Performance-based maintenance of gas turbines for reliable control of degraded power systems

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ABSTRACT

Maintenance actions are necessary for ensuring proper operations of control systems under component degradation. However, current condition-based maintenance (CBM) models based on component health indices are not suitable for degraded control systems. Indeed, failures of control systems are only determined by the controller outputs, and the feedback mechanism compensates the control performance loss caused by the component deterioration. Thus, control systems may still operate normally even if the component health indices exceed failure thresholds. This work investigates the CBM model of control systems and employs the reduced control performance as a direct degradation measure for deciding maintenance activities. The reduced control performance depends on the underlying component degradation modelled as a Wiener process and the feedback mechanism. To this aim, the controller features are quantified by developing a dynamic and stochastic control block diagram-based simulation model, consisting of the degraded components and the control mechanism. At each inspection, the system receives a maintenance action if the control performance deterioration exceeds its preventive-maintenance or failure thresholds. Inspired by realistic cases, the component degradation model considers random start time and unit-to-unit variability. The cost analysis of maintenance model is conducted via Monte Carlo simulation. Optimal maintenance strategies are investigated to minimize the expected maintenance costs, which is a direct consequence of the control performance. The proposed framework is able to design preventive maintenance actions on a gas power plant, to ensuring required load frequency control performance against a sudden load increase. The optimization results identify the trade-off between system downtime and maintenance costs as a function of preventive maintenance thresholds and inspection frequency. Finally, the control performance-based maintenance model can reduce maintenance costs as compared to CBM and pre-scheduled maintenance.

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Abbreviations: LFC, Load Frequency Control; PMU, Phasor Measurement Units; CBM, Condition-based Maintenance; RUL, Remaining Useful Lifetime; NHPP, Non-Homogeneous Poisson Process; EM, Expectation-Maximization; PBM, Performance-based Maintenance; MCR, Maintenance Cost Rate; MCS, Monte Carlo Simulation; HGSAA, Hybrid Genetic-Simulated-Annealing Algorithm; GA, Genetic Algorithms; SA, Simulated Annealing; RT, Rising Time; PO, Percentage Overshoot; ST, Settling Time.

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1. Introduction

Control systems perform critical tasks in many industrial applications, e.g. manufacture systems [1], transportation systems [2,3], and power systems [4,5]. The components of control systems, i.e. actuators and sensors, are subject to degradation when operating under severe working conditions [5–9].
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