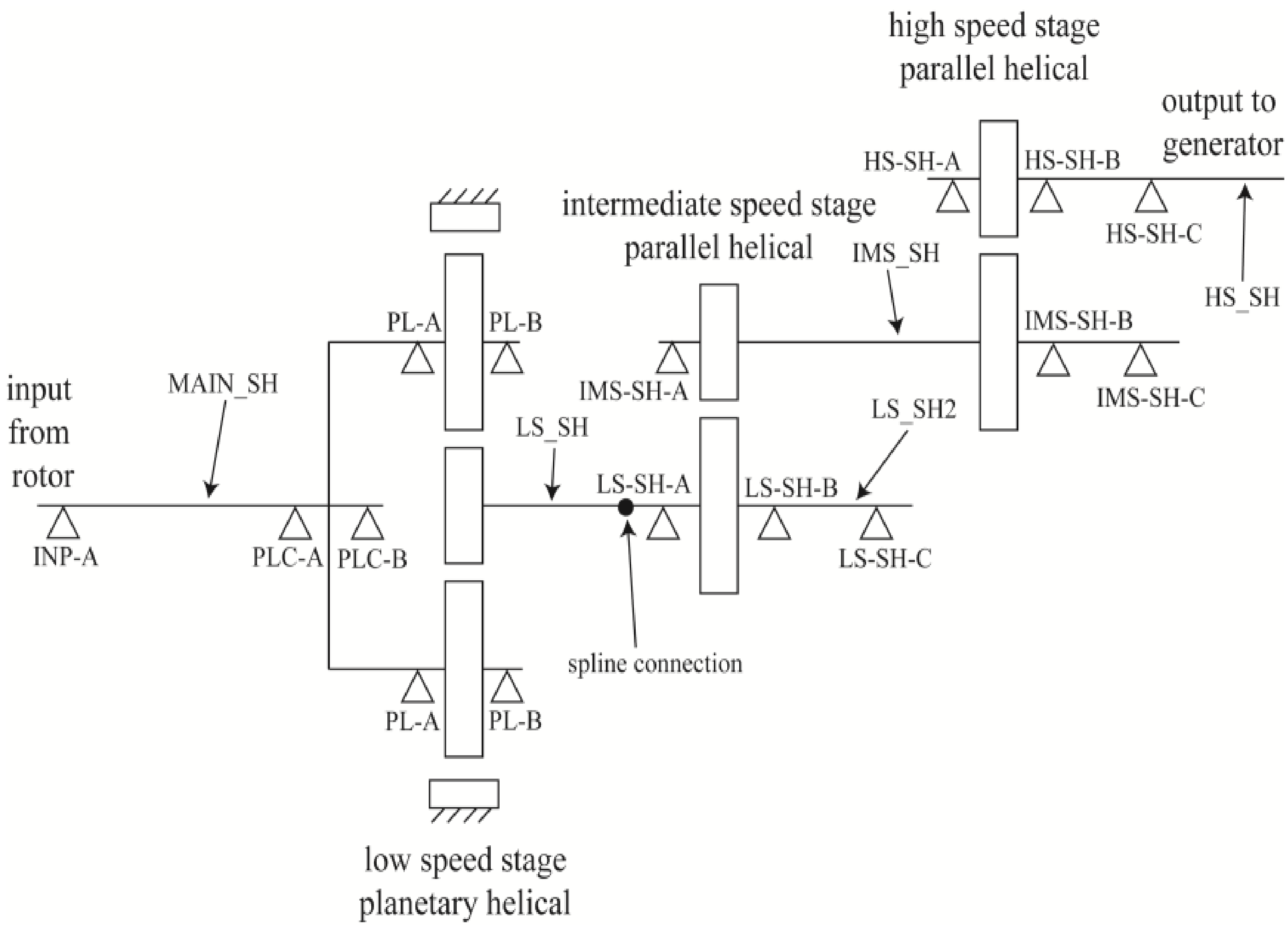
To propose a method for developing the "**vulnerability map**" which can be used for maintenance team to identify the components with lower reliability.

This map is developed based on the fatigue damage of gears and bearings.

