A SMART Software Package for Maintenance Optimisation of Offshore Wind Turbines

Yashwant Sinha[1]*, John A Steel[1], Jesse A Andrawus[1], Karen Gibson[2]
[1]School of Engineering, Robert Gordon University, UK
[2]Stork Technical Services, Aberdeen, UK
***Communicating Author**: y.sinha@rgu.ac.uk

Abstract

Offshore Wind Turbine (OWT) maintenance costs in between 20 - 35% of the lifetime power generation cost. Many techniques and tools that are being developed to curtail this cost are challenged by the stochastic climatic conditions of offshore location and the wind energy market. A generic and OWT centric software packages that can smartly adapt to the requirement of any offshore wind farm and optimise its maintenance, logistics and spares-holding while giving due consideration to offshore climate and market conditions will enable OWT operators to centralise their operation and maintenance planning and make significant cost reductions. This work aims to introduce the idea of a comprehensive tool that can meet the above objectives, and give examples of data and functions required. The package uses wind turbine condition monitoring data to anticipate component failure and proposes a time and maintenance implementation strategies that is developed as per the requirements of HSE and government regulations for working in the offshore locations and at heights. The software database contains key failure analysis data that will be an invaluable asset for future researchers, turbine manufacturers and operators, that will optimise OWT power generation cost and better understand OWT working. The work also lists some prevalent tools and techniques developed by industries and researchers for the wind industry.

Keywords: *Offshore Wind Turbine, operation and maintenance, optimisation, software tool, knowledge base, maintenance database, standardised maintenance procedure*

1. INTRODUCTION

Worldwide installations of Wind Turbines have grown from 7.6 GW in 1997 to 282.58 GW by the end of 2012 [1,2,26] however operation and maintenance (O&M) cost of Onshore Wind Turbines (OnWTs) and Offshore Wind Turbines (OWTs) are still very high at 15% and 20-35% of their lifetime power generation cost respectively [3]. Many techniques have been advocated to economise O&M of wind turbines however the challenges faced by this industry are novel as regularly new methods to solve problems are being developed. Some techniques used to economise O&M of wind turbines are: Performance and Maintenance Risk Assessment [4], assessment of failure using databases like WMEP, LWK and Wind-Stats newsletters [5], cut cutting on insurance, maintenance, repair, spares and administrative [6], reducuction in the repair and spare parts costs [7], use of Condition Based Maintenance (CBM) [8,9], and by customising techniques used in other industries as illustrated by people, like Sorensen (Risk Based Inspection (RBI)) [10], Durstewitz (Mote Carlo Simulation) [11], Andrawus (Modelling System Failure Technique (MSFT) & Delay Time Model (DTM)) (Andrawus, 2008), Wilkinson (Failure Mode and Effect Analysis (FMEA)) [12] and by Tian (Artificial Neural Network (ANN)) [13]. Studies now make use of various types of sensors / actuators [14], generator current [15], SCADA systems [16] and electrical signals [17] to anticipate WT unit failure in an attempt to curtail costs. Some tools, like CONTOFAX[18] and ECN Model[19], have also been developed to assist in maintenance planning and economise power generation cost, however there is a need for a technique as well as a commercial tool that can smartly adapt to any stochastic offshore condition and dynamic market conditions. This work aims to define the requirements and associated guidelines for developing a technique and a commercial tool for optimisation of OWT maintenance.

2. Requirements for OWT maintenance tool

This section provides a list of dynamic linkages to and requirements of an Offshore Wind Turbine Software Package (OWTSP) that will assist in referencing up-to-date information and reliably generate reports using current information. This includes:

- *Status of Wind Turbine Units and their Failures (if observed or anticipated)*
- *Manuals for Wind Turbine and their units servicing, installation and overhauling*
- *List of Industry Standards, HSE Guidelines, Government Regulations and Standard Practices*
- *The flexibility of choosing a maintenance regime from Time Based Maintenance, Failure Based Maintenance and Condition Based Maintenance*
- *Status of spares in inventory, in transit and ordered*
- *Resource availability including* skilled & unskilled manpower, tools, instruments, support staff & vessel
- *Administrative and financial aspects, such as current* costs, budget estimation, authorization / approval, maintenance plan approval, HSE approval, etc.
- *Live data from tracking Wind Turbine units and their operational status*
- *Automated Analysis of Live Data*
- *High System Availability using server clustering or RAID implementation*[25]
- *Data Security - User authorisation and authentication, local and remote data backup*
- *Reliable Hardware and Software Requirements*
- *Highly Interactive User Interface – Web interface*
- *Sensors / Adaptors and suitable choice of suitable programming and database softwares – have used* C# programming language and SQL / MS Access database

Amongst the major advantages of this tool will be the automation of SCADA data analysis over long time periods, which if done manually is voluminous and prone to error. A SCADA system generates a set of data streams, typically over 50 distinct data elements at 5 or 10 minute interval that conveys information about the health of wind turbine units and its surrounding meteorological conditions, such as wind speed, wind direction etc. [20]. A Wind Farm that contains 50 WTs and have 40% availability / year will generate 720,000 data elements per day or over 2 billion data elements during its 20 year life span, a volume that is difficult to analyse and interpret. Hence such a tool will be an asset that would save time and resources for data analysis.

3. A MAINTENANCE DECISION MODEL

A maintenance decision model is designed to check the need for maintenance in WT units. The model proposed here aims to answer five key questions (Figure 1). This model queries maintenance planners in relation to Availability, Safety, Productivity, Reliability and Presence of any Upgrade Technology for WT units. The succession of questions has been sequenced in the model based on the logical significance. A WT unit is first checked for its availability to determine its working condition and if the unit is found unavailable a decision is taken to service the unit. If a unit is available, it is checked for operational safety, as mitigation of unsafe operating conditions is required in accordance to HSE regulation for personal working with rotating or heavy machinery. The units are then checked for productivity and reliability, as high production is obtained from reliable units. If the answer to any of the questions is NO, then there is a need for service maintenance. If an upgrade technology can enhance either the availability, safety, productivity and/or reliability of any WT unit and it is also cost effective, then such an upgrade should be implemented by performing service / maintenance.

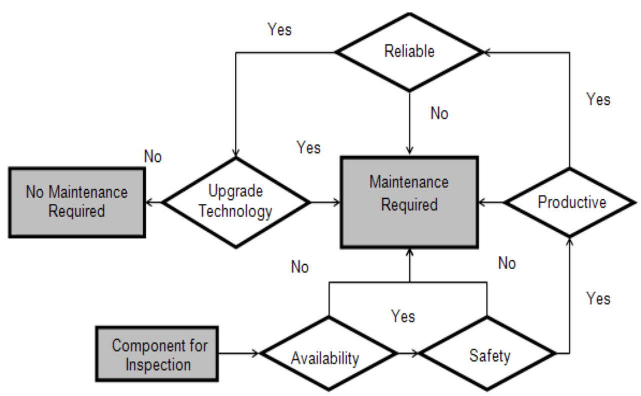

Figure 1 A Maintenance Decision model to check the need for maintenance implementation

As an example, consider a WT gearbox which is diagnosed with failure in its shaft bearing. If this unit is non-operational (unavailable), there will be a need for maintenance, however if this unit is still operational it poses danger (safety) of further destruction as well as threat to other operational units inside the WT, hence requiring maintenance. If the magnitude of failure is less but reduces productivity in WT, there is a need for maintenance. However if at the present time the shaft bearing is functioning well but its condition monitoring suggests impending failure, i.e. a drop in its reliability, there will be a requirement for maintenance, even if it is planned for a later time. If an enhanced model of shaft bearing becomes available in the market that promises to enhance its operational hours and reduce failure, then a cost benefit calculation can easily determine if use of this technology is justified in the WT.

However the model, given in Figure 1, is generic and the above representation has been customised for application in the WT. The sequence of such questions can be altered depending upon circumstances such as for a standby failsafe system, the question about reliability would precede the questions about safety. This model is used in the algorithm of the software.

