Reliawind WP 2

Functional Block Diagrams Specifications

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January 21, 2008

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1. INTRODUCTION

1.1 Generality

This document is produced within the frame of RAM activities required for WP2 of “Reliawind Project”.

1.2 Scope

This document defines the Functional Block Diagram Specifications to be used by Reliawind Partners to create their Reliability Block Diagram at System and Subsystem level . For each identified function of the Wind turbine and its subsystems, a Reliability Block Diagrams (RBD) will be developed.

This document has to be considered as a useful guide for the following:

- **a.** to create the WTG RBD based on a System Functional Analysis;
- **b.** to create the WTG Subsystem RBD based on their functions;
- **c.** to define all Reliability and Maintainability Characteristics associated to each Block Diagram block and to be used for the System and Subsystem Reliability Assessment;
- **d.** to define standard templates to print out the results of all the reliability analysis performed during the WP2 reliability program.

1.3 Application

After approval by the Reliawind Consortium, this document shall form the basis for each Reliawind industrial partner to create single subsystems and component functional and reliability Models.

1.4 Abbreviations

A	Availability
CA	Criticality Analysis
Cm	Mode criticality number
CM	Corrective Maintenance
CMA	Corrective Maintenance Analysis
CMMS	Computerized Maintenance Management System
Cr	Item criticality number
FR	Failure Rate

FBD	Functional Block Diagram
FIT	Failures In Time
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode Effects and Critical Analysis
FRACAS	Failure Reporting Analysis and Corrective Action System
FT	Fault Tree
FTA	Fault Tree Analysis
LCC	Life Cycle Cost
LCN	Life Control Number
LRU	Line Replaceable Unit
LSA	Logistic Support Analysis
M	Maintainability
M&O	Maintenance and Operations
MDT	Mean Down Time
MP	Maintainability Program
MPA	Maintainability Plan Analysis
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
MTTR	Mean Time To Repair
MTTPM	Mean Time To Preventive Maintenance)
PHST	Packaging Handling Storage and Transportation
PM	Preventive Maintenance
PMA	Preventive Maintenance Analysis
PT&I	Predictive Testing and Inspection
R	Reliability
RAM	Reliability, Availability, Maintainability
TBD	To Be Defined
TQM	Total Quality Management
WTG	Wind Turbine Generator

2. APPLICABLE DOCUMENTS

2.1 Reliawind Documents

[1] FP7-ENERGY-2007-1-RTD	Reliability focused research on optimizing Wind Energy Systems design, operation and maintenance : Tools, proof of concepts, guidelines & methodologies for new generation
[2] 081023	Reliawind WP 2 Recovery Plan

[3] D.2.0.1 Common reliability analysis methods and procedures

2.2 Standards Documents

[4] MIL-STD-785B Not. 2 Reliability Program for Systems and Equipment Development and Production

[5] MIL-STD-721C Not. 1 Definition of Terms for Reliability and Maintainability

[6] MIL-STD-756B Not. 1 Reliability Modelling and Prediction

[7] MIL-HDBK-217F Not 2 Reliability Prediction of Electronic Equipment

[8] MIL-HDBK-472 Maintainability Prediction

[9] MIL-STD-1629 Procedures for Performing a Failure Modes, Effects and Criticality Analysis

[10] NSWC-07 Handbook of Reliability Prediction Procedures for Mechanical Equipment

[11] NPRD-95 Non electronic Parts Reliability Data 1995

3. FUNCTIONAL BLOCK DIAGRAMS SPECIFICATIONS

3.1 Operational Requirements and Constraints

The specified operational requirements and constraints provide the baseline against which a System proposed design must be compared. Customer requirements must be studied and all data relevant to reliability must be extracted. If there are any ambiguities or inconsistencies related to reliability, then these must be clarified with the appropriate authorities as soon as practicable so that time and effort is not wasted, and reliability modelling is based on an agreed interpretation of the System requirements. In particular:

- The purpose and functions of the system should be described. If a system has more than one functional mode of operation (e.g., an aircraft, a search and tracking radar, etc.), the requirements for each mode should be identified separately. Requirements for alternative modes (i.e., redundancy) or standby modes of operation should be highlighted.

