Fault Detection and Analysis of Assemblies of Fuel Cells Using Image Processing

[1]Ramsha Firdous, [2]Vivek Borkar, [3]Swapnil Aherrao, [4]Bharati Narute

[1,4]Department of Electronics and Telecommunication, MESCOE, SPPU
2, 3 National Chemical Laboratory, Pune, India
Email: [1]ramsha.f109@gmail.com, [2]vv.borkar@ncl.res.in, [3]sr.aherrao@ncl.res.in, [4]bharati.narute@mescoepune.org

Abstract— Fuel cell is one of the best alternatives of fossil energy. However, there are still two barriers: the durability and reliability, which block the wide application of fuel cells. To overcome these barriers, fault diagnosis is an efficient solution. This paper proposes a method for detection of common faults occurring in membrane electrode assemblies (MEA) of fuel cells using image processing tools for offline fault analysis.

Keywords— Fuel cell, fault detection, image processing.

I. INTRODUCTION

The world today is facing an energy crisis as well as significant environmental problems. Fossil fuels such as petroleum, coal and natural gas are the main resources for generating electricity. But they also have been major contributors to environmental problems[8].

Major efforts to reduce greenhouse gas emissions have increased the demand for pollution-free energy sources, in the last few years[9]. Fuel cells are a promising energy technology with the advantages of high efficiency and low pollution for transportation and stationary applications. They directly convert, through chemical reaction, chemical energy of fuel into electrical energy with almost null pollutant emissions. However, fuel cells also have challenging problems associated with its durability, reliability, lifetime, etc.

Temporary faults in polymer electrolyte membrane (PEM) fuel cell systems might occur during operations due to the functional limitations of some components and the complexity of the physical process, despite the proposal of a variety of design and control strategies to improve the performance of such systems. The development of an effective condition monitoring system is required that can detect these faults in a timely manner [11].

The fault conditions, which might be permanent or temporary , usually are closely related to a critical component of the fuel cell, the membrane-electrode assembly (MEA).

The work carried out so far in the area of fault detection and analysis of fuel cells includes the Hotelling T^2 statistical analysis for fault detection of PEM fuel cells[11], detection of water management faults, i.e. flooding and drying with the use of Electrochemical Impedance Spectroscopy (EIS)[12], fault detection by the temperature behaviour analysis in polymer electrolyte membrane fuel cells[10], fault detection through variable behavior analysis[9], fault diagnosis of a proton exchange membrane fuel cell (PEMFC) system using naive Bayesian classification[8], fault detection for PEMFC dynamic systems using an independent radial basis function (RBF) networks[7] and Gaussian mixture model (GMM) for fault detection[6].

Most of the works mentioned above focus on water management faults, i.e. flooding and drying. Moreover, the hardly any work has been carried out in fault detection and analysis of fuel cells with the use of image processing tools.

In this work, we propose an approach for detection of common faults occurring in membrane electrode assemblies (MEA) of fuel cells using image processing tools during offline fault analysis.

The rest of the paper is organized as follows: In section 2, the PEMFC system is introduced. In section 3, the membrane defects are explained. The details of experiment platform are presented in section 4. Finally, the conclusion and future work are summarized.

II. FUEL CELL WORKING

All fuel cells are electrochemical devices which convert the chemical energy of a fuel (hydrogen) and an oxidizer i.e oxygen directly into electricity. The fuel cell consists of an electrolyte in between two electrodes. The positive ions (protons) pass through the electrolyte while the electrons get blocked. Hydrogen gas passes over anode, and with the help of a catalyst, separates into electrons and hydrogen protons. A graphic representation of a PEM fuel cell structure is given in Fig 1.

The PEM fuel cell electrochemical process starts on the anode side where H_2 molecules are brought by flow plate channels. Anode catalyst divides hydrogen into protons H^+ that travel to cathode through membrane and electrons e^- that travel to cathode over external electrical circuit[8]. At cathode hydrogen protons H^+ and electrons e^- combine with oxygen O_2 by use of catalyst, to form water H_2O and heat.

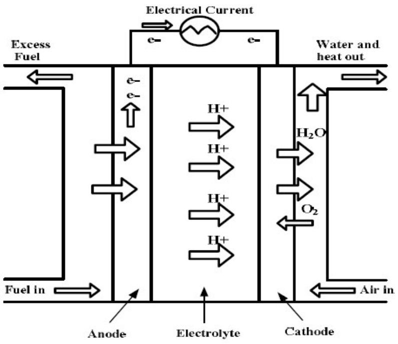


Fig.1 Schematic Diagram of PEMFC

III. DEFECTS IN FUEL CELL MEMBRANE

A. Cracking

Cracking involves the breaking of catalyst layer without breaking of electrolyte membrane. Thus, although the fuel cell can still operate in presence of cracking, it is possible that durability or performance may be affected. Cracking generally occurs over entire catalyst layer surface. Cracking can occur due to several possible causes, such as MEA manufacturing process or simply through poor handling of the membrane[23].