4. FINANCIALLY CRITICAL COMPONENTS

WT units fail due to various reasons including errors during installation, natural causes, aging of units, stress fluctuation, temperature variation, corrosion, etc.. However some typical unit failures and their reasons are: Failure in main shaft - due to parallel / angular or combined misalignments, unbalanced loads; Failure in blades - due to local buckling, fibre / matrix / inter-laminar failure, fatigue, lightening, crack, loose blade hub joint etc.; Failure in gearboxes - due to failure in lubrication, gear / bearing seizure, wear and tear, pitting or broken gears etc.; Failure in cables - due to open or short circuiting, etc. Wind Turbines operate in stochastic weather conditions which may or maynot be simulated and studied in laboratory conditions, such as test for parallel misalignment using vibration analysis of rotor inside a stator; uniaxial and three axes loadings; mass eccentricity and bearing stiffness [21], etc. Hence a typical maintenance tool requires data obtained from an active operational WT from which actual WT unit failure patterns can be studied. However obtaining wind turbine failure data is not easy and hence a detailed study of different reports pertaining to wind turbine unit failures was done and a database compiled. In particular importance has been paid to identify WT units that are costly to repair/replace, critical to WT operation and which fail more often when compared to other units. These units have been classed as Financially Critical Components (FCC) for a WT.

In one report it was found that the pitch system, frequency converter, yaw system, control system, generator assembly and gearbox assembly contributed towards 16%, 12%, 12%, 14%, 6% and 5% of total failure instances observed in WTs of a Wind Farm (Andrawus, 2008). In another report it was found that blade, generator, gearbox, electrical system and yaw system contributed towards 34%, 32%, 21%, 5% and 2% of all the failure instances observed in WTs of another Wind Farm [22]. In yet another study electrical system, rotor, converter, generator, hydraulics system and gearbox [23] were found to be the major contributors of failure in WT and similar results were obtained by other studies [24,25]. However all these observations were taken for different wind farms that operated under varied weather and operating condition, and hence such results cannot be generalised for all WT.

Mathematical Set Theory was used to find a generalised list of FCC units in WTs using all of the above studies. This list contains those costly units which can fail under different operating conditions. The results of these studies were put into three sets: S1, S2 and S3. Union and intersection of these sets provide two sets, one set (S4) shows WT units that are critical and can fail under any condition, and second set (S5) contains a comprehensive list of all components which can fail under different conditions.

S1: {Pitch System, Frequency Converter, Yaw System, Control System, Generator, Gearbox}

S2: {Blade, Generator, Gearbox, Electrical System and Yaw System}

S3: {Electrical System, Rotor, Frequency Converter, Generator, Hydraulic System, Gearbox}

Intersection of above sets

S4 = S1 ∩ S2 ∩ S3 = {Gearbox, Generator}

Union of above sets

S5 = S1 U S2 U S3 = {Blade, Electrical System, Generator, Gearbox, Yaw System, Pitch System, Frequency Converter, Control System, Rotor, Hydraulics System}

The purpose of determining these FCC was to focus the scope of current work and to build an OWTSP system centered around Set 4 FCC, which can be expanded to include Set 5 WT units and other remaining WT units at a later time.

5. CODE CONVENTION

A WT units' hierarchical coding convention is proposed and used to identify subsystems, assemblies, sub-assemblies and components identified inside a generic WT by the EU FP7 ReliaWind Consortium.

Table 1 Representative list of WT Units and proposed Codes

Sub System	Assembly	Sub Assembly	Component	G_CODE
Electrical Module	Frequency Converter	Converter Auxiliaries	-	FCC
Electrical Module	Frequency Converter	Converter Auxiliaries	Vibration Switch	FCCV
Electrical Module	Frequency Converter	Converter Auxiliaries	Watch Dog Switch	FCCW
Drive Train Module	Gearbox	Bearing	Carrier Bearing	GEBC
Drive Train Module	Gearbox	Bearing	Planet Bearing	GEBP
Drive Train Module	Gearbox	Bearing	Shaft Bearing	GEBS

The naming has been done to enable easy identification of WT units while analysing failure and performing maintenance. A representative list of this naming convention is given in Table 1. In this work more than 250 WT units have been identified in a generic WT and have been allocated unique codes.