- The main performance, safety, and physical characteristics should be listed in order of importance. Acceptable limits of satisfactory performance should be stated so that failure criteria can be established, and any acceptable performance degradation that still allows a limited operational capability should also be defined.

- Requirements for the specified reliability characteristics (reliability, Mean Time To Failure [MTTF],Mean Time To Repair [MTTR], Availability, failure rate, etc.) should be stated and quantified along with the time period, or other variable for which the requirement applies. If reliability requirements are specified individually for major sub-systems (rather than as an overall system requirement), the relevant data for each sub-system should be assembled accordingly.

- The specified conditions of use for the system (and sub-systems, if appropriate) should be stated, including operating states, environments, time intervals, maintenance policy, etc.

3.2 Wind Turbine Generator configurations

Two generic WTG configurations have been proposed by Gamesa and Ecotecnia to be considered within the Reliawind project :

The Reliawind R80

A pitch-regulated upwind wind turbine with an active yaw and a three-blades rotor. It represents the state of the art in current commercially available WTG's, with the following characteristics :

The R80 – 1,5 ÷ 2 MW has a rotor diameter of 80÷90 m with a generator rated at 1,5÷2 MW. The turbine utilizes the variable speed concepts. Power can be maintained even in high wind speeds, regardless of air temperature and air density, and the wind turbine is able to operate the rotor at variable speed. At low wind speeds the control system maximizes the power output by giving the optimal RPM and pitch angle.

Main Data	**50 Hz**	**60 Hz**
Nominal Power	1,5÷2 MW	1,5÷2 MW
Rotor diameter	80÷90 m	80÷90 m
Hub height	60÷100 m	60÷100 m
Rotational speed	10÷20 rpm	10÷20 rpm
Aerodynamic brakes	Full feathering	Full feathering
Number of blades	3	3
Class	IIA	IIA
Operating Temperature	-25 ÷ 40 ºC	-25 ÷ 40 ºC
Altitude	0 ÷ 1500 m	0 ÷ 1500 m

The Reliawind R100

A pitch-regulated upwind wind turbine with an active yaw and a three-blade rotor. It represents the future Gamesa and Ecotecnia WTG design, with the following characteristics :

Main Data	**50 Hz**	**60 Hz**
Nominal Power	3÷5 MW	3÷5MW
Rotor diameter	120÷130 m	120÷130 m
Hub height	100÷120 m	100÷120 m
Rotational speed	12÷14 rpm	12÷14 rpm
Aerodynamic brakes	Full feathering	Full feathering
Number of blades	3	3
Class	IIA	IIA
Operating Temperature	-20 ÷ 40 ºC	-20 ÷ 40 ºC
Altitude	0 ÷ 1500 m	0 ÷ 1500 m

As described in [2], these two WTG configurations will be used for the Reliability Prediction and the Reliability Block Diagram Analysis. From these two tasks we will get the input to influence new designs (R100) by determining whether built-in test or redundancy is needed.

3.3 Wind Turbine Functional Analysis

In general terms, a system is a combination of items that are interconnected with each other to perform a specific operational function or functions. At its highest level, a system may consist of a number of individual pieces of equipment, each designed to perform a particular function as a self-contained unit; alternatively, at the lowest level of assembly, a system may be a combination of individual electronic components and/or mechanical parts providing an input function to the next higher level of assembly.

The primary functions of a Wind Turbine are the following :

- ***To extract kinetic energy from the wind and to transform it into electrical energy***
- ***To transfer the electrical energy generated by the generator to the electrical grid.***
- ***To fulfill safely these tasks during its life remaining functional for 20 years considering dedicated and acceptable maintenance.***

These Primary Functions are realized with the following functional elements at subsystem assembly and sub assembly level :

Rotor Module

Pitch System

The function of the pitch system is to optimize the position of the blades based on the prevailing wind conditions to the optimum pitch angle. It is also the primary brake system on the wind turbine: the aero dynamical brake, powered by full-feathering blades. One of the following Pitch Systems can be used:

Electrical Pitch System

Each blade position is controlled by its own DC servodrive. The overriding Pitch control manages the position of the three blades and receives the position references from the wind turbine control system.
In emergency, the DC motors are fed by a battery supply system until a limit switch is reached

Hydraulic Pitch System

The pitch mechanism is placed in the hub. Changes of the blade pitch angle are made by hydraulic cylinders, which are able to rotate the blade from -5º to 90°. Every single blade has its own hydraulic pitch cylinder.
In case of hydraulic failure a pressure reservoir is mounted that stop the turbine by full-feathering of the rotor blades.

