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Short Communication

# A data-based technique for monitoring of wound rotor induction machines: A simulation study

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ABSTRACT

Detecting faults induction machines is crucial for a safe operation of these machines. The aim of this paper is to present a statistical fault detection methodology for the detection of faults in three-phase wound rotor induction machines (WRIM). The proposed fault detection approach is based on the use of principal components analysis (PCA). However, conventional PCA-based detection indices, such as the $T^2$ and the $Q$ statistics, are not well suited to detect small faults because these indices only use information from the most recent available samples. Detection of small faults is one of the most crucial and challenging tasks in the area of fault detection and diagnosis. In this paper, a new statistical system monitoring strategy is proposed for detecting changes resulting from small shifts in several variables associated with WRIM. The proposed approach combines modeling using PCA modeling with the exponentially weighted moving average (EWMA) control scheme. In the proposed approach, EWMA control scheme is applied on the ignored principal components to detect the presence of faults. The performance of the proposed method is compared with those of the traditional PCA-based fault detection indices. The simulation results clearly show the effectiveness of the proposed method over the conventional ones, especially in the presence of faults with small magnitudes.


## 1. Introduction

The history of fault detection and diagnosis of electrical motors goes back to almost the date of their invention. Manufacturers of motors have been the first ones who have investigated simple protection techniques such as the over current, over voltage, and ground fault protection schemes [1]. The increase in the complexity and the importance of motors has generated a corresponding significant progress in the field of fault detection and diagnosis [2,3]. The problem of fault detection in electrical machines has been the subject of research and investigation in various applications, such as electric vehicles [4], wind turbines [5], and many others.

Previously, DC and synchronous machines were commonly used in industrial applications, and thus they were the focus of the reliability-related research. However, with technological and economic developments and the advancements in power electronics, the squirrel cage and the wound rotor induction machines have taken their place in several applications [6], such as transportation, energy production and electrical drives due to their robustness, reliability and lower costs. Although improvements have been made, these machines still remain subject to potential stator and rotor failures [7,8]. Thus, monitoring of these machines is essential for their proper and safe operation.

Proper system monitoring can help minimize their downtime, improve their safety of operation, and reduce their manufacturing costs. Monitoring can be defined as the set of actions carried out to detect and isolate faulty measurement sources and then remove these faults before they affect the process performance [9]. The role of detection is to identify any fault quantified by a change from the nominal behavior of the system. Fault isolation, on the other hand, determines the location of the detected fault. In this paper, the focus will be on fault detection and its application to wound rotor induction machines (WRIM). If faults in WRIM are not detected in time or if they are allowed to propagate further, they may lead to serious failures.

Over the past few decades, various monitoring techniques for induction machines were reported in the literature, and they can

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be broadly classified into three main categories: data-based or model-free techniques [7,10,11], model-based techniques [12–14], and knowledge-based techniques [15–17]. Knowledge-based fault detection is usually a heuristic process [18]. Model-based fault detection methods, on the other hand, rely on comparing the system measured variables with information obtained from a mathematical model, which is usually developed based on some fundamental understanding of the system under fault-free conditions. In contrast to the model-based approaches, where a priori knowledge about the inspected system is needed, in data-based methods, only the availability of historical process data is required [19]. Since they do not explicitly require process models, data-based methods are usually more attractive to practical applications with complex systems. However, the performance of data-based methods mainly depends on the availability and quality of the required data.

