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Design of an active fault tolerant control system for a simulated industrial steam turbine

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ABSTRACT

An active fault tolerant control (FTC) scheme is proposed in this paper to accommodate for an industrial steam turbine faults based on integration of a data-driven fault detection and diagnosis (FDD) module and an adaptive generalized predictive control (GPC) approach. The FDD module uses a fusion-based methodology to incorporate a multi-attribute feature via a support vector machine (SVM) and adaptive neuro-fuzzy inference system (ANFIS) classifiers. In the GPC formulation, an adaptive configuration of its internal model has been devised to capture the faulty model for the set of internal steam turbine faults. To handle the most challenging faults, however, the GPC control configuration is modified via its weighting factors to demand for satisfactory control recovery with less vigorous control actions. The proposed FTC scheme is hence able to systematically maintain early FDD with efficient fault accommodation against faults jeopardizing the steam turbine availability. Extensive simulation tests are conducted to explore the effectiveness of the proposed FTC performances in response to different categories of steam turbine fault scenarios.

1. Introduction

The constantly increasing demand for higher productivity has urged industrial companies to pursue new process and automation technologies for competitive advantages. The progression of deployed emerging technologies has provided a wide range of benefits over the earlier operations environments, but they also created new operational issues. The addition of the advanced control applications enabled the control loop counts to climb up, complicating the supervision of the control loops. Hence, it is no longer a trivial task for operators to detect and identify the root cause of probable process upsets in time on their own expertise to assess their performances. This deficiency results in the operators being unable to effectively manage upset conditions, nor operate the plant for maximum profit contribution. Therefore, it is imperative to explore for fault-tolerant control (FTC) methodologies to minimize the loops performance degradations against potential abnormal situations.

Significant amount of attention has been devoted to FTC schemes over the last decade [1]. The developed methods can be broadly categorized into passive and active approaches [2,3]. Passive FTC approach fundamentally relies on robustness of the embedded control design strategy to accommodate for the induced faults. The approach is inherently conservative-based and hence may provide inconsistent performances in response to all individual spectrums of probable faults due to their different severities. Active FTC approach presents a more reliable control framework to aim for consistent stability and performance

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Nomenclature

W	weight vector
F	fusion output
a_i	ith measurement output
b_i	ith largest of $a_1, ..., a_n$
b^i	ideal outcome
A_i, B_i	linguistic labels
$p1$, $p2$, $q1$, $q2$, $r1$ and $r2$	design parameters
$\mu_{A_i}(x)$, $\mu_{Bi}(y)$	membership functions
OLi	ith output layer of ANFIS
x, y	inputs
C	penalty parameter
K	kernel

Greek letters

ξ_i	positive slack variables
α_i	support vectors
$\varphi(.)$	function for SVM

Subscripts

SVM	support vector machine
ANFIS	adaptive neuro-fuzzy inference system
OWA	ordered weighted averaging
FTC	fault-tolerant control
MPC	model predictive control
GPC	general predictive controller
ANN	artificial neural network
FL	fuzzy logic
NNs	neural networks
FKB	fuzzy knowledge base
HP	high pressure
IP	intermediate pressure
LP	low-pressure
DAGSVM	directed acyclic graph SVM
OAA	one against all
GRBF	gaussian radial basis function
MLP	multi-layered-perceptron
SOM	self-organizing map
FDD	fault detection and diagnosis

objectives via controller reconfiguration on the basis of a priori knowledge of the occurred fault root cause. Therefore, a key element of this motivating FTC approach corresponds to existence of fault detection and diagnosis (FDD) block to recursively provide fast and accurate diagnostic information about the occurrence of a fault, its location and severity size [4]. This can lead to a more reliable control approach to take a proper fault accommodating action following the observation of a fault occurrence. So, every active fault tolerant controller has two main parts; fault detection and diagnosis (FDD) and fault accommodation.

Over the last three decades, the growing demand for safety, reliability, maintainability, and survivability in industrial plants has drawn significant research in FDD. An incorrect or much delayed. FDD action may not only result in a loss of system performance, but also instability of overall system. An inappropriate reconfigurable control mechanism based on incorrect FDD information will also lead to poor performance and even the loss of stability of the system [2,3]. Fault indicators can be elaborated on line with available measurements. Fault detection comprises the conception of any relevant symptom from the fault indicators and the consequent evaluation of the time of fault occurrence. Fault diagnosis refers to fault-root discrimination which can be based on an analytical model of the system, representing the normal system behavior in the absence of any fault [5]. This is by no means an easy task to be carried out, especially in non-linear dynamic systems [6], mainly due to the model imprecision, leading to difficulties in making a clear distinction between deviations made by model uncertainty and those imposed by a fault affecting the system or unknown disturbances. This usually necessitates a trade-off to be considered between false alarm rate and missed detection rate. On the other hand, obtaining a sufficiently precise analytical model for complex processes is by no means an easy task to be done and hence other diagnostic approaches must be utilized [7]. Signal processing is a candidate approach to fault diagnosis when an analytical model is not a priori available [8]. Signal characteristics may be explored within time domain methods (e.g., correlation and mean-change), frequency domain