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# Investigation on a new methodology for thermal power plant assessment through live diagnosis monitoring of selected process parameters; application to a case study

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ABSTRACT

This paper proposes a new methodology for short- and long-term assessment of the operation of a thermal power plant to promote preventive maintenance as well as failure analysis while ensuring a degree of compliance with statutory regulations. This study aims to identify and monitorize the quasi-steady states associated with measurements in time series of power plant process. It was focused on a new procedure for detection over different thermodynamic variables involved, being multivariate and automatic. For each one of these states, statistical calculations are carried out to configure a data pre-processing level. The data settings now available can be used as assessment criteria based on detected deviations from a reference system that has been updated during plant-performance tests, addressing long term variations suggested variables. Although the most important outcome is the highly precise and valuable information that will be obtained on the live operating mode, leading to further improvements of the cycle efficiency and achievements in the overall control system of the thermal plant, the main goal is to detect any anomaly, reacting as quickly as possible to return the plant to a normal operation mode. This study also provides a comprehensive practical application, monitoring a power plant of reference.


## 1. Introduction

The trend in power-plant automation systems towards Distributed Control Systems (DCS) has resulted in the generation of huge volumes of data that must be handled properly if operation is to be properly optimized.

Process supervision entails continuous monitoring of process variables in search of anomalies that may represent operational or quality problems. Depending on the time-frame, it can be applied at two levels: in the short term, the goal is to detect any malfunction and react as quickly as possible to return the plant to normal operation. In the long term, the performance of the process is analyzed basically using past data. The goal in this case is to identify the causes of low performance and further opportunities for improvement [1,2].

This form of monitoring a power plant in terms of safety is a part of a complex system [3] that requires actions at government, regulatory body, company, management [4], and shop-floor levels. At the same time, paying special attention to maintenance based on the introduction of an ongoing diagnostic system helps to reduce costs and avoid unforeseen malfunctions [5,6].

To be precise, the term "steady state" is a misnomer because no system parameter can be considered steady forever. Hence, identification of steady states first requires establishing a definition of what "steady state" means, and then evaluating whether the system in question meets the definition. To achieve this goal, thresholds are used to gauge the observed variations from mean value in selected features. Some of the initial investigations regarding system SS identification took place in different process control field studies [7–9].

Electric power generation systems require continuous monitoring to ensure safe, reliable operation. The data transmitted by in-plant sensors to control systems may also be analyzed to verify proper operation and predict future behavior [10]. Suitable specific diagnostic methods are now being developed at thermal power plants; e.g., for flame monitoring [11], nuclear plants and methods based on thermo-economic principles [12]. The effect of the control system in the propagation of malfunctions in diagnosis has been analyzed [13] to eliminate malfunctions caused by control system intervention. For testing diagnosis method effectiveness, by simulation, data can be produced in order to vary the number of

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anomalies, their location and their value for their identification [14]. A prognosis procedure based on a productive representation of the system is proposed and applied to a system constituted by a gas turbine and a heat recovery system [15]. Thermoeconomic procedure [16] is applied to a waste-to-energy (WTE) system integrated with a gas fueled combined cycle.

Sampled data recorded in the control room form a multidimensional space of signals, as can be seen in Fig. 1a. Providing demanded energy's quantity to the customers is the main goal of an energy production system. While it is performed a set of parameters should meet tolerance conditions. Physical magnitudes in a conversion process when they are acquired along the time by a measuring system are called as signals.

A variable, such as $N_P$, in an energy production system, can be associated to power generated over a wide operation range. It means that during a current operation of energy conversion, a group of variables whose values are distributed in a wide range can be also identified. For several hours or even days, a power plant can produce different levels of output power (i.e., in a wide range, where the difference between a minimum and a maximum value, is greater than those situations typically associated to "narrow levels" of variations). On the contrary, there are other physical magnitudes, such as, profiles of steam temperatures and pressures which always must be kept enclosed into narrow levels.

Finally, as any energy production system becomes so complex to be simply controlled (because, sampled signals valued among wide and narrow range can coexist, where static input–outputs establish commonly non linear relationships), internal control subsystems are introduced in order to provide an improved regulation (for those variables moving in a narrow levels) while different levels of energy are being transferred. Spray desuperheating and combustion gas recirculation subsystems are introduced to keep profiles of steam temperatures as required in a power cycle. Calculated control signals, ($u_{mi}$), for these types of subsystems can be varying in a wide range in order to keep regulated variables such as ($y_{rri}$), enclosed in a narrow range.

