Evaluation of Condition Monitoring and Operational Management for Wind Power Plant

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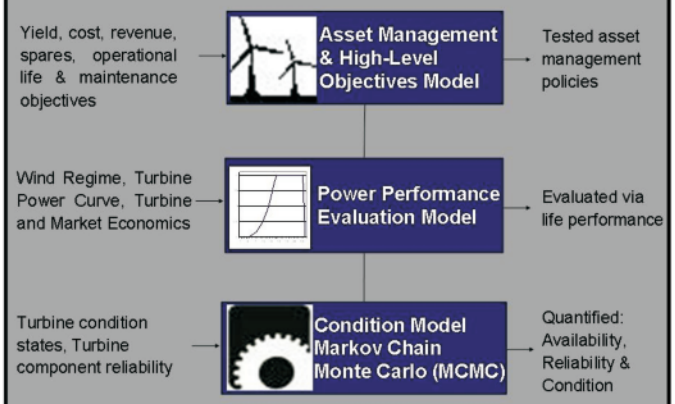
The recent rapid construction of wind farm capacity in the UK has resulted in widespread installation of Condition Monitoring (CM) systems for wind turbines. Effective use of these systems is moving up the agenda, as wind farm operators seek to maximise their operational efficiency. As the number of operational wind farms is likely to increase in future years, more focus will be placed on this issue. A quantitative measure of the benefits such CM systems deliver may therefore be of value to utilities and O&M groups involved in planning and operating wind farm installations.

Modelling Methodology

In order to represent the wind turbine physical deterioration, power performance and effects of high-level management policies based on condition monitoring, several facets of modelling are required. In the figure below, the hierarchical structure of the model is illustrated and description of the model content is provided.

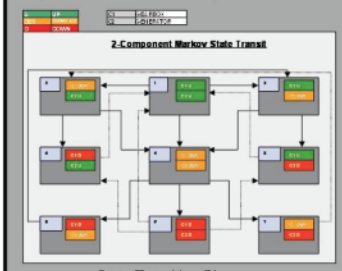


At the lowest level, the wind turbine sub-components are modelled by Markov Chain Monte Carlo. The status of the components acts as an input to both the power performance model and the high-level management model. Through adjustment of the model inputs, different operational scenarios can ultimately be evaluated. These may include different types of monitoring, or different maintenance strategies.

MCMC for Evaluation of CM Systems

To facilitate modelling of a wind turbine as a deteriorating system, initial studies used discrete-time stationary Markov Chain Monte Carlo simulations. The probabilistic nature of this method implies that future uncertainties can be taken account of. MCMC has proved effective in modelling of other infrastructure, and interface between the Markov model and other model facets (such as performance characteristic) is simple. Importantly, this method can model a CM system through implied knowledge of the system state.

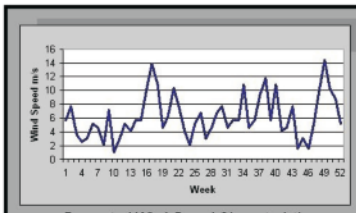
The prototype model illustrated below is a dual component repairable system. On the basis of a utilities' operating experience, the gearbox and generator were identified as the two least reliable wind turbine sub-components. Therefore the prototype system models the wind turbine dependent on these two components.



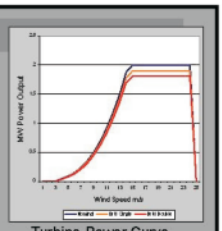
FROM	TO	EXISTS?	Value
1	1	YES	0.984684
1	2	YES	0.012432
1	3	YES	0.0028485
1	4	YES	0.00003541255
1	5	NO	0
1	6	NO	0
1	7	NO	0
1	8	NO	0
1	9	NO	0
		TOTAL	1.0000000

Source: University of Delft

State Transition Diagram

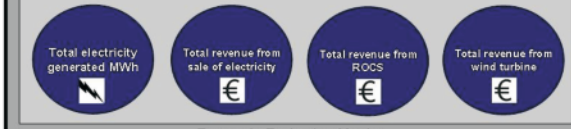


Generated Wind Speed Characteristic



Turbine Power Curve

The simulation generates wind turbine power output based on a fusion of stochastic wind variability, turbine power curve characteristic, and equipment deterioration status. The total revenue is calculated based on electricity generated, cost of component replacement and fixed O&M cost.

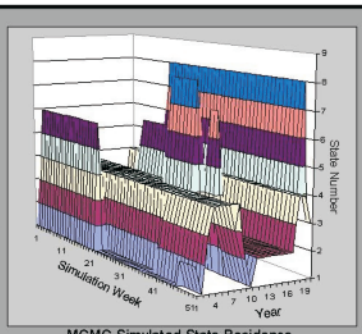


Economic Evaluation Metrics

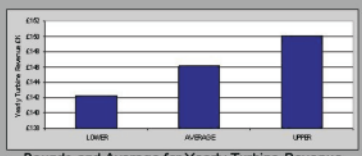
A state residence diagram such as that illustrated on the right, is generated for each run of the simulation. In order to increase the confidence in the results, the program is run multiple times and the answer obtained is the average of these multiple simulations.

Use of the central limit theorem is made in order to establish the confidence interval of the results.

$$\overline{x} \pm \frac{Z_c s}{\sqrt{n}}$$



MCMC Simulated State Residence



Bounds and Average for Yearly Turbine Revenue

Future research will be focused on integrating the existing models with a range of maintenance policies and effects of CM when used as part of the decision-making process. A good understanding of both the physical processes at work, and how much inference can be made from condition data will enable the modelling to become more reflective of the real system. This refined model will provide the base for a decision-support software tool, enabling wind farm operators to quantify the benefits of their wind farm CM systems.

PROSEN: Networking of Distributed Sensors for Proactive Condition Monitoring of Wind Turbines. Web - WWW.PROSEN.ORG.UK

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