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Robust methodology for steady state measurements estimation based framework for a reliable long term thermal power plant operation performance monitoring

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A B S T R A C T

Steady state identification is a process control research approximating the successive values of samples in steady state into its average values. According to the plant-wide control hierarchical model, these results implement monitoring and optimizing functions. Thermal power plant operates into a wide range of mean value active power. Systematic plant-wide slow developing disturbances affect the power plant operation performance through deviations of each process variable between its current true process value and the expected good performance relative value. Supervised records are realizations contaminated with stationary correlated noise carrying successive steady state deviations. Long term thermal power plant operation performance monitoring depending on (i) accuracy and precision of steady state identification method and (ii) fitness approximation per process variable versus mean value active power. This paper bases: (i) a computational experiment design to calibrate a steady state identification before to embed into a real system, and (ii) a solution for curve structure to capture good performance relative value per process variable with few knots availability right after the start-up of the plant at base load regime. A case study tracking the cumulative effects of degradation due to fouling on a heat exchanger was performed.

1. Introduction

In the steam generation process of a power plant, slowly developing disturbances are the main cause of degradation, although disturbances of rapid development may also be present in other processes, such as in chemical plants especially related to the load (feed, throughput) [1]. The IFAC (International Federation of Automatic Control) considered the distinctive features of control for both type of plants and decided that the Technical Committee TC 6.1 would be in charge of the Chemical processes control whereas entrusted TC 6.3 the control of power plants and power systems. Conversely, when processes are steady, it can be helpful to identify and react to potentially abnormal events or symptoms in particular areas of the plant such as, low-pressure steam venting, fouling, slagging and clogging [2].

Plant-wide control hierarchical model applied to structural decisions in chemical plants [3] is also valid in a current EGU (electrical generation unit) connected to an EPS (electrical power system). In practice, real time control system is divided into several layers, clearly separated by time scales. Below this control philosophy of the overall plant timescale separation permits a vertical decomposition. Monitoring and optimizing functions corresponds to the lowest time scale. Supervised records stored into SCADA (supervisory control and data acquisition) systems are data inputs for them. Operation performance monitoring is a main preliminary stage to find reasons affecting compliment an economic target, i.e., an economic cost function and constraints. PID (proportional integral derivative) controllers are typically used in the regulatory control layer, where stabilization of the plant is the main concern, as they should maintain the process in a permanent steady state.

If the process or plant being monitored (passively) and/or optimized (actively) is not at steady state then applying a steady-state model at that time is obviously not suitable given that significant accumulation or rate-of-change of material, energy and

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momentum violates one of the principle assumptions of the model. Methods for SSI (steady state identification) approximate the successive values of samples in steady state into its averaged values. Supervised records are realizations representing the true process value with additive stationary correlated noise and they are carrying plant-wide slow developing disturbances. The scientific community has been applying them in various contexts: chemical processes [4], and others [5]. There is no much research reported in this field, especially related to power plants [6] so its application represents a novel contribution of this research.

Real time operation of a thermal power plant is into a wide range of MVAP (mean value active power). Systematic plant-wide slow developing disturbances affect the power plant operation performance through deviations of each PV (process variable) between its current true process value and the expected GRPV (good relative performance value). Monitoring slowly developing disturbances with SSI means to identify into supervised records per PV its successive SS (steady states) deviations and it is a preliminary step to diagnosing the root cause of performance degradation. In the specific field of power plants, operating conditions are in a "normalized steady state" [7], defined by the maximum deviations and fluctuations with respect to the stabilized mean values [8].

On the one hand, there are a set of methods for detecting slowly disturbances in the long-term. Some examples are operating patterns and algorithmic solutions in Refs. [9,10]. These adaptive models tend to have a wider range of comfort temperatures, which do not match the time-series features recorded for steam generators in power plants. In Refs. [11,12], energy efficiency analysis is proposed for CHP (combined heat and power) systems without considering the long-term effects of degradation. In Ref. [13], a method is applied to predict the degradation of a neural network system, which is somewhat different from the degradation mechanisms observed in power plants.