6. GESTIONE - A OWTSP for Optimising OWT O&M

GESTIONE uses the concept of Bayesian Network, Artificial Neural Network and FMECA procedure in its coded algorithm to optimise the OWT O&M. In its present form it accepts input parameters from condition monitoring data and generates a detailed output to report about a proposed date for next maintenance, resource needs, lists associated rules and regulations governing service maintenance and provides a list of recommended steps to execute the maintenance plan. This software package is being built based on a framework as shown in Figure 2 where a knowledge database is created with historical maintenance records of WT units and weather condition, HSE, Inventory, staff and equipment records, SCADA data, customer and vendor record, amongst others. An active learning mechanism is also developed to improve the knowledge base of the system. The software part of GESTIONE contains a smart algorithm that quantifies the service request with a unique ID and generates a work order and a work agent that collects all the necessary information for closing the service request and reporting.

GESTIONE is in development however in its present form it can display some of its data from its database. Amongst other capabilities, the tool is able to process SCADA data and represent result in different fields (Figure 3). It also shows results of FMEA analysis of WT units, like the one shown in Figure 4 for WT brakes. It also shows the proposed component codes for WT units (Figure 5) amongst many other capabilities. It can also correlate WT failure mode to the nature, type, components affected by the failure and recommended maintenance plan. It stores links to various service and installation guides for various WT units, provides reference to HSE rules and industry maintenance standard

7. DEVELOPMENT STRATEGY

This paper has outlined the broad overall requirements for a software package to optimise O&M of OWT. The overall objectives were subdivided into modules as listed in the Section 2, and future developments will aim to include new features as appropriate to make this package as comprehensive as possible.

8. CONCLUSION

OWT is a progressive industry that requires curtailment in its operational expenses to reduce the high cost of power generation. There is a need for a dedicated and comprehensive software package that can optimise the OWT O&M as it will also assist in improving administration, monitoring and troubleshooting of OWTs. This work has highlighted the importance and main functionalities of such a tool. It also provided evidence of some preliminary results obtained from the development of such a software package. Upon completion this tool will assist planners in maximising their profits and researchers can better study OWT operation, causes of failure and maintenance.

9. ACKNOWLEDGEMENT

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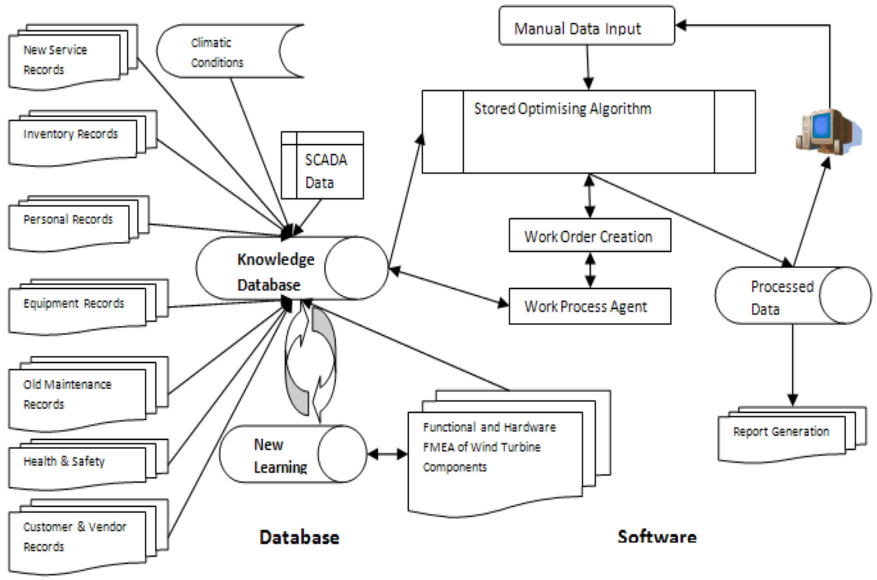

