論　文　の　内　容　の　要　旨

論文題目
Prediction of Dynamic Response of Wind Turbines Using SCADA Data and Updated Aeroelastic Model
（SCADA データと精緻化された空力弾性モデルを利用した風力発電設備の動的応答評価に関する研究）

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Prospective wind turbines, adopting Condition-Based Maintenance (CBM) for Operation and Maintenance (O&M) strategy instead of inspection visits and corrective maintenance actions for all turbines, can make wind energy costly competitive with reduced O&M costs. Among various applicable CBM methods, Measurement-based Condition Monitoring (MCM) is the most obvious and direct way to get insight of loads and to detect damage in real-time on structures. MCM is, however, costly difficult to be implemented in wind energy field due to requirement of sensors for all main components and lifetime measurement. Simulation-based Condition Monitoring (SCM) is possible for load estimation at all main components without additional measurement, but it is difficult to reflect system change and to apply for damage detection. Statistics-based Condition Monitoring (StCM) has been recently studied by several researchers due to possibility of load estimation at all main components at reasonable cost by integration of supervisory control and data acquisition (SCADA) system and short-term measurement campaign. StCM is, however, impractical to reflect system change and to apply for damage detection as well as difficult in extrapolation for different operating and wind conditions.

In this study, a Physical model-based Condition Monitoring (PCM) concept, including system identification and dynamic response analysis using advanced wind field model, is proposed for cost-effective and reliable condition monitoring of wind turbines. System identification is introduced to evaluate damping effect of movable parts as well as to describe structure properly. The advanced wind field generation method with link of wind speed measured by the SCADA system is presented to provide a high correlation coefficient which can be used as an indicator of damage detection and accurate estimation of maximum responses. The proposed system identification and dynamic response analysis methods are validated on the basis of measurement data recorded from a 400kW stall-regulated wind turbine.

In Chapter 1, the general background of this study, review of previous researches, objectives and outline of this thesis are presented.

In Chapter 2, the detail description of Physical model-based Condition Monitoring (PCM) which consists of a SCADA system, dynamic response analysis, system identification and condition evaluation schemes is given. SCADA system provides both the measured wind speed data to be linked for dynamic response analysis and the measured acceleration to be used for system identification.

In Chapter 3, methodology for model updating of wind turbines is presented. Stiffness parameters in the aeroelastic model are identified based on the natural frequencies derived by the Eigensystem

Realization Algorithm (ERA) and those obtained from the SCADA. In addition, equivalent model of movable parts is introduced to describe difference of damping between in the fore-and-aft and side-by-side directions, and methodology to determine parameters of the equivalent model is proposed based on the objective function including damping derived by Random Decrement Technique (RDT) from the SCADA. In the both stiffness and damping identifications, Simplex Method is used to determine structural parameters by minimizing objective functions.

In Chapter 4, model updating for the wind turbines is validated on the basis of measurement data recorded from a 400kW stall-regulated wind turbine. The aeroelastic model is modified to represent detailed drive-train in the nacelle, including bedplate and flexible low and high speed shafts. The stiffness parameters for the aeroelastic model are updated based on the measured acceleration data, with frequency discrepancies become less than around 2%. As a result, the Power Spectral Density (PSD) of the estimated moments using the updated model has been in good agreement with the measured those. Parameters of the equivalent model of movable parts are determined and natural frequency's changes due to adding of movable parts to the structural model are calibrated by updating stiffness parameters again.

In Chapter 5, a wind field generation method based on the Auto-Regressive (AR) model is expanded to consider 3-dimensional wind fields and is linked to time-series of measured wind speed to provide high correlation coefficient between the predicted and measured wind responses by reducing uncertainty of the error terms in the AR model.

In Chapter 6, dynamic response of wind turbines with both conventional and advanced wind field models are predicted and compared with the recorded data from 400kW stall-regulated wind turbine. The improvements in the estimated dynamic response by using the modified wind field model are depicted. More stable and accurate estimation of maximum moments could be also predicted by using modified wind field model; standard error is reduced from around 70% to 27.5%. High correlation coefficient between the predicted and measured time series of wind response could be estimated by using modified wind field model; average of correlation coefficients for 12 simulation cases is increased from 0.14 to 0.55. The reason of improvement on the correlation coefficient is discussed on the basis of spectrum analysis.

Chapter 7 summarizes the conclusions of this study. A Physical model-based Condition Monitoring (PCM) has been proposed and verified with measurement data for a 400kW stall-regulated wind turbine. Aeroelastic model with the equivalent model of movable parts was proposed to describe the flexible low and high speed shaft, and parameters of the equivalent model have been determined, consequently leading to provide difference of damping in the fore-and-aft and side-by-side directions properly. In addition, the efficiency of modified wind field generation method is demonstrated. The result shows that correlation coefficient between observed and simulated moments increased and accurate estimation of maximum moments was achievable.