Model: 750 kW NREL Drivetrain



Model: 750 kW NREL Gearbox Topology

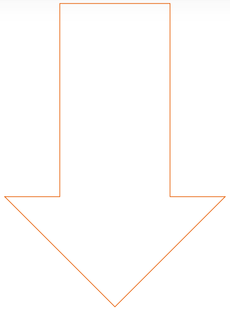


Methodology : decoupled approach

Step I:

NREL dynamometer test bench.

Torque time series



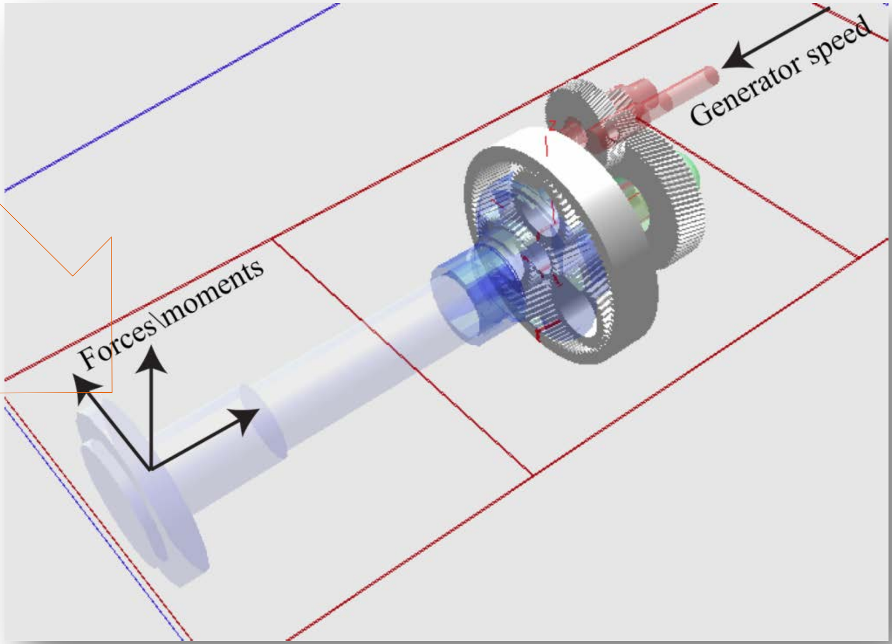
Methodology : decoupled approach

Step II:

Torque time series

are applied on Gearbox

MBS model.