Figure 2 A Design Framework of GESTIONE

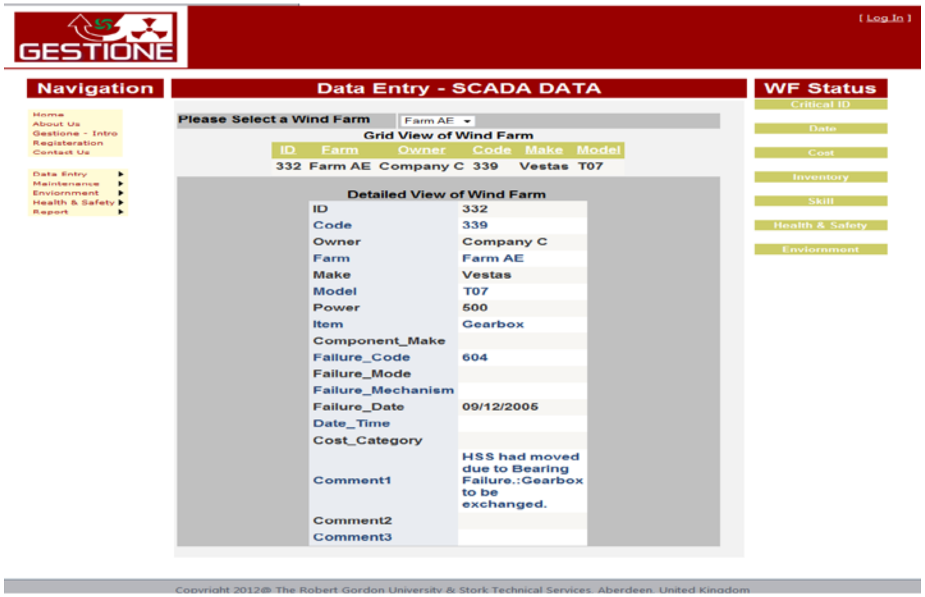

Figure 3 Processed SCADA data entries for a Wind Farm

Figure 4 Example FMEA data for Mechanical Brakes

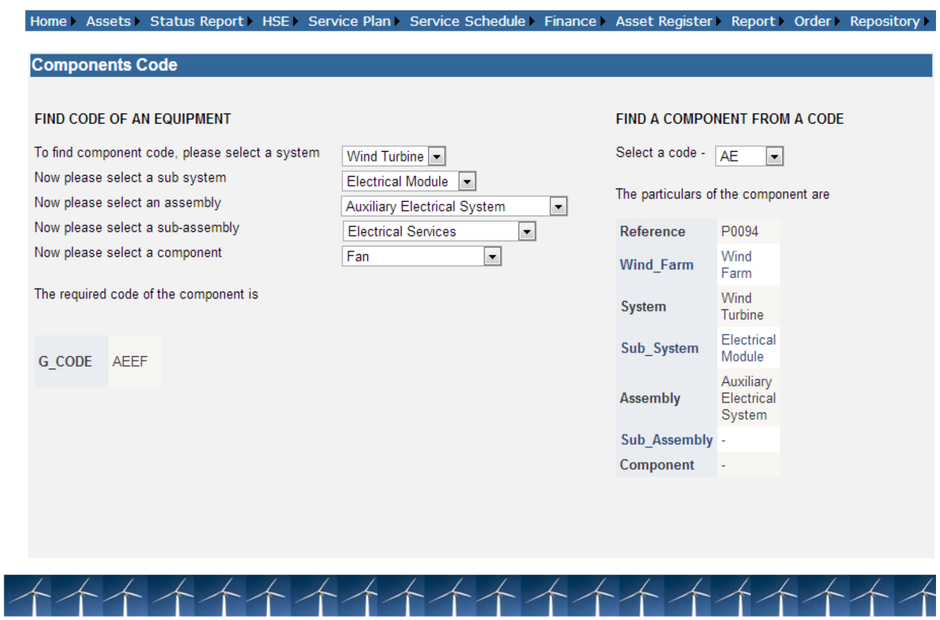

Figure 5 Example of component coding

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