Hub

The hub is mounted onto the main shaft; it is used to transmit the wind power to the generator through the gearbox. The hub contains all the pitch mechanism.

Blades

Each blade consists of a load carrying spar cap integrated on the shells with two shear webs build separately. The blades are designed for optimised output and minimised noise and light reflection. Blade design should minimize the mechanical loads applied to the turbine

Each blade has a lightning protection system consisting of one or several lightning receptors on the blade. They also have draining points to avoid water accumulation inside the blade.

Blade Bearings

The blade bearing is a double raced 4-point ball bearing bolted to the blade hub. Each bearing has a sealed automatic lubrication system.

Hub Cover

The hub cover function is to protect the elements inside the hub, it is made of fibreglass.

Drive Train Module

The drive train transmits wind forces and torque from the rotor to the main shaft.

Main shaft

The main shaft is bolted to the hub in one end and to the gearbox in the other. With two bearing support.

Gearbox Assembly

The gearbox is a combination of a planetary stage followed by 2 parallel stages with a total ration of approximately 100 yielding an input speed of approx. 16 rpm and an output speed of approx. 1600 rpm

Mechanical Brake

This brake is hydraulically activated and is installed in the high speed shaft of the gearbox. The Mechanical brake works as emergency and parking brake:

- Emergency: when the turbine is running and one of the emergency buttons is activated, the Mechanical Brake supports the aerodynamic brake (full-feathering of the rotor blades).
- Parking brake: when rotor needs to be stopped for maintenance reason.

Nacelle Module

Yaw System

The system enables the nacelle to rotate on top of the tower into the upwind direction to maximise power production and minimise loads on the nacelle and untwist medium voltage cables when the nacelle turning is accumulated in one direction. The system transmits the forces from the turbine-rotor/nacelle to the tower through the yaw bearing. Four electrical yaw gears with motor brakes rotate the nacelle.
To restrict the nacelle movements the yaw system has five claw brakes with passive and active actuators moved hydraulically to lock the nacelle.

Nacelle Cover

The nacelle cover function is to protect the elements of the WTG, it is made of fibreglass. An opening in the floor provides access to the nacelle from the tower.
The roof section is equipped with several skylights which can be opened to get access the roof. Also the nacelle has several access doors to replace major components in the rear part and in the roof and inlets are located in the front and the top of the nacelle to reduce the inside temperature.
Heat exchanger, aviation lights and wind sensors are mounted on the nacelle roof. Different hoisting points should be considered for maintenance.

Nacelle Bedplate

The bedplate is made of two parts.

- The front part contains the drive train module and the yaw system.
- The rear part supports the nacelle cover and the service crane and contains the auxiliary equipments.

Structural Module

Tower

The tower is a steel tower conical tubular construction with an internal, safety cable (rail blocks), ladder and service lift.
The tower has modular construction and is split in several parts bolted together. Hub height is 60÷100 m

Foundations

The foundation can vary in accordance with the terrain characteristics and wind conditions of every site.

Power Module

Generator Assembly

The generator is a doubly - fed induction type with rated power 1.5 - 2.0 MW, 50 Hz, three phase with four poles, 690 V ac on the stator winding. The rotor winding is supplied via a three phase brush and slip ring assembly from the converter. The stator windings have no phase shift. The generator has a nominal rotation speed in the area of 1600 RPM. The generator is air-cooled, work temperature = 50 ºC.
Overvoltage or undervoltage protection: ± 10 %
Power factor range: 0.95 CAP – 0.95 IND.

Converter

The converter is connected between the generator rotor and the grid, and it is a 4 quadrant converter with IGBT generator-side and grid-side inverters converter with an active crowbar unit on the generator-side to ensure the compliance with Grid Code requirements. The grid-side and generator-side inverters are IGBT based and linked by a capacitor bank DC link. Filters are provided in the grid-side inverter to reduce harmonic content, and in the generator-side to reduce dv/dt . The converter is liquid air-cooled and supplied by the nacelle cooling system. The converter is located in the rear part of the nacelle.