In this paper, a PCA-based exponentially weighted moving average (EWMA) fault detection scheme is proposed for monitoring wound rotor induction machines (WRIM). PCA is a well known data-based multivariate statistical technique and has receive important attention in last few years [20–22]. PCA is a linear dimensionality reduction modeling technique, which is very helpful when dealing data sets having a high degree of cross correlation among the variables. The central idea of PCA is to reduce the dimensionality of highly correlated data, while retaining the maximum possible amount of variability present in the original data set [23]. This reduction is achieved by transforming correlated variables into the set of new uncorrelated variables which are called principal components (PCs), each of which is a linear combination of the original variables. The PCA by reducing the dimension of the process variables is able to eliminate noise and retain only important process information, and can be employed to compress noisy and correlated measurements into a smaller informative subspace for measurement data sets. PCA-based anomaly detection have been widely used in practice because they need no prior knowledge about the process model, the only information needed is a good historical database describing the normal process operation [24]. Unfortunately, the conventional PCA-based monitoring indices, such as $T^2$ and $Q$ statistics , often fail to detect small or moderate changes [25,26]. A key shortcoming of these conventional detection indices ($T^2$ and $Q$) is that they only use the information in the last observation thus they have a short memory. Consequently, these detection indices are relatively insensitive to small changes in the process variables, and thus may result in missed detections [26]. These shortcomings of the $T^2$ and $Q$ statistics motivate the use of other alternatives in order to mitigate these disadvantages.

- This paper is aimed at presenting new indice to improve the detectability of conventional PCA-based methods such $T^2$ and $Q$ statistics. Indeed, the history data obtained before actual point contain useful information for process monitoring; but, conventional PCA-based monitoring indices ignore such information at all. The ability to detect smaller parameter shifts can be improved by using a chart based on a statistic that corporate information from past samples in addition to current samples. Alternatively, the exponentially weighted moving average (EWMA) monitoring chart consider not only the last data point, but the entire past data [27]. It makes them more sensitive than the $T^2$ and $Q$ charts to small anomalies. The main contribution of this work is to exploit the advantages of the exponentially weighted moving average (EWMA) chart and those of PCA modeling for enhancing detection performances of conventional PCA, especially for detecting small faults in highly correlated multivariate data. Such a choice is mainly motivated by the greater ability of the EWMA metric to detect small fault in process mean, which makes it very attractive as anomaly detection. In fact, the objective is to extend the abilities of the univariate EWMA monitoring chart to deal with multivariate processes.
- In this approach, PCA is used to express a process data matrix as the sum of two matrices: approximate and residual. After a model is obtained using PCA, the EWMA control scheme is applied using the ignored principal components (which have smallest variances) to improve fault detection. The smallest ignored PCs are used as an indicator about the existence or absence of anomalies.

The remainder of this paper is organized as follows. The analytical modeling of WRIM and a description of the various possible faults in these machines are presented in Section 2. Then, a brief introduction to PCA and how it can be used in fault detection are presented in Section 3. Then, the EWMA control scheme is described in Section 4, followed by a description of the proposed PCA-based EWMA fault detection approach (which integrates PCA modeling and the EWMA control scheme) in Section 5. Then, in Section 6, the performance of the proposed PCA-based EWMA control scheme is illustrated through a simulated example using WRIM data. Finally, some concluding remarks are presented in Section 7.

## 2. Analytical modeling of wound rotor induction machines (WRIM)

Effective monitoring of wound rotor induction machines requires developing a model that can accurately describes the behavior of these machines. In this work, a three-phase model that is based on magnetically coupled electrical circuits is used. To develop such a model, some modeling assumptions need to be made, which are described next.

### 2.1. Modeling assumptions

In the proposed approach, its is assumed that the:

- magnetic circuit is linear, and the relative permeability of iron is very large compared to the vacuum,
- skin effect is negligible,
- hysteresis and eddy currents are negligible,
- air gap thickness is uniform,
- magnetomotive force created by the stator and the rotor windings follows a sinusoidal distribution along the air gap,
- stator and rotor have the same number of turns in series per phase,
- coils have the same properties,
- WRIM stator and rotor coils are coupled in star configuration and connected to the considered balanced state grid.

### 2.2. Dynamic modeling of the WRIM

Defining the voltage vectors $([V_S],[V_R])$, the current vectors $([I_S],[I_R])$ and the flux vectors $([\phi_S],[\phi_R])$ for the stator and the rotor as:

$$[V_S] = \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix}; \quad [I_S] = \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}; \quad [\phi_S] = \begin{bmatrix} \phi_A \\ \phi_B \\ \phi_C \end{bmatrix};$$

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