On the other hand, there are a set of methods for detecting changes in operating systems, but they are meant to process fast disturbances within a short time period. In Ref. [14], steady states with transient detection are combined to assess behavior with short-time horizons, while a fault diagnostic system on vibration data processing is proposed in Ref. [15]. EMD (empirical mode decomposition) is applied in Ref. [16] to fault diagnosis in rotating machinery.

The main physico-chemical causes of degradation in steam generation are, among others: corrosion and fouling of surfaces, leakage of gases and steam and water, loss of insulation on pipes and the overheating of metal impellers. These occur over lengthy periods of time [17–21], in the order of hours, days or weeks, known as "slow disturbances". Robustness in long term thermal power plant operation performance monitoring depends on (i) accuracy and precision of SSI-method and (ii) fitness approximation per PV versus MVAP (mean value active power).

In the process of steam generation, when the steady state values of the key selected variables are detected by the units connected to the electrical system, the deviations are calculated with regard to the values of good performance, so called: "reference values" [22]. Monitoring over different periods of time consists of identifying deviations between the expected value of each variable and the current measured output.

A precedent for steady state detection was previously undertaken in Ref. [23]. The purpose of the present paper is to provide the three key aspects to design and to exploit a robust long term thermal power plant operation performance monitoring: applied over a set of PV rightly chosen, supported in SSI method and detecting the succession of SS deviations respect to a reference system in long time which it is determined by EGU operation conditions regarded just to start up later to a restoring maintenance. It is stated for the following new research outputs: (i) computational experiment definition to calibrate an SSI method for an EGU's processes operating a base load regime for the EPS, (ii) SS deviation long term detection below a changing scenario operation conditions respect to restoring maintenance, and (iii) solid criteria for the selection of variables that can reveal degradation information.

Downgrades are mainly caused by external sub-processes, due to control system malfunctions when trying to maintain fuel-to-air ratios, leading to poor quality combustion but also to intrinsic changes caused by the essential mechanisms of degradation, so this novel numerical method is finally applied to the long-term monitoring of fouling on a heat exchange surface, in view of the reference values of the key variables.

2. Aims and methodology

As a preliminary step to diagnosing the root cause of performance degradation, the objective of this study is to provide a full methodology to design and to exploit a robust long term thermal power plant operation performance monitoring based on steady state measurements estimation over supervised records, which they are carrying successive steady state deviations per PV chosen.

In this paper assumes the following simplifying assumptions: (i) it is disregarded outliers and missed values in processed time series and (ii) measurement instruments are calibrated, being disregarded data reconciliation among steady states detected PV's values.

In view of the aforementioned analyses of degradation effects in thermal power plants and the role installing a robust long term thermal power plant operation performance monitoring based on steady state measurements estimation, methodology addresses the following issues:

(i) **Computational experiment definition** to calibrate, previous to embed an SSI method into a real time industrial. Experiment is an EGU's system operating at base load for an EPS. It demands addresses the following interdisciplinary aspects:

   Characterization of supervised records at EGU base load's regime

   a Operation modeling and dynamic characterization below plant-wide control.
   b Noise characterization and its variance estimation.
   c Supervised records decomposition: base wave, additive stationary correlated noise.

   Statistical principles for computational experimental designing:

   d Experimental region: all factor influences upon SS identification and its expected robustness. SSI on synthetic records must assert its reproducibility and repeatability on industrial records.
   e Noise: Randomization, Replication.

   Demonstration of promoted experimental computational techniques:

   f To choose a variance estimator.
   g To calibrate an SSI method: Quantitative criterion and analysis of results.

(ii) **Curve structure foundation** to capture GRPV per PV with few knots availability right after the start-up of the plant at base load regime.

(iii) **Criterions for key variables selections** to monitor degradation effects in thermal power plants combining theoretical base and industrial expertise from several power plant practitioners