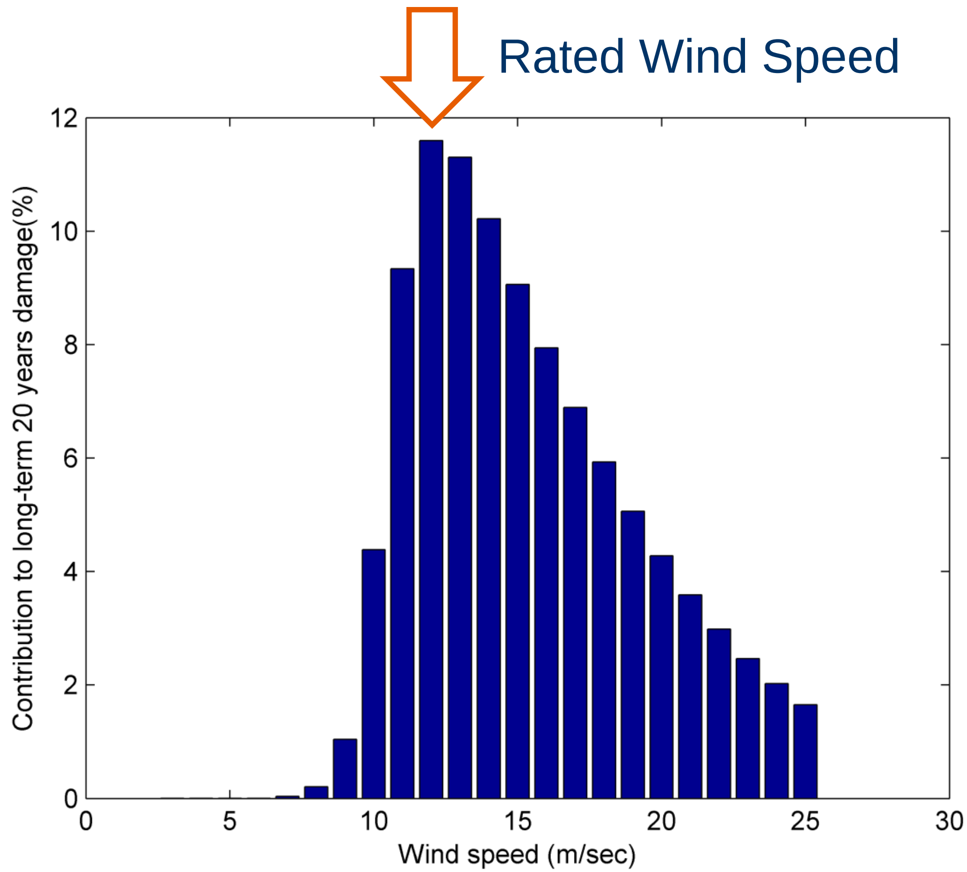
Gearbox multibody dynamic (MBS) model

Step III:

Loads on gears and bearings are measured.

Methodology

We rank the gears and bearings based on their fatigue damage.

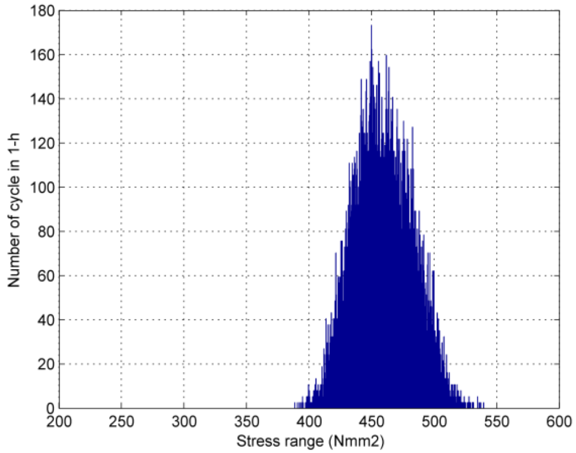


Contribution to fatigue damage [5]

Methodology

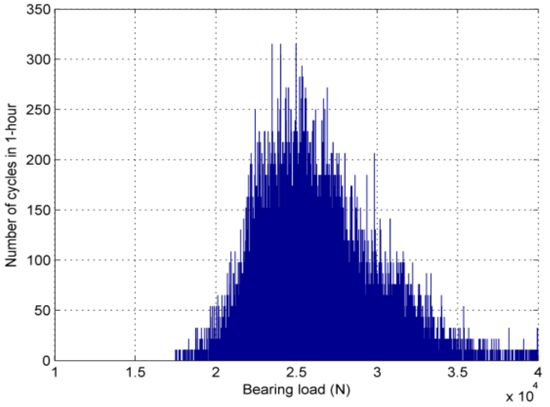
Gear Fatigue Damage (gear tooth root):

$$D = \frac{N_T}{K_c}\int_0^\infty s^m \cdot f(s)\cdot ds = \frac{N_T}{K_c}\left\{A^m \cdot \Gamma\left(1+\frac{m}{B}\right)\right\}$$



Bearing Fatigue Damage:

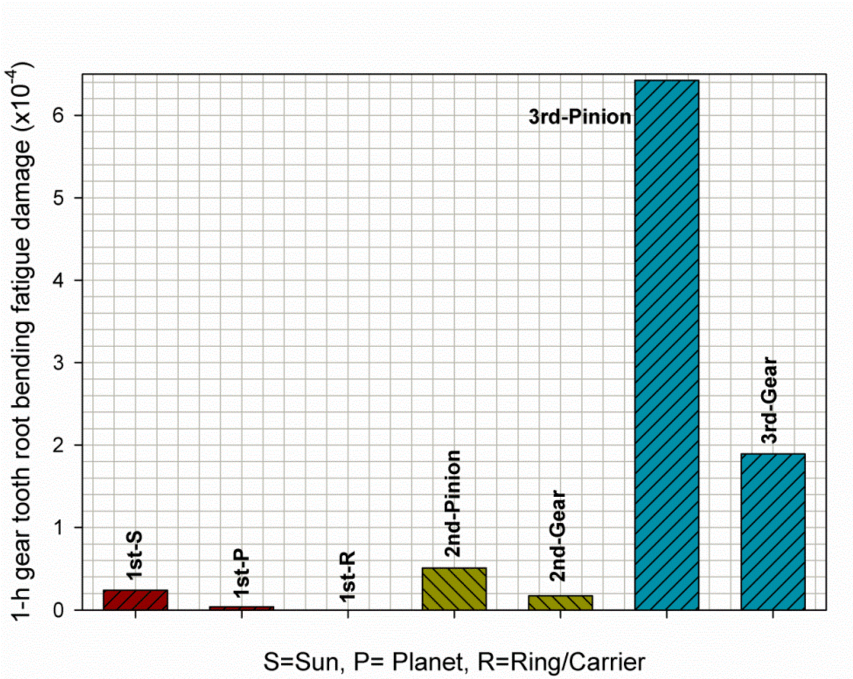
$$D = \frac{v_{P0}.T}{L_{10}.C^a}\cdot A^a \cdot \Gamma\left(1+\frac{a}{B}\right)$$

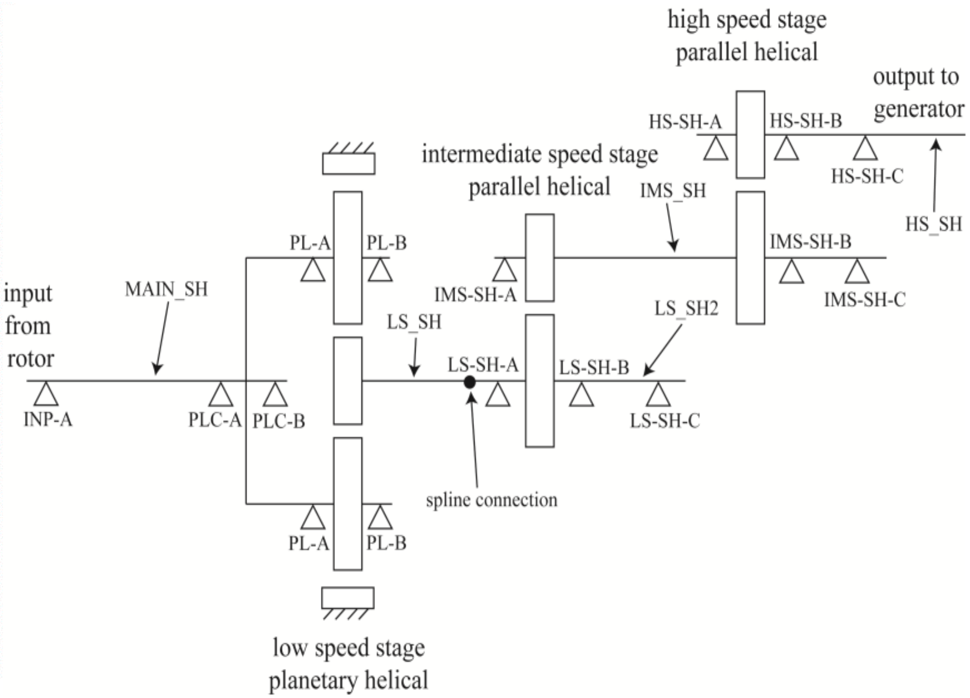


Load Duration Distribution (LDD) method is used for cycle counting [5].