B. Orientation and Roughness

Orientation of the material gives features on catalyst layer of the order of 10–100 μm that are arranged or angled in a particular direction. The most common cause for orientation in the catalyst layer is from the processing equipment of the catalyst layer [23].

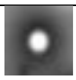
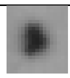
C. Delamination

Delamination is an MEA feature whereby the catalyst layer has separated from polymer membrane electrolyte. Possible causes may be the lamination conditions used during manufacturing, such as catalyst casting speed, pressure and temperature [23].

D. Electrolyte Clusters

An electrolyte cluster is essentially an area with significantly more electrolyte than in the surrounding areas. Electrolyte clusters are formed if carbon agglomerates are not well dispersed during the mixing stage or if too much electrolyte is used in the ink[23].

TABLE I : Defects Present in Fuel Cell Membrane

Defect	**Backlit Image**	**Side view**	**Qualifications**
Hole or Pinhole			There is no material covering the substrate in a a localized area
Air Entrainment or Bubble			A pocket of air below the material surface
Thinning			Concavity on the surface of the material
Gel or Particulate			A dark contaminant in the thin film

IV. RELATED STUDY

Ref [1] introduces fault diagnosis and separation, mitigation, and modeling of a proton exchange membrane fuel cell (PEMFC). Flooding and drying faults were to be detected from the cell voltage and impedance response of the cell. Impedance response at low frequency is used to identify the cause of the fault. Slope of the magnitude and/or the negative phase response of the cell impedance at low frequency are observed to allow separation of a fault.

Ref [3] is centered in the PEM fuel cell stack health diagnosis and on stack fault detection monitoring. It presents a fault detection method using the simple and non-intrusive on-line technique based on the space signature of the cell voltages. It have the objective to minimize the number of embedded sensors and instrumentation in order to get a precise, reliable and economic solution in a mass market application.

In [5], a supervisor system, able to diagnose different types of faults during the operation of a proton exchange membrane fuel cell is introduced. This diagnosis is developed by applying Bayesian networks, which qualify and quantify the cause–effect relationship among variables of the process. Fault diagnosis is based on on-line monitoring of variables easy to measure in the machine such as voltage, electric current, and temperature. Fault effects are based on experiments on fault tolerant fuel cell, which are reproduced in a fuel cell model.

Ref [6] proposes a diagnosis approach for large PEMFC stack. In this approach, flooding fault is concerned. Individual cell voltages are chosen as original variables for diagnosis. A dimension reduction method, Fisher linear discrimination (FDA) is adopted to extract features from the cell voltage composed vectors after which, a classification methodology, Gaussian mixture model (GMM) is applied for fault detection.

In [7], an intelligent model-based fault detection is developed for proton exchange membrane fuel cell dynamic systems using an independent radial basis function (RBF) networks. Based on this information, the RBF model performed the fault detection including identification and classification. 5 types of faults have been introduced to the PEMFC dynamic systems which occur in the actuator, component and three sensors part.

Method of naive Bayesian classification is used in [8] in fault diagnosis of a proton exchange membrane fuel cell (PEMFC) system. Based on the PEMFC model, fault data are obtained through simulation experiment, learning and training of the naive Bayesian classification are finished, and some testing samples are selected to validate this method.

In [9], a new method for fault detection through the variable behavior analysis is introduced. A supervisor system is responsible for searching unexpected changes in some variables, since each fault cause has a specific variable behavior. 4 fault conditions are considered such as faults in the reaction air fan, low pressure in the hydrogen feed line, rupture of the membrane-electrode assembly, and refrigeration system fault.

Ref [10] presents the method of fault detection by the temperature behavior analysis in PEM fuel cells. In order to avoid damages in the other components of stack due to the increase of operational temperature, a method for fault treatment is proposed. It consists of the adjustment of the load demand reducing the operational temperature increase. These methodologies are applied in 2 types of faults: fault in the refrigeration system and sudden ruptures in the polymer electrolyte membrane.

In [11], a model-based condition monitoring scheme is proposed which employs the Hotelling T^2 statistical analysis for fault detection of PEM fuel cells.

In [12], the focus is on water management faults, i.e. flooding and drying. It deals with their detection with the use of Electrochemical Impedance Spectroscopy (EIS). The EIS was successfully applied as a diagnostic tool to a fuel cell stack consisted of 80 cells without the usage of any special purpose measurement equipment, where, in addition to the stack current, only the voltage of the complete stack was measured.

The production of MEA of fuel cells is performed in bulk. If inspection of a membrane is done manually, it will take a lot of time. Besides not all faults present in the membrane will be visible to the human eye. So a machine vision system performing image processing tasks for inspection of defects is one of the ways to reduce the time for inspection in the industry.It is practical and economical to employ computerized machine vision tools for quality assurance purposes in mass production systems because they improve the inspection accuracy, reduce human error, and allow faster production speeds.

V. APPROACH

The objective of these processing techniques is to remove noise and enhance features of interest, e.g. the defect regions.