Focusing on energy production systems, variables can be classified, attending to operation range and levels of variation, in three main groups; (i) sampled signals valued in narrow operation range and fixed levels ($y_{rri}$), (ii) sampled signals valued in a wide operation range at different levels ($y_{rsi}$, some ($u_{mi}$)), (iii) sampled signals valued in a wide range among fixed levels (some ($u_{mi}$)).

Quantity of demanded energy is a load signal ($d_i$). Control system must be able to calculate those control input signals for the process ($u_{mi}$) such as a zero deviation between demanded energy (di) and supplied energy ($y_{rsi}$), which is, in fact, the process' response to ($u_{mi}$). This kind of action is derived from a tracking control system because load signal, ($d_i$), must be followed by the process response ($y_{rsi}$). At the same time, quality parameters, ($y_{rri}$), must be kept inside a low percentage of tolerance. This kind of action is derived from a regulation control systems because output process variable or parameter ($y_{rri}$), must be kept (in spite of existence of ($d_i$) and other internal deteriorations) by control input signals ($u_{mi}$) in a narrow range and fixed limits. In a regulation control system, a ($y_{rri}$) is determined by a "setting point" ($u_{ri}$) and ($u_{mi}$) must be calculated such as a zero deviation between ($y_{rri}$) and ($u_{ri}$). Malfunctions in any of these control structures may seriously compromise the proper operation of any power plant [17].

Fig. 1b shows an example outlining the flows of fuel, air, and steam in a conventional plant, although the method could also be applied to other schemes, such as combined cycles. The net power $N_p$ (which is a $d_i$ variable) and $T_s$ (superheating steam temperature) should be carefully regulated (which is an $y_{rri}$ variable) and tracking control system must supply to turbine $\dot{m}_s$ (which is an $y_{rsi}$ variable). For $\dot{m}_s$ to be produced, $\dot{V}_f$ (which is an $u_{mi}$ variable) must be sourced to the burners. According to the concept of stoichiometry $\dot{V}_a$ is a dependent variable to $\dot{V}_f$. $T_s$ is regulated at a constant value (between narrow levels) and determined by its setting point. Nevertheless, $T_g$ and $T_{w(eco)}$ are also indirectly regulated variables, but their monitored values are a function of $N_p$.

A control system of this type must be designed on the basis of a robust method that facilitates thermal power plant performance assessment for diagnostic purposes. The possibilities offered by the Matlab™ package [18] have been rated as highly positive for these purposes as one effective way of detecting anomalies is to examine the scale and duration of those variables that operate outside the narrow thresholds set [19]. Operation along with such anomalies is often the cause of future malfunctions or breakdowns. As shown later in a case study, this method enables such situations to be promptly detected.

## 2. Aims and methodology

This study aims to identify and monitorize the quasi-steady states (QSS) associated with power-plant processes, to facilitate the identification and diagnosis of potential failures and other malfunctions following a new methodology.

Thermal power plants operate at different power levels, $N_P$, as shown in Fig. 2a, the full set of QSS, e.g., A, B, C, D, E, must be in a range between a lower bound (A) and the nominal level (C) for which the plant was originally designed.

Four main stages are keys; (i) QSS identification, (ii) deviation calculation between measurements and a respective reference system of 'good operation's performance', (iii) memorized data system by saving sequenced deviations with date and time stamping (as it is drawn in Fig. 2b), and (iv) association of detected deviations to their possible causes and also between variations of them and their possible causes.

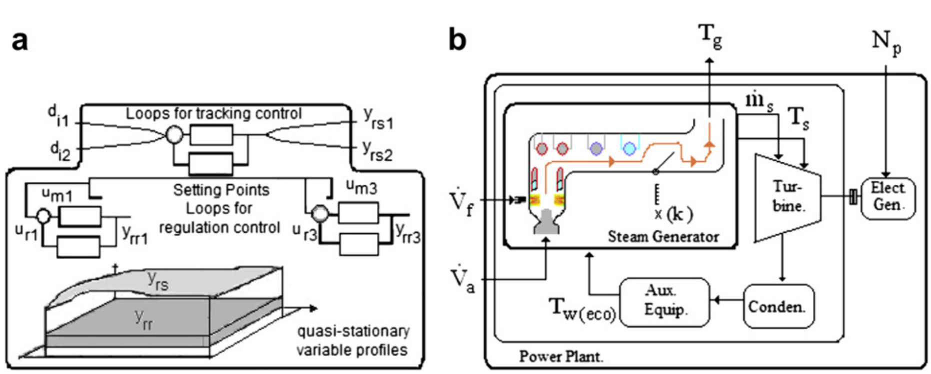


**Fig. 1.** Supervision and monitoring: a) recorded signals, b) inputs and outputs scheme over a power-plant layout.