Transformer

The step up transformer is rated at 1.5-2.3 MVA, 50 Hz, 690V/6kV-31.5kV depending on the grid connection and is located in the nacelle. The transformer is a three phase dry-type cast resin transformer and air cooled. The output voltages available are from 6 to 31.5 kV. The transformer's compartment is equipped with arc detection, temperature sensors and other protection systems.

Switchgear

The function of the switchgears is to switch the wind farm network and to protect the WTG from possible electrical failures.
The ratings are up to 36kV, 50 or 60 Hz depending of the grid connection. The switchgear consists of a complete sealed system where all live parts and switching functions are in constant atmospheric conditions. Switchgear is classified as per IEC 62271-200. Pressure absorber or arc killer device is integrated in the switchgear.
The Switchgear is installed inside the tower at ground level or integrated in compact substations. The complete switchgear is suitable for indoor installations.

Control & Communication System

The control system consists of algorithms and hardware for regulation and supervision of the turbine and generator. The function of this system is to control the pitch, the yaw and generator excitation to maximize the power output for any wind condition, minimizing loads in the WTG and guarantee the WTG protection on emergency and fault conditions.

Monitoring System

This system monitors the WTG main components from maintenance point of view. It detects and processes alarms and provides remote access to system data.

Auxiliary Equipment

Electrical Cabinets

All the different cabinets to contain the converters, the electrical distribution system, and other electric and electronic components not included in other systems.

Hydraulic System

A Hydraulic Power Units provides pressure for the pitch, the yaw and the mechanical brake and the rotor locking mechanism, so the common components to these systems are included in the hydraulic system. In case of grid or system failure backup accumulators provide sufficient pressure to full-feather the blades and stop the turbine. The system can be heated or cooled for extreme weather conditions.

Cooling System

There are two cooling system:

- Air-cooled
- Water-cooled

The air-cooled system regulates the nacelle temperature through several inlets located in the front and the top of the nacelle. Air is blown outside by fans.
Gearbox and hydraulic system use water/oil/air Heat Exchange Units located on the roof of the nacelle.

Lightning Protection System

The Lightning Protection System protects the turbine against damage from lightning strikes. The system prevents the blades and the nacelle, including bearings, gearbox, generators, control systems, auxiliaries and monitoring equipment, from damage by the lightning currents.

Service Crane

The nacelle houses the internal 1 Ton service crane.

WTG Meteorological Station

Include all the sensors that provide information about meteorological conditions. Primarily temperature, wind speed and direction.

Wind Farm System

The WTG monitoring signals are integrated into a Supervision, Control and Data Acquisition system (SCADA), which allows users to access the wind farm.
The Wind Farm System (WFS) must be easily configurable and adaptable to any wind farm distribution configuration, even those with a large variety of wind turbine models. It should be capable of communicating quickly and reliably with any wind farm topology based on modern Ethernet network technologies. It also allows the integration of wind farm installations like electrical substations, reactive power equipment, capacitor banks and more.

The SCADA system supports a wide variety of communication protocols used in WFS, such as OPC DA, MODBUS and DNP3.
The WFS includes the following overall functions:

- **Monitoring**
- Measurement monitoring
- Equipment status monitoring
- Alarm status monitoring
- Integrated predictive functions

- **Control**
- Wind turbine start-up / stop / pause / test orders
- Switch opening / closing orders
- Optional functions for active power control
- Optional functions for reactive power control

- **Data collection**
- Databases for alarms, notices, events, measurements, wind turbine statuses, etc.
- Database filtering and storage in historical files

- **Reports**
- Historical record of values stored in a MS-SQL database
- Increased data analysis and report generation functions from the management offices
- Integration with the client's own system by means of ODBC/ADO
- Ability to use any report application that works with ODBC/ADO
- Ability to use any data analysis tool that works with ODBC/ADO

- **Management and security**
- Alarm management functions
- Advanced, flexible alarm and event filtering
- Access and security control based on MS Windows systems
- User management based on MS Windows systems

- **Configuration**
- Adapts to the wind farm infrastructure based on templates
- Easy integration of any equipment used at the wind farm

4. WTG Reliability Block Diagrams

An RBD (Reliability Block Diagram) is a visual representation of the portions of the system to be modeled. Since reliability predictions assume that all components in a system are in series, they cannot be used to analyze a system with redundant components. RBDs are used to evaluate the reliability of systems that are complex in their configurations. RBDs also provide an efficient and effective way to compare various configurations to find the best overall system design.