Results

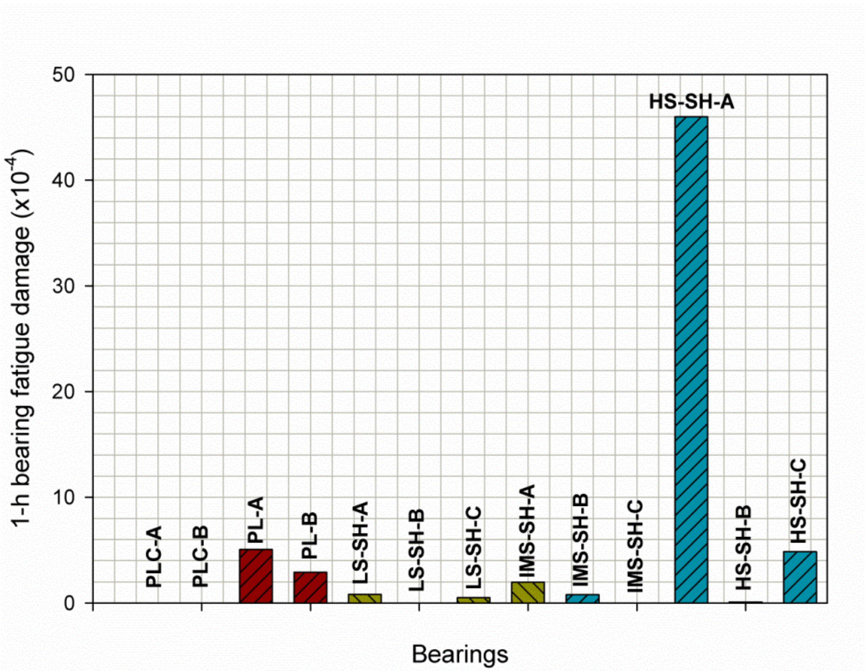
Gear Fatigue Damage (gear tooth root):

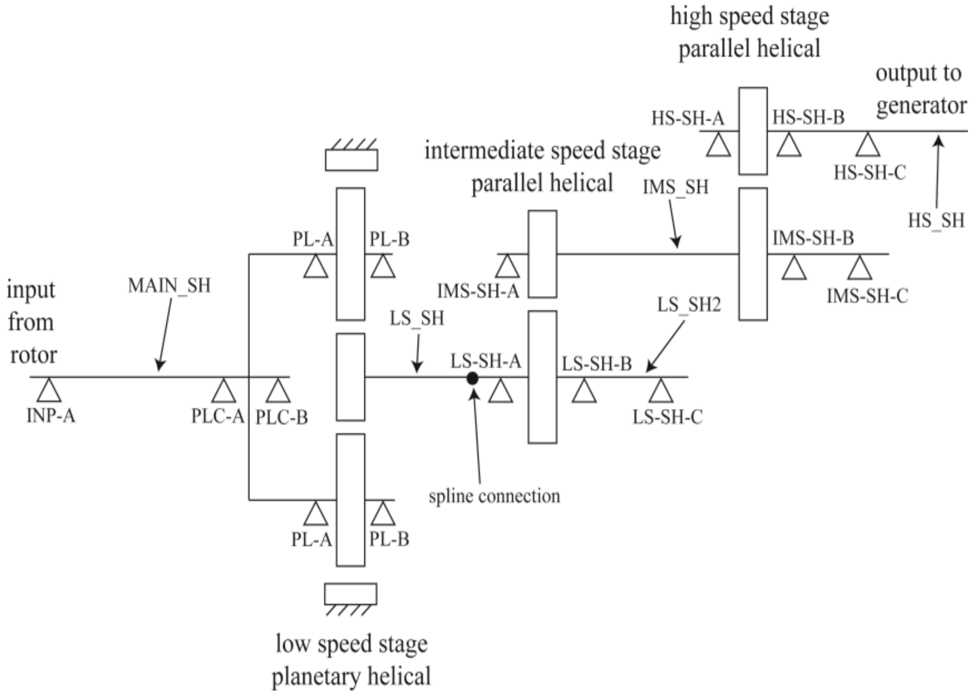




Results

Bearing Fatigue Damage:

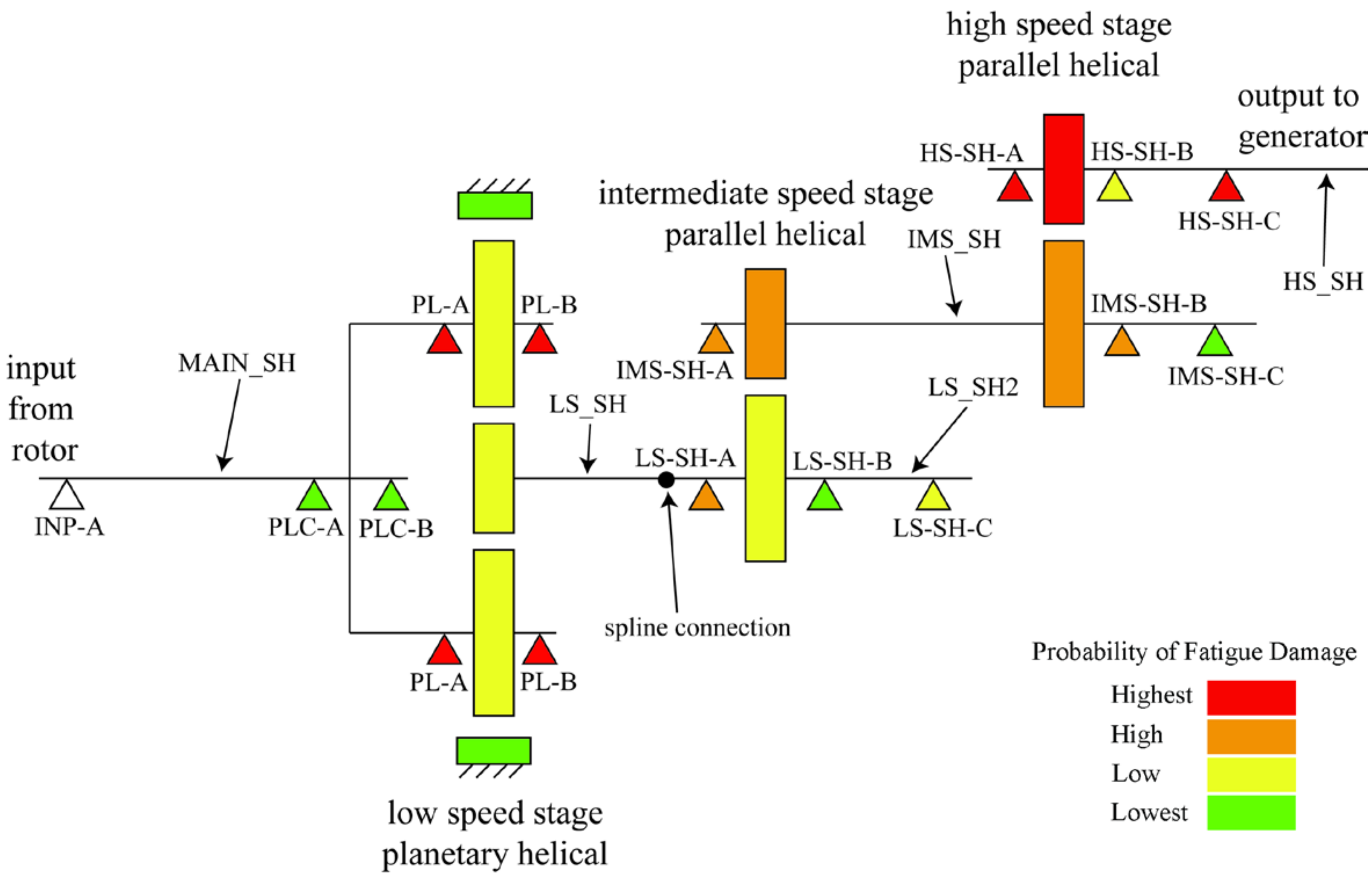




Results

Rank	Gear or Bearing	Name	*Damage* x 10^{-4}
1	Bearing	HS-SH-A	46.00
2	Gear	3^{rd} Pinion	6.423
3	Bearing	PL-A	5.064
4	Bearing	HS-SH-C	4.846
5	Bearing	PL-B	2.921
6	Bearing	IMS-SH-A	1.954
7	Gear	3^{rd} Gear	1.893
8	Bearing	LS-SH-A	0.812
9	Bearing	IMS-SH-B	0.777
10	Gear	2^{nd} Pinion	0.509
11	Bearing	LS-SH-C	0.507
12	Gear	1^{st} Sun Gear	0.241
13	Gear	2^{nd} Gear	0.171
14	Bearing	HS-SH-B	0.096
15	Gear	1^{st} Planet Gear	0.039
16	Bearing	IMS-SH-C	0.021
17	Bearing	LS-SH-B	0.020
18	Gear	1^{st} Ring Gear	0.004
19	Bearing	PLC-A	0.000
20	Bearing	PLC-B	0.000