The operations in the defect identification program are as follows [19]:

1. The image is captured from the area camera

2. If the image is colored, it is turned into grayscale

3. The image is thresholded at a grayscale value selected by the user

4. The defect regions are obtained by edge detection.

5. The regions are then segmented and classified.

A. Image Acquisition and Capturing

We intend to create images that are more suitable for human visual perception, object detection and target recognition. We will use the principles of Image processing and Morphological operations on the membrane images. We get new images that contain the surface defect only to make easier for the detecting process and classification operation via the judgment of the operator. The membrane images will be captured through a mounted camera with a constant backlight source. The image captured will be converted to other kinds of images (Binary, grayscale, etc) to be suitable for the various defect detection algorithms to be used for the different types of defects[22].

B. Preprocessing

1) Noise Reduction : Noise reduction is typically carried out by spatial or temporal averaging techniques. Depending on the noise characteristics, we can employ filters such as median filters (impulsive noise), Gaussian smoothening filters (Gaussian white noise), adaptive smoothening filters (signal-dependent white noise) and Kalman filters (signal-dependent colored noise) for noise reduction tasks.

2) Contrast Enhancement: Contrast enhancement improves the intensity contrast in the input image, highlighting the defect regions while leaving the unimportant background regions intact. This enables the defect detection stage to perform better in locating and representing each defect in the image.

C. Image Segmentation

The objective of image segmentation is to describe the significant quantity of information contained in the image by seeking relevant information and discriminating visual indices permitting to represent it in a more condensed and easily exploitable form. Segmentation constitutes one of the most significant problems in image processing, because the results obtained at the end of this stage strongly govern the final quality of interpretation. We can define segmentation as the process that subdivides an image into its constituent parts or objects in the form of connected regions having same properties. These regions can be characterized by:

• their edges, it is the case of segmentation by edge detection, where we partition an image based on abrupt changes in the gray levels.

• the pixels which compose them, it concerns with the segmentation in homogeneous regions, of which the purpose is the image segmentation based on intrinsic properties of region. The principal approaches in the second case are the thresholding, the region-oriented segmentation and the multiresolution approach.

D. Edge Detection

An edge can be regarded as a boundary between two dissimilar regions in an image. These may be different surfaces of the object, or perhaps a boundary between light and shadow falling on a single surface. Many edge detection techniques can be broken up into two distinct phases:

• Finding the pixels in an image where edges are likely to occur by looking for discontinuities in the gradients.

• Linking these edge points in some way to produce descriptions of the edges in terms of lines curves etc.

Thresholding produces a segmentation that yields all pixels that, in principle, belong to an object or objects of interest in the image. An alternative to this is to find those pixels that belong to the borders of the objects [22].

E. Morphological Operations

Morphological operations are methods for processing binary images as well as gray scale images based on shapes. Value of each pixel in the output image is based on the corresponding input pixel and its neighbours. By choosing neighbourhood shape appropriately, we can construct a morphological operation that is sensitive to specific shapes in the input image. As binary images frequently result from the segmentation processes on gray level images, the morphological processing of the binary result permits improvement of the segmentation results. Defects are extracted from background by thresholding the image and classified according to the size and shape parameters. In most defect images, a dilation operation is carried out to enhance the results [22].

F. Defect Classification

Classification of the defects into categories of holes, bubbles, gels, and thinning is a challenging engineering problem because of diversity of parameters which accompany the same defect type. For example, a hole may have an area of 30 pixels or 3000 pixels.

In order to create a classification tool, defect parameters from each of the defect regions are to be collected and analyzed[19].

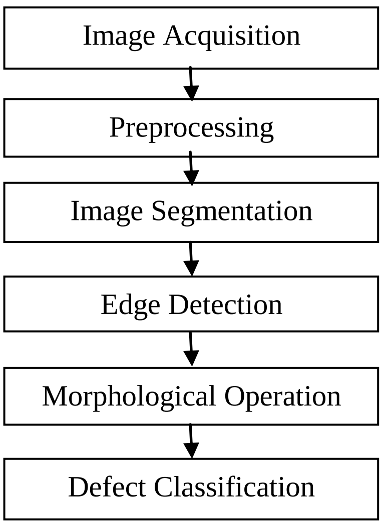


Fig. 2 Flow Chart of the Proposed Method

VI. CONCLUSION

Defect identification is a challenging problem for machine vision systems, especially when the environment or subject changes. Since there is a wide range of defect sizes and types, selecting thresholds and the structuring element sizes to capture only the holes, gels, thinning, and bubbles, is not a trivial task. However, once the proper structuring element sizes and thresholds are determined, the candidate defect regions can be correctly located on the image. Through this work, we intend to carry out the detection of common faults occurring in membrane electrode assemblies (MEA) of fuel cells using image processing tools during offline fault analysis. It is practical and economical to employ image processing tools for quality assurance purposes because they improve the inspection accuracy, reduce human error, and allow faster production speeds.

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