The model used for a System Reliability Analysis will require a large number of Reliability Block Diagrams (RBDs) to describe the System, the System functions and its operating states.

The goal of reliability block diagrams is the determination of almost all reliability and maintainability metrics of a complete system, like:

Reliability

Availability

Failure rate

MTTR (mean time to repair)

These values are calculated taking into account the operative configuration of the system including redundancies. The first step is to develop an RBD at system level as follows:

- Specify the functions of the system and the operating states (e.g., standby, full power, etc.) by reference to the data assembled during System Definition;
- Specify the minimum requirements for the system to operate successfully in terms of the functions of the system;
- Draw a system RBD in terms of the system functions;
- Specify the sub-systems that are required to perform the system functions;
- Draw a system RBD in terms of the sub-systems and simplify as necessary.

Once an RBD has been constructed to show the reliability dependencies at the system level, a similar procedure should be followed to construct RBDs for each sub-system at successive levels of assembly down to the level at which reliabilities, or failure rates, can be estimated from the component/part data.

This process is illustrated in the following Figure 4.1 :

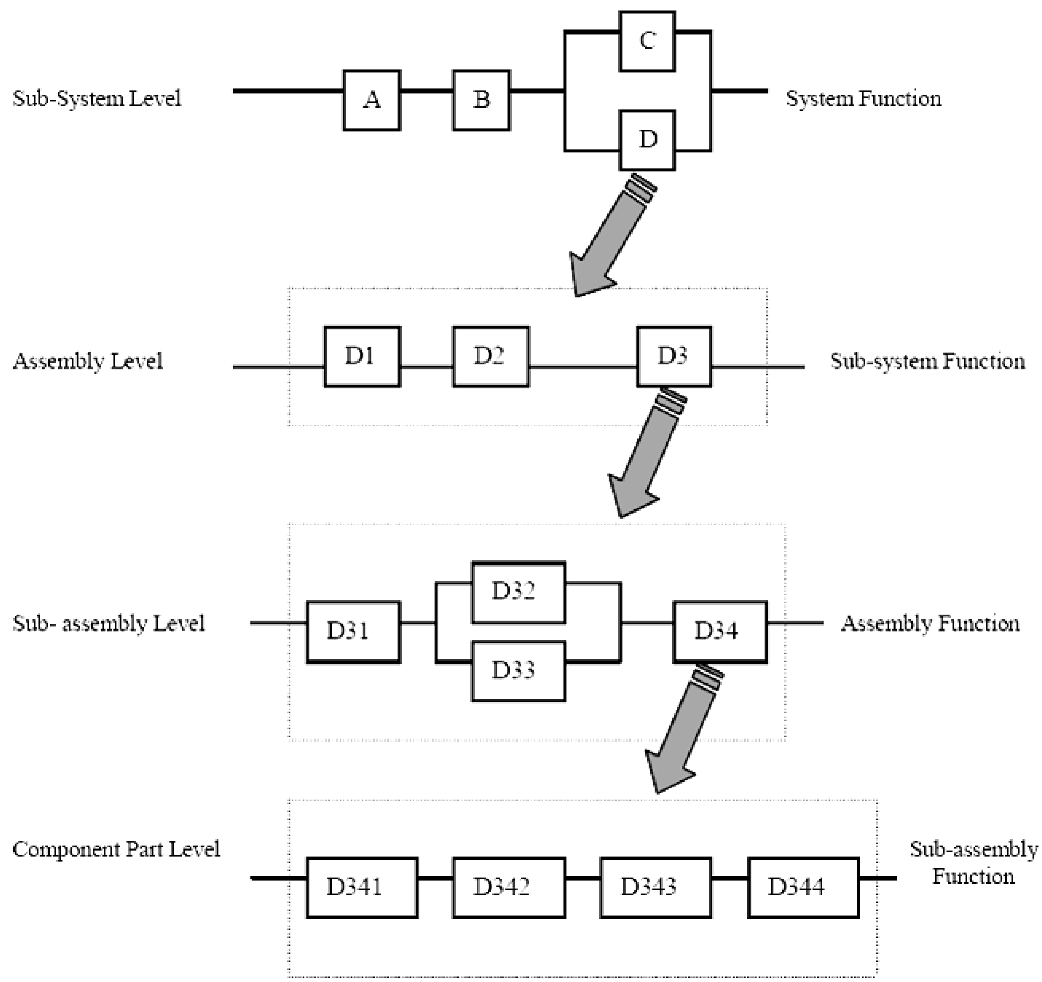


Figure 4.1 Development of Reliability Block Diagrams Within a System

The following points should be noted when constructing RBDs at system, sub-system, and lower assembly levels:

- More than one RBD may be necessary to depict different operational objectives or alternative functional modes.
- Elements of an RBD should contain only items that have the same operational duty cycle.
- When constructed to its lowest level, the blocks comprising an RBD should contain only series equivalent elements, or have known reliability characteristics established from previous analysis.
- When functional relationships between elements cannot be represented by straightforward series, active redundant or standby redundant configurations, the group of elements concerned must be isolated and highlighted for special consideration. In general, reliability evaluation of such groups can be made using Bayes Theorem.

Each Reliability Block Diagram is made up by connection of several figures (blocks) and each figure is characterize by :

- o The General information (Name, Part Number, Reference Designator, Description .)
- o The Failure rate and the failure distribution.
- o The total number of units present in the system
- o The type of redundancy. Choices are:
  - Series.
  - Parallel Operating.
  - Standby.
- o The corrective maintenance or repair information.

After failure and repair data have been specified for the figures in the RBD, sophisticated mathematical algorithms or a Monte Carlo simulation engine are used to calculate many different reliability measures, including failure rate, MTBF, reliability, availability, and more.

The following table describes all of the Relex results that can appear on the Calculation Results page for each figure.

The results that do actually appear depend on the selections made on the RBD page in the Calculate property sheet prior to performing RBD calculations.

Time	The time at which the calculated results display.
Reliability	The reliability of the figure at each time point.

Unreliability	The unreliability of the figure at each time point.
Availability	The availability of the figure at each time point.
Unavailability	The unavailability of the figure at each time point.
Mean Availability	The average availability of the figure at each time interval.
Mean Unavailability	The average unavailability of the figure at each time interval.
Failure Frequency	The frequency of failures expected during each time interval.
Total Downtime	The cumulative downtime expected during each time interval.
Expected Number of Failures	The number of times the component is expected to fail during each time interval.