Results



Vulnerability map of 750 kW NREL GRC gearbox

Results

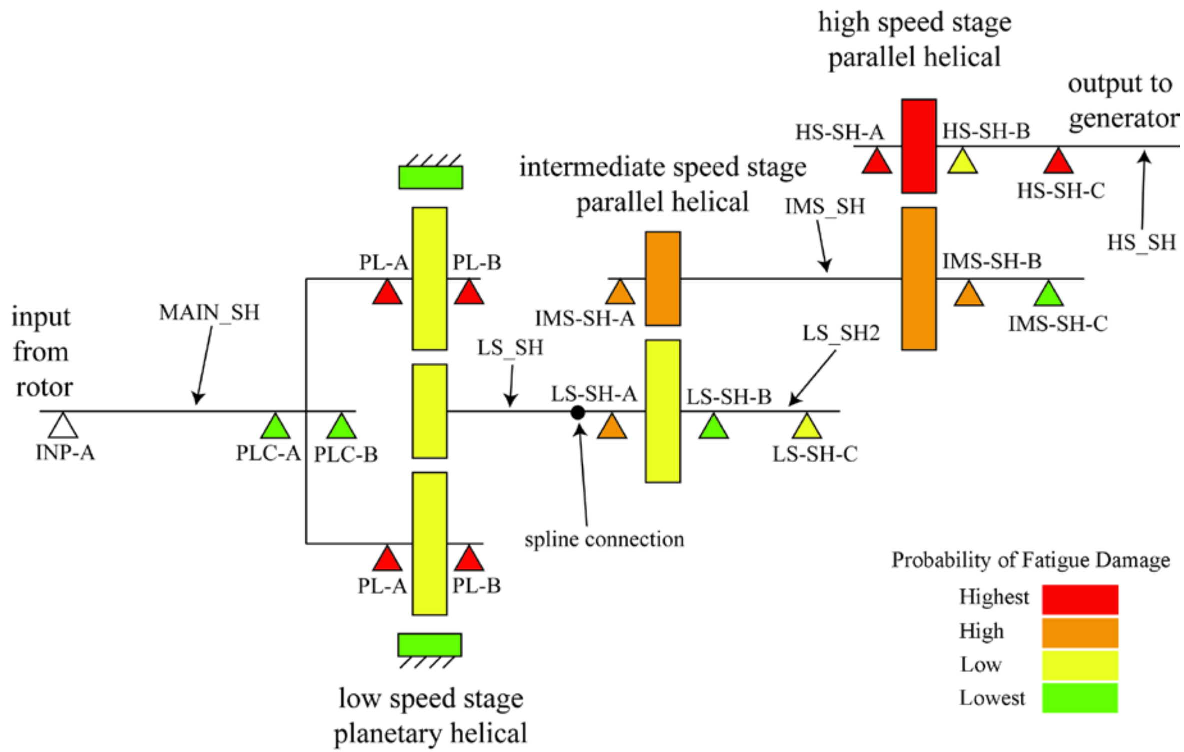
Good agreement with ReliaWind project [6,7]. Failure modes identifed through FMEA includes:

1)Planetary gear failure.

2)High speed shaft bearing failure.

3)Planetary bearing failure.

4)Intermediate shaft bearing failure.



Vulnerability map of 750 kW NREL GRC gearbox

Summary

- ✓ An inspection and maintenance planning map "vulnerability map" based on the fatigue damage of gears and bearings is presented.
- ✓ The procedure for calculating the short-term fatigue damage for gears and bearings is described and exemplified for the NREL GRC 750 kW gearbox.
- ✓ This maintenance map can be used for maintenance planning and inspection of components during routine preventive maintenance inspections.

Advantages:

- Reducing the maintenance time.
- Focusing on those with higher probability of failure.
- It can also be used for condition monitoring system, interpreting the field data and searching the source of problem within those with higher probability of damage.

References

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[7] Tavner P. Offshore wind turbine reliability, availability and maintenance. IET, 2012.

For more details, the reader is encouraged to review the paper associated with this presentation in “Energy Procedia”, June 2014.

Thank you for your attention!