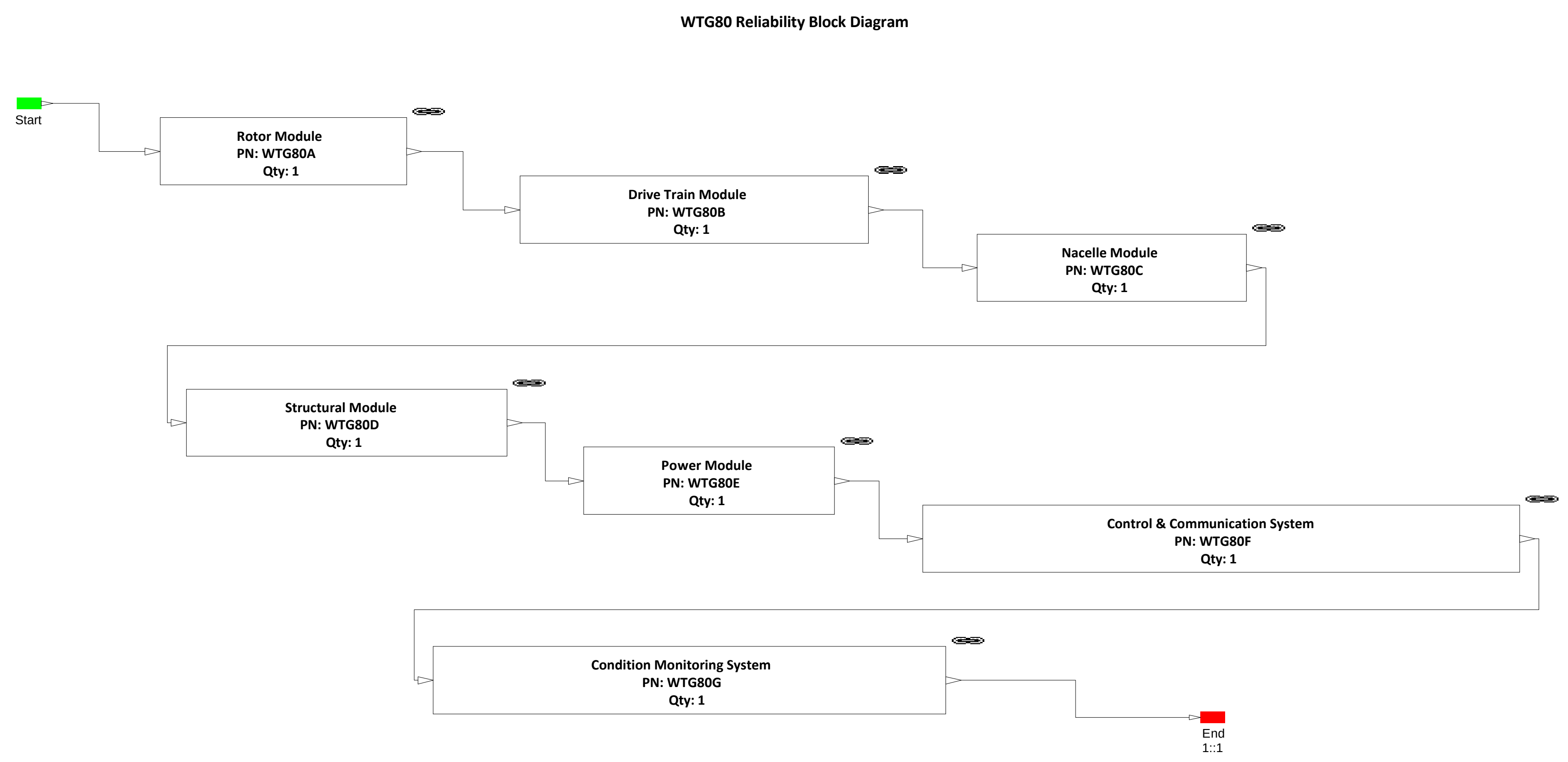
Table 4.1 Relex RBD Calculation Results Page

In Appendix A the WTG80 Reliability Block Diagram and an example of a Relex RBD Calculations template are given.

The Reliability Block Diagram reported in Appendix A is included in the Relex Project delivered to the Reliawind Partners together with D.2.0.3 Deliverable “WTG Reliability Model Specification”.

Appendix A - WTG Reliability Block Diagram

File Name: WTG.rfp



Print Date: 03/01/2009

Print Time: 18.58

RBD
Calculation Results

File Name: WTG.rfp
RBD Name: RBD1
Calc Method: Analytical
MTBF (hrs): 68.342.793
MTTF (hrs): 68.342.793

Results at Time (hrs): 8760
Reliability: 0,999872
Availability: 1,000000
No. of Failures: 0,00
Total Downtime: 0,00

Time	Reliability	Unreliability	Availability	Unavailability	Failure Rate	Number of Failures	Total Downtime
0	1,000000	0,000000	1,000000	0,000000	0,014632	0,000000	0,000000
730	0,999989	0,000011	1,000000	0,000000	0,014632	0,000011	0,000000
1460	0,999979	0,000021	1,000000	0,000000	0,014632	0,000021	0,000000
2190	0,999968	0,000032	1,000000	0,000000	0,014632	0,000032	0,000000
2920	0,999957	0,000043	1,000000	0,000000	0,014632	0,000043	0,000000
3650	0,999947	0,000053	1,000000	0,000000	0,014632	0,000053	0,000000
4380	0,999936	0,000064	1,000000	0,000000	0,014632	0,000064	0,000000
5110	0,999925	0,000075	1,000000	0,000000	0,014632	0,000075	0,000000
5840	0,999915	0,000085	1,000000	0,000000	0,014632	0,000085	0,000000
6570	0,999904	0,000096	1,000000	0,000000	0,014632	0,000096	0,000000
7300	0,999893	0,000107	1,000000	0,000000	0,014632	0,000107	0,000000
8030	0,999883	0,000117	1,000000	0,000000	0,014632	0,000117	0,000000
8760	0,999872	0,000128	1,000000	0,000000	0,014632	0,000128	0,000000

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